Road to Renewables

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

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Abstract

The history of the development of human society is closely intertwined with energy use. This development has come to rely on unsustainable energy supplies, leading to increasingly negative environmental, economic and social impacts at national and international levels. As the world population grows to 8 billion by 2030, predominantly in developing countries, the demand for energy use is set to increase as these nations strive to alleviate poverty through economic growth and development. With 82% of current energy consumption coming from unsustainable sources, predominantly fossil fuels, future global energy use must transition towards renewables if irreversible climate change is to be averted. The research attempts to outline the challenges and opportunities for the acceleration of renewable energy deployment with respect to the level of development of individual nations, and how this relates to climate change, energy security and the economy. This research centres on two country analyses: Sweden and Kenya. It looks at their potential to increase their renewables deployment by 2030, and the subsequent economic, political and societal challenges that must be overcome. These two case studies were used as the basis from which to generalise results for developed and developing countries. The results highlight the negative average substitution cost of fossil fuels by renewables in the two countries. Furthermore, it is found that that developed countries are in a better position to increase future renewables deployment beyond business as usual conditions, despite the need for all nations to work together to facilitate true change towards a sustainable energy future.

Keywords

Renewable energy; national development; total final energy consumption; climate change; energy security; energy use

> "Our dependence on fossil fuels amounts to global pyromania, and the only fire extinguisher we have at our disposal is renewable energy."
>
> – Hermann Scheer

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List of Abbreviations

EJ – Exajoules

GDP – Gross Domestic Product

GNP – Gross National Product

GWh – Gigawatt-hours

IEA – International Energy Agency

IRENA – International Renewable Energy Agency

PJ – Petajoules

RE – Renewable Energy

REmap – Renewable Energy Roadmap

TFEC – Total Final Energy Consumption

TWh – Terawatt-houra

1 Introduction

1.1 Background

“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.

Such demands have not gone unanswered, with the United Nations (UN) launching the ‘Sustainability for All’ (SE4ALL) initiative in 2011 as part of the UN International Year of Sustainability for All in 2012 (UN, 2012). This initiative strives to engage governments, the private sector and civil society in the need for the global deployment of renewables to maximise the developmental progress of nations and to achieve the stabilisation of climate change (SE4ALL, 2013). To reach this end, SE4ALL stresses three objectives that need to be achieved by 2030 (SE4ALL, 2013a):

- Ensure universal access to modern energy services;

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[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.

- Double the global rate of improvement in energy efficiency, and;
- Double the share of renewable energy in the global energy mix.

Emphasis on the need for renewables was further underscored when these objectives were used as the foundation for the establishment of the 2014-2024 ‘Decade of Sustainable Energy for All’, further highlighting the need for all countries, both developed and developing, to assist one another in achieving “universal access to sustainable modern energy services” in order to enable sustainable global development (UN, 2012).

However, in the path of this need for global cooperation lies a historical rift between developed and developing nations regarding their responsibilities and capabilities to undertake such development. This rift first became evident in the proceedings of the Kyoto Protocol climate change agreement in 1992 in which developing nations protested at their need to undertake costly reductions in greenhouse emissions (GHGs), arguing that the responsibility lay with developed nations whose historic emissions had a higher impact on the effects of global warming. These arguments, resulting from concerns from the developing nations over the potential cost which could hinder their national growth and development and keep them in poverty (Weisbach, 2012), led to the 1992 Kyoto Protocol refraining from implicating developing nations in the need to address climate change (UNFCCC, 2014). More recently these arguments have resulted in the inability for nations to agree on a treaty to deal with climate change (Tollefson, 2011), however, recent studies suggest that both developed and developing countries should be held responsible, with arguments for or against this boiling down to the mathematical modelling applied to historic emissions (Weisbach, 2012).

In spite of this ongoing climate change debate, both developed and developing nations have a vested interest in transitioning towards a higher level of renewable energy use. 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, more developed and developing nations are turning towards renewables for solutions to these problems, and are meeting both barriers and opportunities in their search (IRENA, 2012).

1.2 Research Problem

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.

An in-depth understanding of the challenges and opportunities facing the implementation of renewables in developed and developing nations necessitates case study analyses from the perspectives of a developed and developing country respectively. Such analyses allow the ongoing debate of country responsibility for the uptake in renewables to be bypassed, in order to focus on the environmental, political and economic realities. The research will strive to develop an understanding of whether developed or developing nations are in a more effective and viable position to accelerate future renewables deployment. This understanding will be constructed by addressing the following central research objectives, and subsequent research questions.

1.3 Objectives 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. This analysis is undertaken through the development and subsequent deconstruction of national renewable energy roadmaps that explore the possibility of doubling the global share of renewable energy by 2030 via technology development, cost reduction potential, and policies at the level of individual nations. In contrast to typical renewables development studies which aim to achieve fixed levels of renewables (typically 100%) at either a national or global level and are typically theoretical "desktop studies" (Teske, Muth & Sawyer, 2012; Gustavsson, Särnholm, Stigsson & Zetterberg, 2011; IEA, 2013; PwC, 2010; Heller, Deng & van Breevoort, 2012), the IRENA roadmaps aim to collaborate with national representatives to translate existing plans and additional options for renewables into a feasible, realisable framework (IRENA, 2014). Furthermore, the aim of the study is not to focus on the renewables deployment possibilities of the individual nations in these roadmaps, but rather to assess these future opportunities in the context of developed and developing countries.

The objectives of the research entail:

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

From these objectives the following hypothesis has been developed:

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 will help to guide the research towards the achievement of the aforementioned objectives.

1.4 Research Question

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?

1.4.1 Sub Research Questions

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?

1.5 Significance of the Research

With future energy consumption projected to come largely from developing countries, rising from 54% of global energy use in 2010 to 65% in 2040 (IEA, 2013a), the need to overcome historical blame-games concerning responsibility for the looming threat of climate change is critical to ensuring a sustainable energy future. Furthermore, the humanitarian impact of energy poverty in developing nations and economic impacts in all nations due to the volatility of non-renewable fuel prices is driving the need for national energy security through the deployment of renewable energy solutions. This research will benefit the host institution IRENA by providing a better understanding of the key generalised issues facing developed and developing countries separately, and as part of a global energy consuming community. More specifically, the research will provide the institution with key opportunities and lessons to be supplied to member countries searching for the most effective way of deploying renewable solutions in their future energy mix. Furthermore, this research will benefit the academic engineering community by providing additional insight into how developed and developing nations can learn from one another and adapt best practices – technologically, economically, socially and politically – to achieve positive environmental, economic and social benefits at both national and international levels.

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

2.0 Energy & Development – a history of consumption

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 is 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 humble beginnings of human energy consumption, representing the "first energy era" from +300 000 BCE to 10 000 BCE, centred around the search for foodstuff and its chemical conversion into energy usable by the body in addition to a basic usage of fire (Smil, 2004). The first great energy transition followed the settlement of societies around 10 000 BCE, with the domestication of animals for labour and increased control over fire for industrial purposes representing an increase in per capita energy consumption by an order of magnitude (Smil, 2004).

Subsequent harnessing of renewable energy flows, wind and water, by some societies millennia later allowed for the transition from muscular exertion to the first forms of energy generating devices such as windmills and waterwheels representing the first steps towards modern power generation (Kostic, 2007). Often dubbed the 'industrial revolution', the penultimate transition in the history of human energy consumption is represented by the complete shift of industrialised societies from animal labour to steam-engines and from biomass to fossil fuel over the last two centuries, but this transition has yet to fully occur in many "less developed" countries (Smil, 2004). Similarly, the invention of electricity generating stations and the widespread consumption of electricity in "more developed" countries, and to a more limited extent in developing countries, over the past 140 years represents the latest transition in humanities energy consumption (Union of Concerned Scientists, n.d). This 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 GDP/GNP/GNI[2] (see Figure 1 below). These development levels, as denoted in the rest of this report, divide countries into 'developing' and 'developed' nations, with developing countries defined as those that have GNI per capita of less than US$ 12 616 per year and developed countries as having GNI per capita greater than this level (World Bank, 2014a). However, whilst such a definition allows for an approximate understanding of the economic development level of a nation respective of energy usage, it has been argued that GNI lacks the ability to accurately depict the quality of life in a country (European Commission, 2014). When taking into account indicators directly related to development such as life expectancy and educational attainment in addition to income, it is argued that a more accurate picture of the relationship between energy consumption and the level of national development

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[2] (World Bank, 2004) Gross Domestic Product (GDP) - The value of all final goods and services produced in a country in one year; Gross National Product (GNP) - The value of all final goods and services produced in a country in one year (GDP) plus income that residents have received from abroad, minus income claimed by non-residents; Gross National Income (GNI) - The value of all final goods and services produced in a country in one year (GDP) plus income that residents have received from abroad, plus income claimed by non-residents.

can be attained using the United Nation Development Programme’s (UNDPs) Human Development Index (HDI) (Smil, 2004).

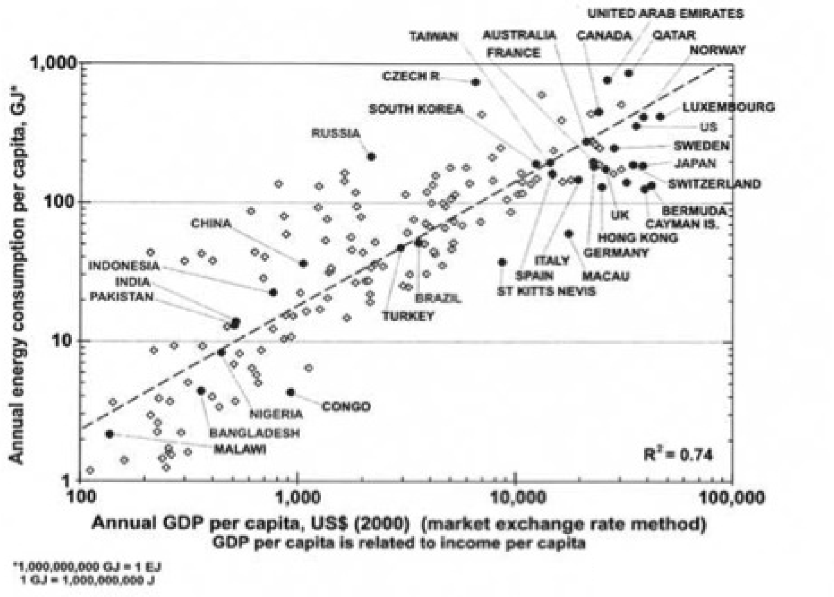

Figure 1 - Energy consumption versus GDP (EIA, 2005)

The comparison of national HDI with energy consumption (see Figure 2) 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. 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. Furthermore, Figure 2 provides an understanding of the likely future global energy demand levels of nations as they develop. Given this 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).

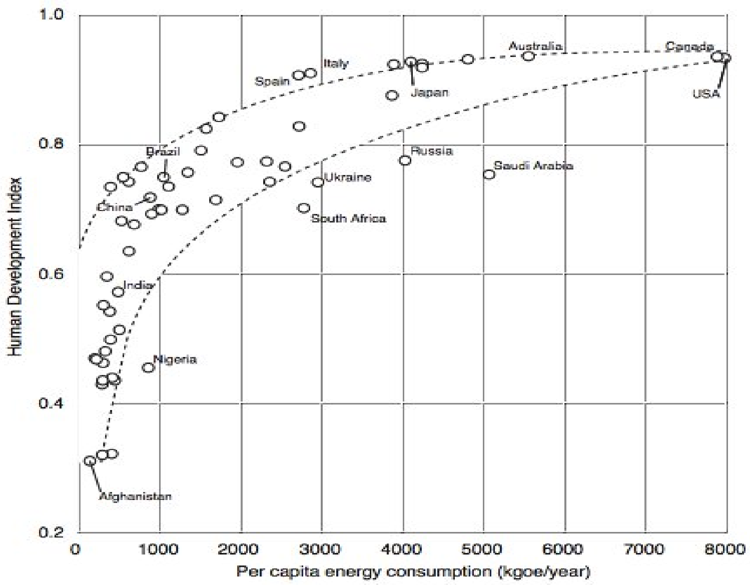

Figure 2 - Human development Index versus energy consumption in 2000 (Smil, 2004)

From the perspective of developing nations, access to energy represents a significant present and future challenge to be overcome in order to improve the prosperity of their citizens. Over 2.4 billion people in the developing world are dependent upon the combustion of traditional biomass[3] on open fires for their cooking and heating needs, resulting in high levels of indoor pollution which contributes to over 1.6 million deaths annually (Holm & Ach, 2005). This dependence on traditional biomass stems from the lack of affordable alternatives, with the alternative use of kerosene for lighting in some regions contributing to up to 25% of a family's income (Solar Aid, 2013). Similarly, a lack of affordable access to electricity due to lack of grid infrastructure or unaffordable connection costs results in an ongoing cycle of poverty, with women typically spending much of their free time collecting fuel-wood and foregoing the opportunity of education and a chance to break the cycle of poverty through gainful employment (ISES 2005).

On a national level many developing countries face a lack of natural resources, resulting in a reliance upon economically volatile fossil fuel imports in addition to issues of deforestation and desertification arising from the unsustainable consumption levels of traditional biomass. This dependence on fossil fuel imports costs developing governments an average of 3% of their GDP in subsidies to the public (UNEP, 2014), and opens their economies to the energy security risk of fluctuating international fuel prices. Similarly, this over reliance on traditional biomass and fossil fuels in combination with growing populations has fuelled the global debate on the responsibility of developing countries for GHG emissions and their contribution to climate change (Weisbach, 2012). These ongoing energy challenges highlight the need, if not the method, for developing countries to find a sustainable alternative solution to meet their growing energy needs and eliminate poverty.

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[3] The UN Food and Agriculture Organization defines traditional biomass as "woodfuels, agricultural by-products, and dung burned for cooking and heating purposes." In developing countries, traditional biomass is still widely harvested and used in an unsustainable and unsafe way. It is mostly traded informally and non-commercially. So-called modern biomass, by contrast, is produced in a sustainable manner from solid wastes and residues from agriculture and forestry (World Bank et al., 2013)

Contrastingly, the historical growth and increased prosperity of developed nations has in part resulted from their ongoing access to an abundance of energy resources (Smil, 2004). Whilst developed nations typically have universal access to electricity and comparatively high levels of consumption of modern forms of energy, this access has come as a result of an increasing dependence on unsustainable fuels. In 2012 over 90% of the fuel consumed by developed countries came from unsustainable sources (83% fossil fuels, 8% nuclear) (BP, 2013). Such a heavy dependence on fossil fuels has resulted in a history of economic shocks in developed countries, with the oil crises of the 1970s highlighting severe energy risks in developed countries due to their energy dependence on potentially volatile fossil fuel imports (Lovins & Lovins, 1983). Similarly, the use of fossil fuels has been linked to long-term environmental impacts both in terms of emissions and with regards to the direct degradation resulting from the search for increasingly inaccessible or alternate forms of this resource e.g. shale oil (UNWCED, 1987; Bierbaum & Matson, 2013). These energy challenges are pushing developed nations to seek out alternative, more sustainable forms of energy to maintain their current levels of prosperity, but many such as the Intergovernmental Panel on Climate Change (IPCC)(2012) and Garnaut (2011) fear that this deployment of renewable energy is progressing too slowly under current conditions to address the potentially devastating global effects of climate change.

3.0 Climate Change & Energy

Similar to that of human development, the global 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 maintaining temperatures at a habitable level, recent human development has started to amplify this effect. As can be seen in Figure 3, a rapid and unprecedented rise in GHG levels coincides directly with the onset of the industrial revolution in the early 1800s and the transition of many societies towards increased energy consumption through the harnessing of fossil fuel resources.

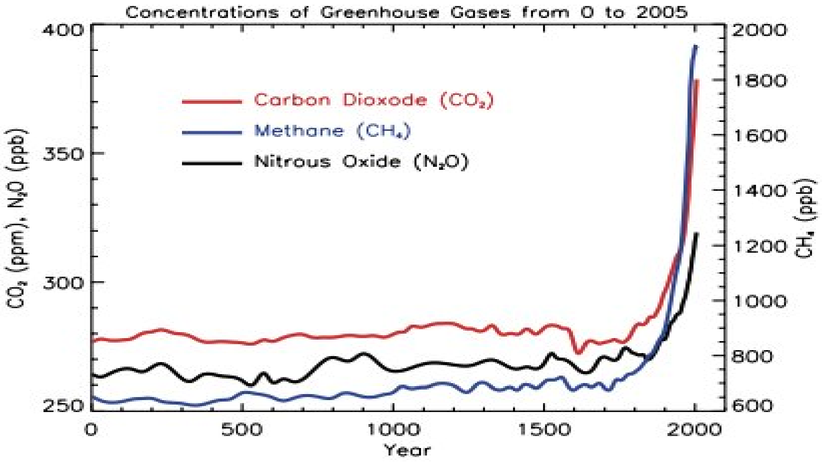

Figure 3 - Historic levels of greenhouse gases (IPCC, 2007)

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 (see Figure 4), is a direct result of the increasing global consumption of fossil fuels, and is projected to result in potentially catastrophic climate change (IPCC, 2007). Developing nations are predicted to be the worst affected by future climate change due to their comparatively lower levels of resources and infrastructure to help mitigate the effects of this change (Gilbert, 2009). Energy appears to be a double-edged sword, with the energy required for future national development also contributing to their potential climatic downfall. This dilemma has raised the issue in developed and developing countries alike of the challenge to move away from fossil fuels to more sustainable forms of energy.

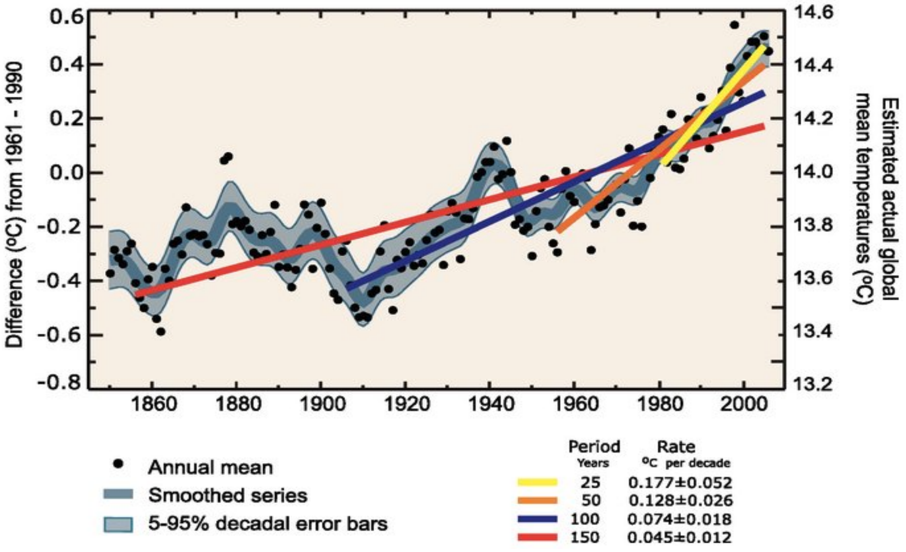

Figure 4 - Historic global mean temperature (IPCC, 2007)

Future global development trends predict a world population greater than 8 billion by 2030, with over 80% located in developing countries (Garnaut, 2011a). Whilst projections estimate that the standard of living in developing nations will likely double by 2030 (Garnaut, 2011a), their contribution to global GHG emissions is set to increase from roughly 50% today, to 70% in 2030 under 'business as usual' conditions (see Figure 5). This ominous long-term forecast for future global emissions, and subsequently for potentially irreversible climate change, appears to be directly linked to the growing energy demand resulting from the struggle of developing nations to lift their citizens from poverty. However, the global community is currently at an impasse regarding the physical transition towards more sustainable energy consumption due to heated debate between countries over national responsibility.

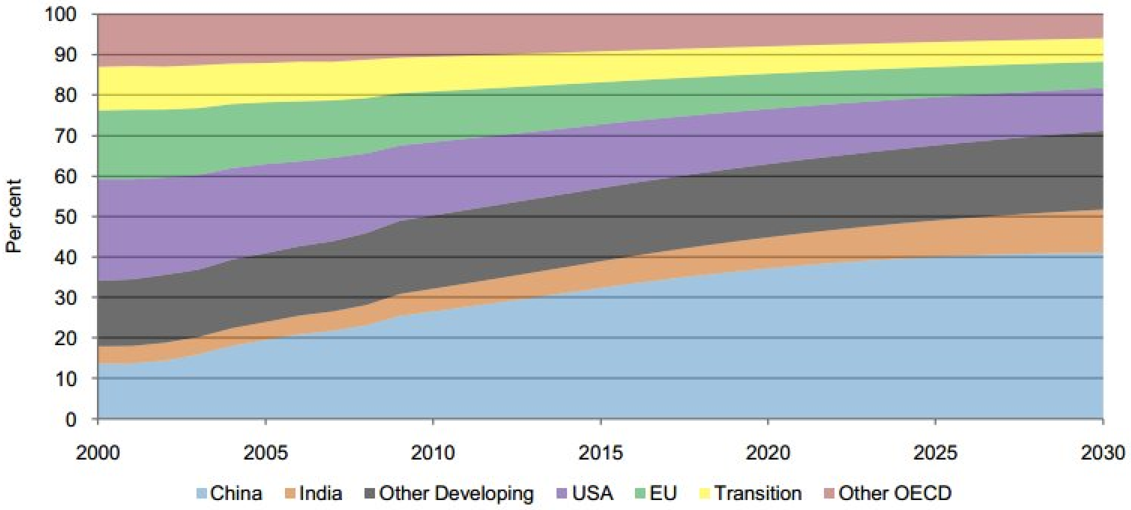

Figure 5 - Global business as usual emissions shares by region, 2000 to 2030 (Garnaut, 2011a)

Historic discussions regarding climate change (UNWCED, 1987; UNFCCC, 1992) have emphasised the past and ongoing contribution of developed countries to global emissions and climate change, and subsequently their responsibility for its future correction. Such allocation of responsibility has resulted from concerns that the imposition of emission reduction requirements on developing countries would restrict their growth and their ability to rise from poverty (Weisbach, 2012). However, this allocation of blame solely at the feet of developed countries has come into question in recent years (Weisbach, 2012), leading to the aforementioned inability of developed and developing nations to settle upon a global agreement to address the economic and environmental threat posed by increasing (fossil-based) energy consumption (Tollefson, 2011). Whilst these ongoing quarrels may affect the extent to which individual nations must contribute to a shift away from GHG emissions due to energy use, the future impact of climate change is unlikely to heed national borders. The need to de-carbonise energy consumption and to transition to more sustainable and secure methods of energy use is a global challenge that needs to be tackled from a global perspective.

4.0 Energy Security

Energy security is defined as “the reliable, stable and sustainable supply of energy at affordable prices and social costs” (World Economic Forum, 2014). Historically this concept has been focused on the ability of humanity to access food to obtain the energy required to live and function. However, the modern concept of energy security traces its roots back to World War I, with the newfound dependence of Britain and the U.S on oil to fuel their armed forces raising the need to secure access to a continual supply of oil (Van Vactor, 2007). 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). Whilst this global economic impact first raised the issue of nations’ peacetime dependence on non-renewable fuel imports such as oil, it failed to highlight the true threat to the security of the sustainable and affordable supply of energy to even partially import dependent nations. Lovins and Lovins

(2001) showed that the current infrastructure used for both the supply of modern fuels (i.e. gas and oil pipelines, centralised shipping routes etc.) and of electricity (i.e. centralised, large-scale power generators, large-scale transmission networks etc.) is vulnerable to both accidental failure, as well as malicious attacks.

The vulnerability of energy supply in both the developed and developing world is a result of 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, this 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). In terms of electricity supply, large-scale interdependent systems have become the norm in modern societies, and have threatened the energy security of millions of people in recent history. In 2012 over 600 million people in India were left without power for up to two days due to a cascading network failure arising from a lack of supply capacity (Outlook India, 2012). Similarly, over 50 million people in North America were left without power in 2003 due to a software bug (Andersson et al., 2004), whilst over 100 million people in Indonesia suffered from a blackout in 2005 due to the cascading effects resulting from the failure of a single transmission line (Donnan, 2005). Such examples are neither a rare occurrence, in neither developed nor developing countries, nor are they likely to reduce in frequency, with more nations pushing towards electrification as a means of poverty reduction and economic growth (SE4ALL, 2013a).

Given this trend of increasing electricity consumption, especially in developing countries (EIA, 2013), the continued threat to energy security appears assured if nations continue using traditional, centralised generation and distribution systems (Lovins & Lovins, 2001). However, 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.

5.0 Renewable Energy

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). Renewable energy represents the original source of energy harnessed by humanity, dating back more than 250 000 years to the initial use of biomass to create fire (Smil, 2004). Prior to the widespread uptake of fossil fuel usage in the 19th and 20th centuries, renewable energy in the form of hydropower, wind energy and solar energy represented the dominant forms of energy used in society outside of direct human and animal-based labour (Sørensen, 1991). However, 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).

Although the uptake of renewable energy technologies has made a resurgence since the oil shocks of the 1970s, it only represents 18% of all energy consumption, 75% of which comes from biomass (two-thirds of which is traditional, often coming from unsustainable sources) (IRENA, 2014). Furthermore, whilst some countries with access to significant renewable resources such as hydropower (Norway, 97% renewables in power generation) and hydropower & geothermal (Iceland, 99.99% renewables in power generation) are able to reliably harness high levels of renewables (FindtheData.org, 2014), this is currently not the case for all nations. Moreover, the ability for renewable energy to be harnessed for use in transportation is limited, with only 2.5% of all transportation energy consumption being sourced from renewable energy (biofuels and electricity) (REN21, 2013). In spite of these current limitations, the key challenges to the widespread adoption of renewables in developed and developing countries lies in its current perception.

Renewables are often criticised for being more expensive than their fossil-based counterparts, whilst the intermittent nature of solar and wind power for electricity generation is often cited as a key barrier to large-scale adoption. From a cost perspective, not only are renewables now cheaper than fossil fuels in many regions (Paton, 2013; Tagwerker, 2014), there is a significant financial bias against renewables, with fossil fuels receiving between US $523 billion and US $1.9 trillion worth of subsidies globally compared to US $88 billion for renewables (Tagwerker, 2014). With regards to intermittency, it is argued that with correct technology selection in addition to some fossil fuel back-up generation, widespread renewable electricity generation would not pose an issue (Foley, 2014). Although, 100% production from intermittent sources is still difficult due to the limitations of pumped-hydro, batteries and other storage technologies (Deutch & Moniz, 2011). In spite of these rapidly diminishing challenges to the widespread use of renewable energy, there are also many benefits that are encouraging its adoption.

Renewable energy represents a significant opportunity for countries to benefit environmentally, economically and developmentally. From an environmental perspective, the substitution of fossil fuel technology with zero-net-GHG-emission renewables represents the only course for humanity to avert irreversible and potentially catastrophic climate change whilst maintaining current and increasing levels of energy consumption (IPCCC, 2012; REN21, 2013). Similarly, from an economic perspective, reduced environmental impacts from energy consumption result in reduced future costs, whilst the ability for renewables to improve energy security by reducing developed and developing nations' dependence on imported fossil fuels (and their potential price volatility) also reduces the overall economic cost of national energy consumption (Lovins & Lovins, 2001; REN21, 2013). Furthermore, renewables represent a unique opportunity to rapidly increase energy access to the 1.3 billion people without electricity (IEA, 2011), due to their ability to be implemented on a small but widespread scale (REN21, 2013). Finally, the combination of reduced environmental impact, reduced energy costs, and increased access to energy due to renewable energy implementation represents a sizeable opportunity for national growth and the reduction of poverty in developing countries (Bierbaum & Matson, 2013).

The benefits of a renewable energy future are evident for both developed and developing nations alike, but the road to its implementation is varied. 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. More specifically, this historic fossil fuel dependence has resulted in a centralised power and refueling infrastructure, which is typically at odds with the distributed nature of renewable energy resources (Kostic, 2007). 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. However, it must overcome concerns regarding financial uncertainty and lack of familiarity with the available technological solutions in addition to inhibitive governmental legislation (World Future Council, 2009). Furthermore, the contribution of developing nations to fossil fuel subsidies worth on average 3% of GDP (UNEP, 2014) and a lack of governmental support for renewables represents the ‘status quo’ that must be overcome to realise the adoption of renewable energy as the norm. Based on the current status of renewables, there is significant potential for future uptake and renewable energy usage on a global scale.

6.0 Literature Gap

From the review of existing literature it is apparent that the link between energy use and development, climate change, energy security and renewables is well established. However, much of this previous research focuses the analysis at global, regional and national levels, or on the potential for renewable energy use in developing nations. The interdependence of developed and developing countries with regards to a sustainable global future, and the potential for a complimentary approach between these nations for sustainable energy development and increased energy access and consumption in developing nations, is typically overlooked. The following work will attempt to contribute to this knowledge gap by answering the proposed research questions, and will highlight the opportunity for developed and developing countries to work together towards a sustainable energy future.

7.0 Case Study Overview

7.1 Introduction

As introduced in section 1.3, the research conducted for this master thesis was undertaken in concert with IRENA as part of their ongoing renewable energy roadmap (REmap 2030) project. The researcher was imbedded as an employee within IRENA, and was tasked with completing REmap analyses of two countries: Sweden and Kenya. This research was undertaken under the supervision of the REmap Program Officer Dr. Deger Saygin, and contributed to the 2014/2015 project objective of completing 10 country analyses in addition to the initial 26 completed over the course of 2013. The following section of the report provides an outline of the overarching vision and mission of IRENA, and the purpose for which the REmap project was developed.

7.2 History

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. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity (IRENA, 2014). Founded in 2011, 20 years after the initial proposal for the establishment of an international agency dedicated to renewables, IRENA seeks to make an impact in the world of renewable energy by maintaining a clear and independent position, providing a range of reliable and well-understood services that complement those already offered by the renewable energy community and gather existing, but scattered, activities around a central hub (IRENA, 2014a).

As part of this mandate, 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). Acting as the renewable energy hub for the SE4ALL initiative, IRENA developed the REmap 2030 project to help achieve this SE4ALL objective, in addition to supporting the efforts of SE4ALL partners responsible for the energy access and energy efficiency 2030 objectives.

7.3 REmap 2030

REmap 2030 is a roadmap to doubling the share of renewable energy by 2030. It is the first global study to provide renewable energy options based on a bottom-up analysis of official national sources. 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). IRENA works together with national renewable energy roadmap experts to translate existing national plans and additional options for renewable energy deployment into a common global framework. REmap assists national experts to conduct the necessary country analyses. In 2013, IRENA launched REmap 2030 with 26 countries, including those seen as the largest energy consumers in 2030 and others from different regions that have advanced the deployment of renewables. Together these countries are projected to consume 75% of all final energy by 2030.

REmap technology options are characterised by their potentials and cost. Market opportunities and barriers have been assessed, as have investment needs. The analysis also considers macroeconomic, social and environmental benefits from accelerated renewable energy uptake, in particular the impacts on jobs, health and climate change. REmap 2030 also examines policy planning frameworks, best practices, opportunities for international cooperation, and the linkages between renewable energy, energy efficiency and energy access (IRENA, 2014). IRENA is also working with the modelling community to verify its country analyses with national models developed by research institutions and academia.

Over the course of 2014/2015 IRENA is seeking to extend the number of country analyses, with the completion of REmap assessments for an additional 10 countries. It is this extension to the REmap project from which the research is derived. More specifically, the aforementioned completion of two country analyses – Sweden and Kenya – are used as case studies for the completion of the research objectives outlined in this report. The following section of the report outlines the methodology used by IRENA as part of the REmap 2030 project, and how the case study results will be translated into a better understanding of the potential for developed and developing nations to increase their renewable energy uptake.

8.0 Research Design and Methodology

8.1 Introduction

In seeking to test the hypothesis proposed in section 1.3 and answer the research questions posed in section 1.4, the research uses the two REmap country analyses as the basis from which to compare the potential for developed and developing countries to transition towards a future with significantly increased renewable energy use. These case studies were developed based on the standard IRENA REmap 2030 methodology, as outlined below. Following the completion of the two REmap analyses, a direct comparison of the country-specific results was used to form the basis of the research analysis.

8.2 Methodology

REmap country analyses aim to explore the potential of a country to contribute to the global target of doubling the renewable energy (RE) share by 2030, and to identify actionable items that can be put into practice if governments decide to act. The project follows 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)[4] in the three energy end-use sectors in society: industry, buildings, and transport. TFEC is analysed instead of Total Primary Energy Supply (TPES) due to its selection as part of the SE4ALL Global Tracking Framework. More specifically, TFEC was selected as it provides a more representative contribution of directly produced renewable energy to the total energy mix, whilst also representing usage information (e.g. the amount of heat and electricity consumed in its final form) that is more useful to the end-user i.e. governmental ministries, policymakers etc. Furthermore, the use of TFEC instead of TPES allows for the issue of which of the three efficiency conventions – physical content method, direct equivalent method, substitution method – to be bypassed, allowing for the "straight comparison for low-carbon electricity producing technologies given [their] expected increasing role [in the energy mix]" (SE4ALL, 2012).

In determining the RE share in national TFEC, it is 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

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[4] 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.

resources, energy consumption sourced from traditional biomass is considered to be equivalent to fossil fuels (i.e. non-renewable) for the purpose of the REmap analyses. The REmap process includes the following steps:

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

8.2.1 Data collection

The country analysis is based on national data. The starting point of the analysis are the Internal Energy Agency (IEA) extended energy balances, which provides the RE share in TFEC broken down by both fuel and sector. In subsequent steps, projections, plans, prospective studies or scenarios on RE deployment in the power, transport, buildings, and industry sector are collected. In many cases, these national studies differ markedly from projections by international organisations such as IEA, and provide a more accurate description of the national reality. For this reason, publically available country plans and scenarios are collected and key national organisations are approached regarding their willingness to engage in REmap. The following data sources are typically used:

- National data: energy balances (country national data, IEA statistics and IRENA database); main energy-economic indicators; national energy plans/strategies to 2030; energy projections/scenarios to 2030 and beyond; national RE energy policies in place and under implementation (e.g. country documents and national communications to UNFCCC);
- International and national data on performance and costs of RE demand and supply technologies (IRENA database, IRENA-IEA technology briefs, and; country national data).

8.2.2 Analysis of the reference case

The analysis of the reference case commences with the 2010 country extended energy balance provided by the IEA. The data is converted into a simplified energy use balance, with emphasis placed on the role of renewables. Subsequently, the energy balances for 2030 are estimated based on the national data regarding planned energy system developments between now and 2030 collected during the data collection stage. If no national data is available, data from the IEA World Energy Outlook (WEO) is used as a proxy. Country experts are consulted where possible to update these values.

National cost data for renewable and conventional energy options is also collected during the reference case analysis. The average incremental ‘cost of substitution’ for the RE technologies in the reference case is obtained as the difference between the average cost of the renewable technology being deployed (for the technology category it belongs to, e.g. small-scale hydro power etc.) and the cost of a representative conventional technology to fulfill the same energy demand (e.g. coal-based thermal power plant etc.).

8.2.3 Analysis of the REmap Options

Following the compilation of the national 2030 Reference case, REmap Options are developed to assess the potential to further raise the share of renewables by 2030 beyond the Reference Case. The cost of substitution associated with this increased RE deployment is also calculated. Country dialogue with national REmap experts is crucial in this step to determine the 'realisable potential' of additional RE options, especially given the potential for national policies, regulations, and other conditions to influence the future deployment rates of renewables. Furthermore, national REmap experts are also engaged to provide additional insights as to how local conditions may constrain the deployment of RE technologies in the end-use sectors.

It should be noted that there is no single list of options to increase the country RE share. Whilst in theory there is a least-cost solution for each country, any solution is subject to significant uncertainties and would not entail absolute levels of cost and benefits (e.g. impact on GDP). As a consequence, the key purpose of the analysis is not to determine renewables objectives for individual countries, but rather to inform policy makers on what is known today regarding the consequences of higher national shares of renewable energy. The results of the REmap analysis can also give rise to additional activities such as the mapping of technology strategies, or the analysis of key uncertainties through scenarios and uncertainty analysis.

8.2.4 Development of cost curves

Upon completion of the REmap Options for a given country, a cost-supply-curve based on a combination of the Reference Case and REmap Options is created. The cost-supply-curve highlights the potential for increasing the RE share in a national energy mix by further deployment of RE options, and the associated costs. For each country two sets of cost-supply-curves are created. The **'international version'** uses standard data for commodity prices and costs of capital. This version allows a comparative analysis of cost-supply-curves between countries, and the subsequent creation of a global cost-supply-curve. The **'national version'** uses national data for cost and technology performance of RE and conventional energy technologies, and includes local subsidies, national interest rates, CO_2 emission taxes, and other cost and performance parameters.

The cost-supply-curve is not a prescriptive scenario, but it shows options to increase the share of RE in TFEC within a given country between 2010 and 2030, and the investment costs associated with the RE technology options that could be deployed. The cost of RE options is calculated based on the average costs of substitution. In other words, the costs represent the difference between the RE option and a conventional energy technology (fossil fuel, nuclear, or traditional biomass) used to produce the same amount of energy (including fossil fuel savings). Therefore, the RE costs also depend on the conventional technology that is substituted. It can be a positive (incremental) cost or a negative cost (saving) as some renewables energy technologies are already cost effective when compared to conventional technologies.

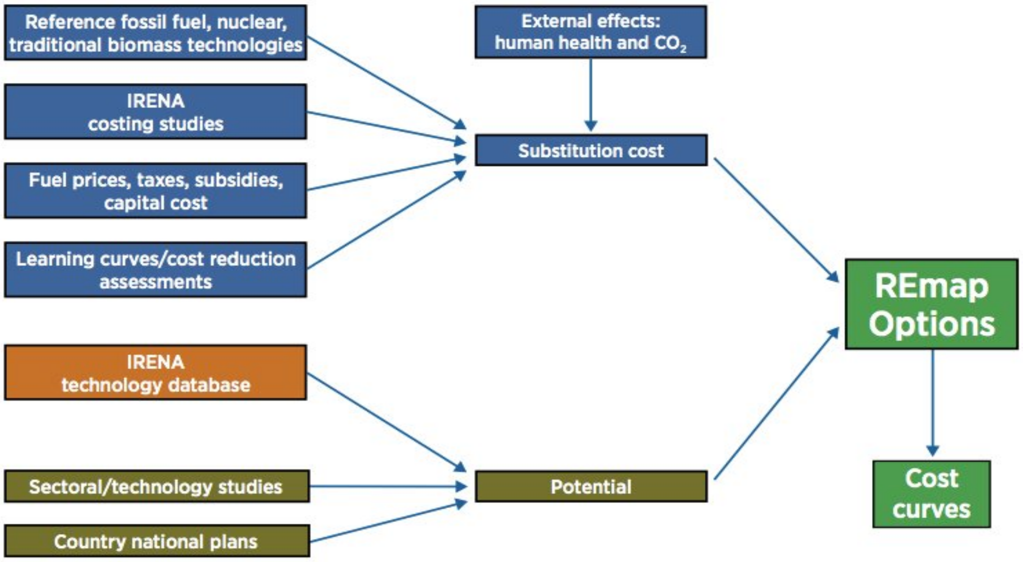

Figure 6 - REmap 2030 process methodology (IRENA, 2014b)

Upon completion of the REmap analyses for the two case study countries (following the aforementioned methodology, as depicted in Figure 6), the results were then analysed to provide a basis for discussion regarding the potential for the uptake of renewable energy by developed and developing nations.

8.3 Analysis

Upon completion of the REmap country assessments for Sweden and Kenya, the results will then be 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. With the results for Sweden representing developed nations, and the results for Kenya representing developing nations, a direct comparison of their respective potential to increase their RE share, level of RE consumption and subsequent cost of substitution will be undertaken. This analysis will also address the potential social, environmental and political issues and challenges facing the deployment of renewables in the two countries. These challenges will be expanded to form an indicative assessment of the potential for RE in developed and developing countries, with the analysis of the REmap results being used to address the hypothesis and research questions outlined at the beginning of this report.

8.4 Strengths and Limitations

8.4.1 REmap process

As a means of facilitating discussion regarding the potential for countries to increase their future deployment of renewable energy technology, REmap provides 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 in section 8.2 gives rise to two key limitations that, as with all data analyses, results in the need for careful, objective consideration of the process findings that result from the analysis. These two limitations pertain to:

Data availability; depending on the country being analysed, the energy consumption data available for analysis can be quite limited, requiring substantial extrapolation from historical trends. Similarly, national data and national development plans, whilst providing the starting point for REmap analyses, must be treated with caution. More specifically, such plans are often overly optimistic, or overly pessimistic, depending on the political agenda of the government behind their development.

Simplified analysis approach; for ease of use, and subsequent discussion with national experts, the REmap process has been simplified. In addition to being dependent on the available data due to its nature as a 'desktop study', the analysis treats technologies as stand-alone systems (outside of their consumption of available energy resources). That is, the substitution of non-renewable technologies with RE solutions does 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.

8.4.2 Analysis of REmap results

In attempting to discuss the general RE environment in developed and developing countries, the analysis of the REmap results of Sweden and Kenya provides a reasonable starting point to facilitate the discussion of the challenges and opportunities for RE deployment in developed and developing nations. Given the similar nature of renewable energy technology currently available in both countries (as detailed later in section 9.0) in spite of their respective differences as a developed and developing nation, it can be argued that results from the analysis of both countries could be reasonably comparative and provide an adequate means for comparing RE potential in developed and developing countries. However, in spite of this, there remains one key limitation to the representation and subsequent comparison of all developed and developing countries by two representative nations. More specifically, whilst Sweden and Kenya are comparatively similar, every country is unique in its energy consumption trends, resource availability and social, environmental and political trends. As such, it is difficult to condense the RE potential of all developed and all developing countries down into two representative cases.

9.0 Results

9.1 Introduction

The following results represent a condensed version of the REmap analysis results for the two countries analysed, based on the REmap reports developed for IRENA. Given the sensitivity of IRENA's position as an advisory institute for its member states, the following results attempt to provide an objective and politically sensitive analysis of the current state of energy consumption in the respective countries. Furthermore, the renewable energy roadmap (REmap) proposals attempt to work with the existing political, social and economic norms of each individual country to suggest the most feasible path to an increased national RE share.

9.2 Developed Nation - Sweden

9.2.1 Present energy situation

With a total final energy consumption (TFEC) of approximately 1.4 exajoules (EJ) in 2010, Swedish energy consumption (see Figure 7) 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).

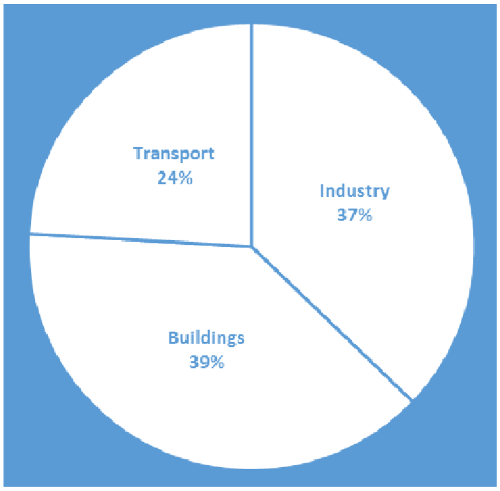

Figure 7 - Swedish total final energy consumption 2010 by sectoral share

This high sectoral distribution of TFEC in industry reflects the leading engineering and manufacturing segments operating in export-oriented Sweden, with heavy energy usage in industry reflected in its 506 petajoules (PJ) of TFEC. Energy consumption in industry is dominated by 'pulp, paper and printing' which constitutes almost 56% of industry TFEC, with 'iron and steel' representing the second highest share at 8.5% (IEA, 2012).

The pulp and paper sector in Sweden is currently undertaking research and development into a transition towards a more value-added approach to biomass conversion into pulp (and subsequently paper), investigating the use of biorefineries to produce biofuels, power, heat and value-added chemicals from black liquor produced during the production of pulp. This transition currently involves 12 commercial (4 of which are based at pulp-paper mills) and 10 demonstration biorefineries, reflecting a high level of investment and research expertise pushing for a future transition towards widespread biorefineries in Sweden (Joelsson & Tuuttila, 2012).

Constituting the highest share of Swedish TFEC at 527 PJ, the building sector reflects the northern latitudinal location of Sweden, with almost 38% of this consumption coming from building heating demand (IEA, 2012). However, whilst the housing stock in Sweden is quite old, with only 8% built after 1990 (21% pre-1945, 43% 1945-1970 and 28% 1970-1990), compared to similarly located countries with similarly aged housing stocks (e.g. the UK), the share of heating consumption in the building sector TFEC is relatively low (with the UK using around 60% of building TFEC for heating) (Norris & Shiels, 2004; IRENA, 2013). This is a result of historically high levels of insulation (BPIE, 2011), suggesting future heating technology retrofits would be limited by housing design (i.e. lack of ducts etc. in older houses) rather than by heat-losses from aging building stock.

Finally, the sector with the lowest share of TFEC is that of transport, consuming 327 PJ in 2010. This comparatively lower share of TFEC primarily consists of road transportation (304 PJ) predominantly concentrated in the more heavily populated southern regions of Sweden.

Contributing to these three end-use sectors, power generation and district heating (DH) represent close to 50% of TFEC; 34% electricity, 16% district heating. The 148 terawatt-hours (TWh) of electricity generation (including 20 TWh from combined heat and power (CHP)) is provided by two main technologies, hydropower (66 TWh) and nuclear (58 TWh), with smaller contributions from solid biomass (13 TWh from CHP) and wind power (3.5 TWh). This generation is predominantly distributed between the industry and buildings sectors (as shown in Figure 9) (IEA, 2012), and is distributed by a heavily interconnected grid infrastructure which is part of the Nord Pool network (see Figure 8 below). This network allows for the export or import of electricity between Norway, Sweden, Denmark and Finland, with Sweden importing 8 PJ (net) of electricity in 2010 (SEA, 2012).

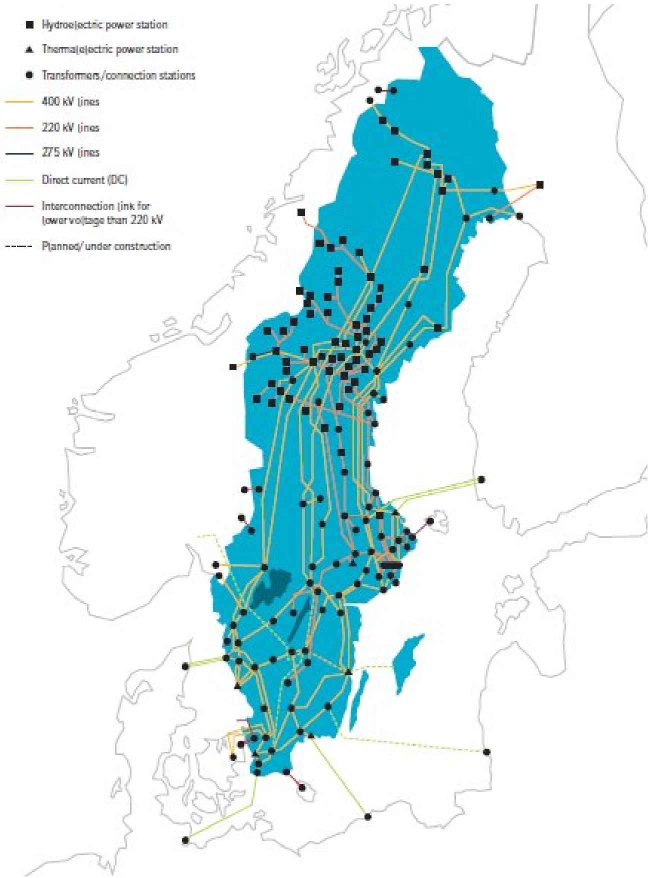

Figure 8 - Sweden electricity transmission network (Swedish Energy Markets Inspectorate, 2011)

Similarly, district heating (215 PJ in 2010), comprising 70% solid biomass, 10% coal, 9% natural gas, 7.5% oil and 3.5% biofuels, is used solely in the building and industry sectors, distributed as shown in Figure 9.

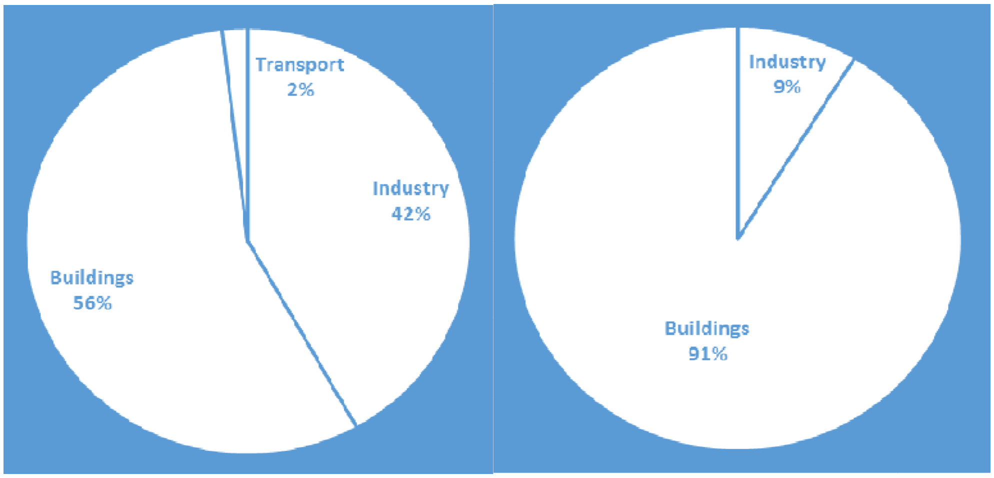

Figure 9 - Share of electricity consumption (left) and district heating consumption (right) by sector 2010

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, as shown in Figure 10 below (IEA, 2012). Industry has a renewable energy (RE) share of 58%, with 39% of these renewables coming from electricity and DH, whilst in the buildings sector, a 58% share of renewables in buildings TFEC comes predominantly from heating and electricity (90%). Thirty-two percent of total renewable energy use in Sweden is dominated by biomass, making up close to 30% of 2010 TFEC (and close to 63% of renewables). This prevalence of biomass consumption was a result of the movement of Sweden away from fossil fuels after the oil crisis of the 1970s, with a steady increase in bioenergy use since the beginning of the 1980s (Ericson, 2011).

However, despite this high level of progress towards its EU mandated target of 50% renewable energy in TFEC by 2020, Sweden is still heavily dependent on conventional fuels (i.e. fossil fuels and nuclear), with more than 93% of energy consumption in the transport sector being derived from oil as of 2010 (IEA, 2012). In light of this dependence, the Swedish government committed to a binding target of 10% renewable energy use in the transport sector by 2020 (Swedish Government, 2010), with the vision of *nationwide fossil fuel independent transportation* by 2030[5] (IEA, 2013b).

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[5] The term fossil fuel "independent" is currently undergoing clarification; given the significant share of fossil-based transport in present-day Sweden, this term is likely to refer to a) future security of fossil-transport-fuel supply, or b) independence of government vehicle fleet from the procurement of fossil fuels (i.e. private consumption of fossil fuels would remain).

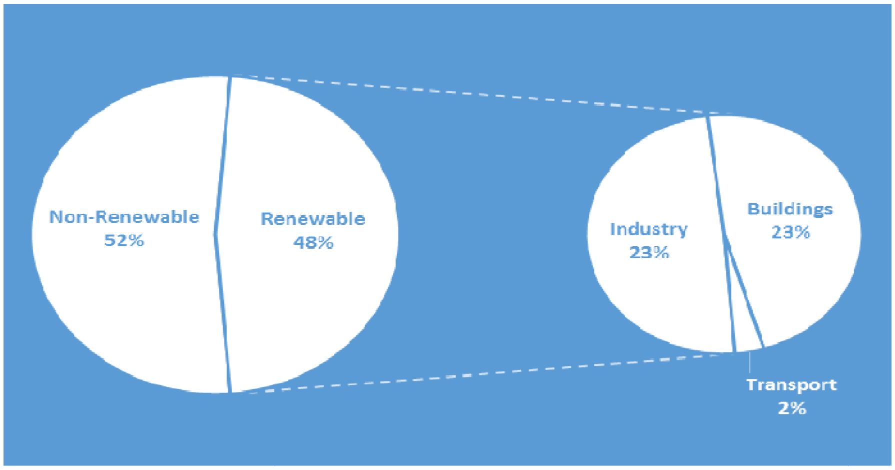

Figure 10 - Renewable energy (including electricity & DH) contribution to TFEC 2010 by sector

In the electricity generation sector over 56% of the 148 TWh of electricity generation (including CHP) in 2010 came from renewables, with the share of renewables dominated by hydropower, representing almost 45% of total generation (including CHP). Following a similar trend towards a high share of renewables usage, 70% of DH (including CHP) in 2010 was generated from renewables, comprising solely of biomass (IEA, 2012). This increase in renewables use for DH is a result of the gradually increasing carbon tax in Sweden which resulted in biomass becoming the cheapest fuel for heat production (Ericsson, 2009). Given this advantageous environment for biomass in a DH market that represents approximately 16% of the TFEC of Sweden (IEA, 2012), and the significant biomass resources in Sweden, future development in the DH sector could result in a sizeable increase to the renewable energy share in Sweden.

9.2.2 Energy resource potential

With the current situation befalling Swedish energy consumption outlined in the previous section, the next step in exploring the potential for Sweden to increase its renewable energy share by 2030 is to assess the potential for growth and structural change of energy consumption through 2030. Examining this potential in terms of available resources and relevant legislation allows for a comparison of the 2030 Reference Case projections developed by the Swedish Energy Agency (see Section 9.2.3) and the realistic potential for renewable energy development in addition to the Reference Case (i.e. the REmap Options case outlined in Section 9.2.4).

Whilst the renewable 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[6] biomass and hydropower resources (see Table 1). In light of this, whilst there still remains approximately ≥200 PJ/year of economically feasible biomass resources and another 25 PJ/year of economically feasible hydropower to be

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[6] Economically feasible resources refer to those resources that can be extracted and exploited for a positive financial return; technically feasible resources refer to those resources that can be extracted by current technology, but do not necessitate positive financial returns.

harnessed[7], 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. Furthermore, due to the stringent regulation of the current Swedish hydropower market, future growth is likely to be limited to small hydropower plants of less than 1.5 megawatt (MW) (IEA, 2013b). Similarly, legislation passed by the Swedish government in 2010 limits the construction of new nuclear generation capacity to preexisting nuclear power plant sites (under the provision that an older plant is shut down), whilst the Swedish government will provide no assistance in financing or developing such projects (IEA, 2013b). Given these limitations for the future development of hydropower or nuclear, Sweden will need to access its significant alternative renewable resources (see Table 1) if it is to increase its renewables share of TFEC.

Table 1 - Swedish Energy Resource Potential Estimates

Resource	Technically Feasible	Economically Feasible	Environmentally Feasible	Currently Exploited[f]
Biomass[a] (PJ/year)	700-1,136		▨	486
Wind (onshore, wind speed 6m/s at 71m)[b] (TWh/year)	510	7 – 12	▨	4
Wind (offshore, wind speed 6m/s at 71m)[b] (TWh/year)	46		▨	
Solar PV[c] (TWh/year)	60	0.3 – 2	▨	▨
Solar Thermal[c] (TWh/year)	12	▨	▨	▨
Hydro (>10MW)[d] (TWh/year)	120	85	66	66
Hydro (≤10MW)[d] (TWh/year)	40	32	25	
Wave[e] (TWh/year)	<6	▨	▨	▨

[a] (IRENA, 2014b), http://pub.epsilon.slu.se/1038/1/Hagstrom_thesis_Vol_I_Epsilon.pdf;
[b] http://www.elforsk.se/Global/Vindforsk/Rapporter%20fran%20Vindforsk%20II/09_61_rapport.pdf;
[c] http://www.polis-solar.eu/IMG/pdf/Sweden_National_Assessment.pdf;
[d] http://streammap.esha.be/20.0.html;
[e] http://www.elforsk.se/Global/El%20och%20varme/V%C3%A5gkraft/11_02_rapport_screen.pdf (theoretical potential; only assesses the stretch of coastline between Gothenburg and the Norwegian border which is approximately 150 kilometers in length);
[f] Swedish energy usage in 2010 – Swedish Energy Agency (SEA, 2012).

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. An understanding of this mindset, as reflected in Swedish energy policy, provides improved insight into what renewable development, in addition to the Reference Case, is likely to be supported by current and future Swedish governments. The current energy policy targets (Swedish Government, 2010) include:

- at least a 50% share of renewable energy in TFEC by 2020;
- at least a 10% share of renewable energy in the transport sector by 2020;
- the phasing out of fossil fuel use for heating by 2020;
- at least a 20% increase in energy efficiency by 2020 compared to 2008;

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[7] This is the difference between the currently exploited and economically feasible resources given in Table 1.

- development of 30 TWh/year of wind power by 2020 (20 TWh/year on- & 10 TWh/year off-shore);
- a vision for a national vehicle stock that is independent[8] of fossil fuels by 2030;
- a vision for a zero net greenhouse gas (GHG) emissions energy sector by 2050.

It should be noted that, outside of the 'visions' for a fossil fuel independent transport sector by 2030, and zero net GHG emissions by 2050, the Swedish government has established no detailed, legislational targets for renewable energy development past 2020 as of the writing of this report.

9.2.3 Business as usual: energy trends to 2030

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 a 'business as usual' (BaU) (referred to as the 'Reference Case' throughout this study) first needed to be achieved. The development of the Reference Case allowed for the assessment of what renewable energy resources could be developed in addition to those already projected to have occurred by 2030. This Reference Case was taken directly from the Swedish Energy Agency (SEA, 2013). The SEA developed a Reference Case TFEC projection for Sweden to 2020 and 2030 (in both years TFEC remains approximately at the present level of 1.4 EJ), resulting in the breakdowns for 2020 and 2030 shown in Figure 11 below. These projections were based on the preexisting policy instruments from the Swedish climate and energy legislation, as outlined in the Swedish national renewable energy action plan (2010). As such, all specific taxes and policy instruments in place at the time of the creation of the Reference Case were assumed by the SEA to still be in place in projections to 2020 and 2030.

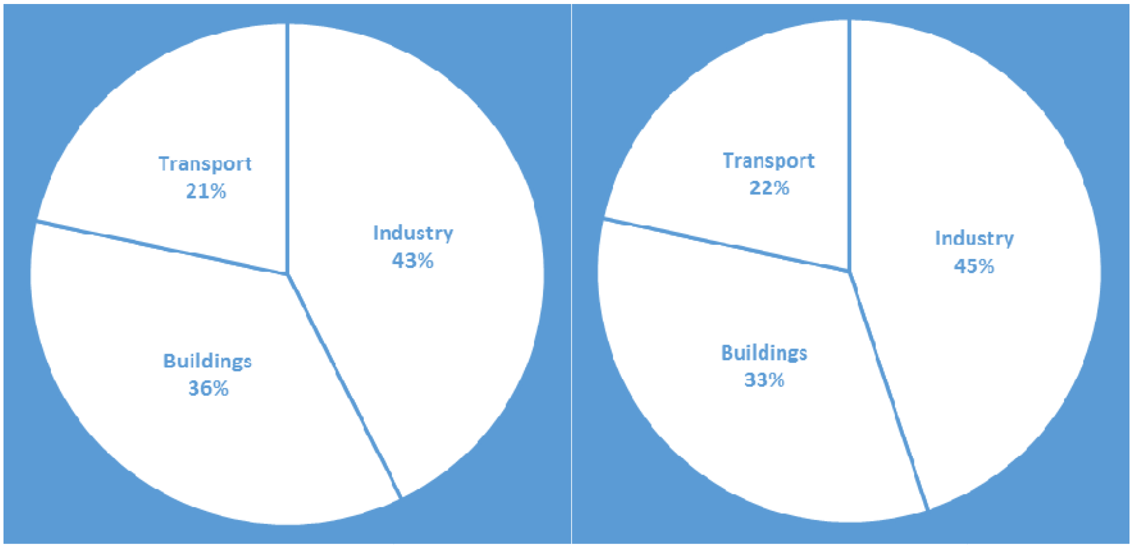

Figure 11 - Share of Swedish TFEC (including electricity & DH) 2020 (left) and 2030 (right) by sector

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[8] The definition of this 2030 transport vision is currently under discussion with the Swedish Energy Agency (2014). The term fossil fuel independent is currently undergoing clarification; given the significant share of fossil-based transport in present-day Sweden, this term is likely to refer to a) future security of fossil-transport-fuel supply, or b) independence of government vehicle fleet from the procurement of fossil fuels (i.e. private consumption of fossil fuels would remain).

The comparison of these projected TFEC values to the TFEC sector breakdowns in Figure 11, gives rise to the following assumptions made by SEA:

- Most of the growth in TFEC to 2020 is expected to come from industry, increasing from 506 PJ in 2010 to 610 PJ in 2020 and 642 PJ in 2030, resulting in an increasing share of TFEC through to 2030; 37% in 2010 to 45% in 2030;
- The TFEC of the buildings sector (527 PJ in 2010) is expected to decrease through 2030 to 477 PJ due to energy efficiency gains and partly from fuel switching resulting in lower consumption in spite of a projected increase in population from 9.4 million in 2010 (Statistics Sweden, 2011) to 10 million in 2020 and 10.4 million in 2030 (SEA, 2013);
- Final energy use in the transportation sector is projected to decrease from 325 PJ in 2010 to 308 PJ in 2020 and 303 PJ in 2030. This reduction in total transport sector consumption, in spite of a growing population reflects the increasing taxation to 2020 in place against vehicles emitting high levels of CO_2, resulting in the use of more efficient vehicles and thus lower sectoral energy consumption.
- DH use is projected to decrease from 215 PJ in 2010 to 183 PJ in 2020 and to 175 PJ in 2030, with a minor increase in sectoral share distribution from 9% industry, 91% buildings in 2010 to 11% industry, 89% buildings in 2030. This change in the sectoral shares of DH reflects the high level of growth in industry compared to the contraction in the buildings sector.

Electricity end-use consumption is also projected to see a minor increase from 468 PJ in 2010, to 479 PJ in 2020 and 477 PJ in 2030, with this small increase in comparison to the increasing population a result of the energy efficiency targets in place through to 2020. However, compared to this 9 PJ (2%) increase in electricity consumption between 2010 and 2030, total yearly electricity production increases by 96 PJ (18%) from 2010 to 2030, reflecting the projected shift from the import of electricity (7.6 PJ in 2010) to electricity export (90 PJ in 2030) (SEA, 2013).

From these detailed Swedish Energy Agency energy consumption projections for 2020 and 2030 (SEA, 2013) the renewable energy mix for the Reference Case was established. Figure 12 below details a sectoral breakdown of the renewable energy share in the aforementioned TFEC projections.

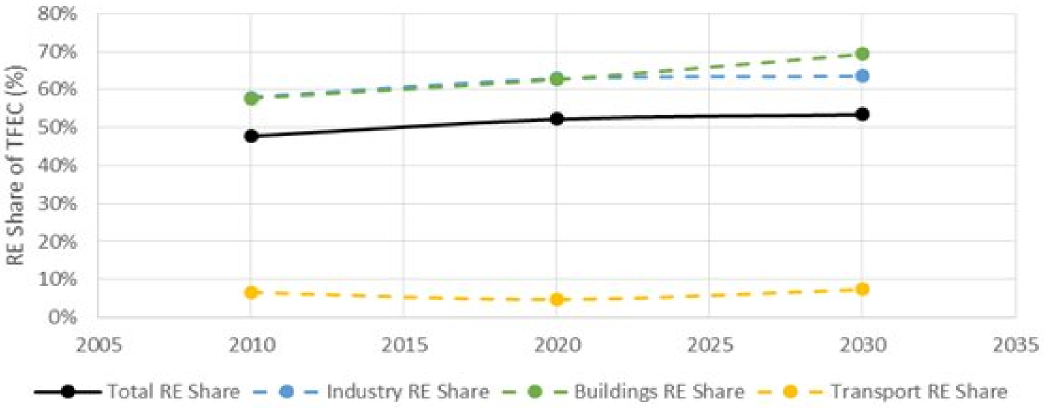

Figure 12 - TFEC share of RE by sector (including electricity and district heating)

The total RE share in TFEC is seen to increase by 4.5%, from 47.7% in 2010 through 52.2% in 2020, before plateauing between 2020 and 2030 seeing a smaller increase of 1.2%, to an RE share of 53.4%. Increases in the RE share (including electricity and DH) in both the industrial and building sectors, from 57.9% and 57.6% respectively in 2010 to 63.7% and 69.4% in 2030, results from minor decreases in the level of natural gas and oil use, whilst an increase in the use of coal is offset by a larger increase in the use of biomass (see Figure 13). The transport sector sees little in the way of change to the preexisting renewable energy mix, with projections showing the apparent inability of the transport sector to reach the legislated target of 10% renewables by 2020[9]. This is also reflected in the consistently high level of fossil fuels in the future sectoral TFEC mix (see Figure 13), outlining the potential for the implementation of higher shares of renewable energy in Sweden to substitute these non-renewable energy sources.

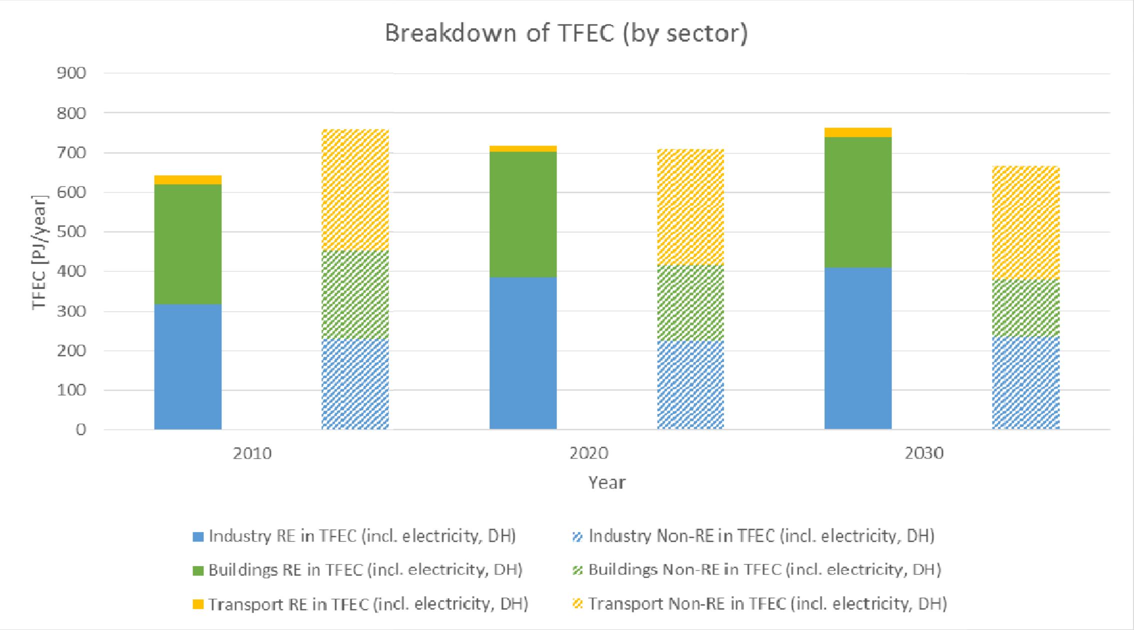

Figure 13 - Breakdown of TFEC projections by sector

In terms of overall TFEC (including electricity and DH), the increased share of renewables from 47.7% in 2010 to 53.4% in 2030 can be attributed to increases in the renewable fuel use in both the industrial and building sectors and increases in RE shares in power generation and DH. This increase in renewables in power generation through 2030 is a result of a three-fold increase in wind energy capacity by 2020 (from 2.2 GW in 2010 to 6.98 GW in 2020, with a smaller increase through 2030 to 7.4 GW) and the uptake of biomass in power generation (see Figure 15). Whilst power generation capacity is seen to increase in Figure 15 by approximately 50% from 2010 to 2030, a simultaneous increase in Swedish electricity consumption is not projected to occur, with electricity consumption in TFEC projected to increase by 1%. This projected increase in generational capacity despite the lack of domestic demand is a result of the projected increase in electricity exports, moving from 8 PJ of imported electricity in 2010 to 90 PJ of exports in 2030.

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[9] This is based on the rough assumption of an average of 5% ethanol in ethanol blend fuels and 5% biodiesel in FAME blend diesel (SEA, 2013).

Contrastingly, the increasing share of renewables in district heating from 67.1% in 2010 to 86.4% in 2030 results from an overall decrease in the TFEC of DH from 215 PJ in 2010 to 175 PJ in 2030, with an increase in solid biomass usage combined with a decrease in the consumption of fossil fuels. Given the continuing high share of TFEC in the end-use sectors provided by electricity production (34% in 2010 and 33% in 2030) and DH (16% in 2010 and 12% in 2030) (see Figure 14), their high shares of renewable energy can have a pronounced effect on the final renewables share in the end-use energy mix.

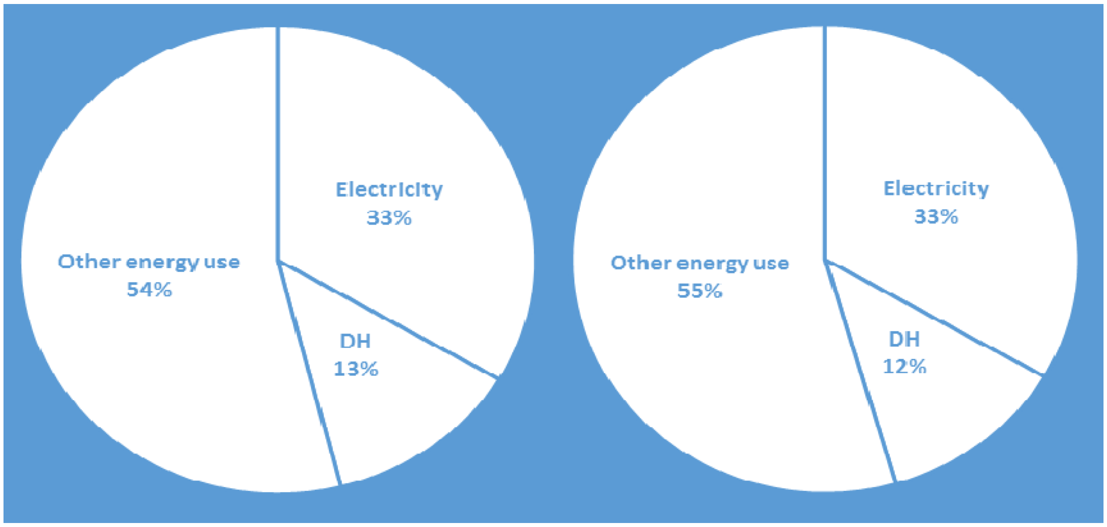

Figure 14 - Electricity & DH share of TFEC 2020 (left) and 2030 (right)

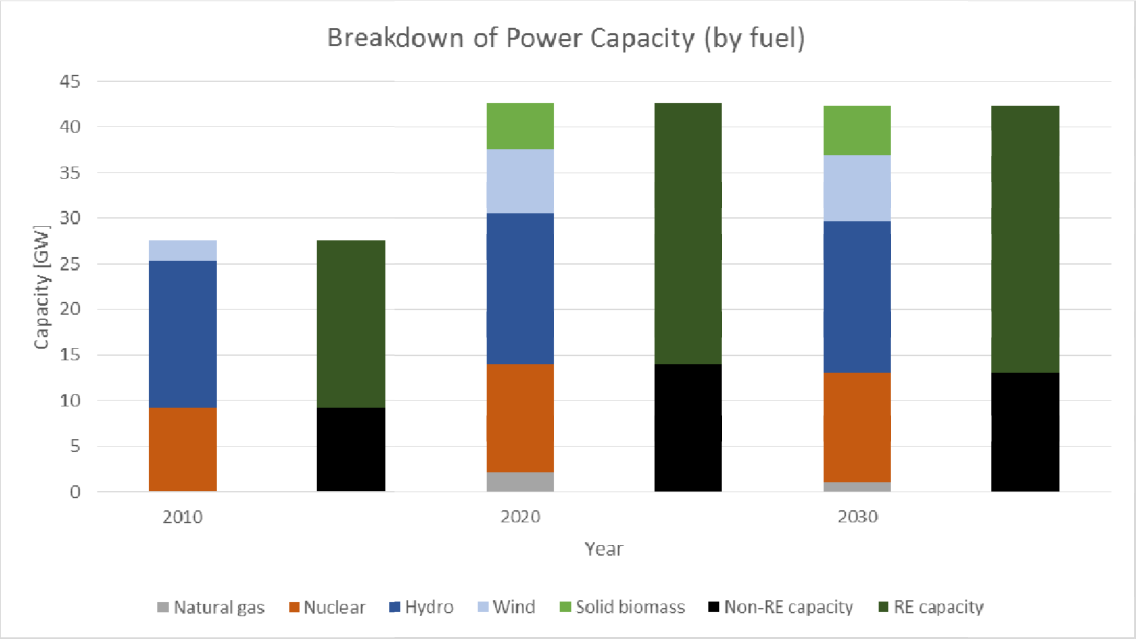

Figure 15 - Breakdown of power generation capacity projections by fuel

Whilst there remains significant potential for the future reduction of non-renewable power generation (predominantly nuclear), this could be difficult given the heavy focus the Swedish government has towards greenhouse gas emissions reductions (IEA, 2013b). A push for renewables could perhaps be better spent on other sectors (this is discussed further in Section 9.2.5).

9.2.4 REmap Options

With a defined understanding of the present situation, market potential and Reference Case projections of energy use in Sweden, the 'REmap Options' analysis can now be assessed.

The REmap Options are an analysis of the realistic potential for further renewable energy deployment in Sweden in addition to that set out by the Reference Case. When establishing the REmap Options for Sweden, the potential for fossil fuel substitution in the national energy mix was first considered from the perspective of the present energy policy situation, the available renewable resources, and the projected Reference Case growth. Based on this assessment, **three key opportunities** for renewables development in Sweden became apparent:

- **Biomass:** A predisposition towards the utilisation of biomass resources exists in Sweden, with almost 22% (486 PJ) of the 2010 primary energy supply comprising biomass (including waste) (SEA, 2012). Whilst this consumption of biomass resource is seen to increase in the 2030 Reference Case to 550 PJ (SEA, 2013), this still leaves roughly 400 PJ/year of economically feasible biomass which could be exploited within Sweden (IRENA, 2014c). The combination of already high levels of biomass use, and the potential for further expansion of biomass resource consumption in Sweden presents a key opportunity for Sweden to add to its Reference Case through increased utilisation of biomass for power and heat generation, and liquid motor fuels in its energy mix.
- **District heating:** In addition to this high level of biomass consumption is a well-developed district heating infrastructure of 22 800 km distribution network, already providing heating demand for 56% of the building sector and connecting 12% of family homes in Sweden in 2011 (Euroheat & Power, 2013). DH represents 12% of the projected TFEC share in Sweden in 2030 (170 PJ). With the Swedish government targeting nationwide fossil-free heating in 2020, and much of the current heating in the building and industry sectors coming from fossil fuel sources, there exists an opportunity for a structural change towards district heating to provide a more renewable heating alternative (renewables share of DH in the 2030 Reference Case is 86.4%).
- **Electrification:** As an alternative to the previous key opportunity, there also exists potential for Sweden to eliminate fossil fuel use in heating through the process of electrification[10]. This electrification of heating demand would be achieved through the use of heat-pumps, utilising this already widespread method of heating family homes in Sweden (Euroheat & Power, 2013) on a national scale, and would continue the current trend of Sweden leading Europe in the development and deployment of heat-pump technology (Forsen, 2005). In addition to the electrification of heating,

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[10] Electrification means that services provided by end-use sectors which are currently based on fuel-based technologies (e.g. gasoline running passenger vehicles, coal-based industrial production processes) are being substituted with their electricity-based counterparts (e.g. electric vehicles, electrolysis for chemical production processes). This raises the share of electricity use in the TFEC of the end-use sectors since less fuel is used whilst more electricity is consumed.

the widespread electrification of Sweden (including the industry and transport sectors) would provide the means for Sweden to reach the Swedish government's vision of a fossil fuel independent transport sector by 2030.

The application of these three opportunities for additional renewable energy development in Sweden resulted in an analysis of four cases (summarised in Table 2) reflecting the feasible avenues of renewable energy development.

Table 2 - Summary of REmap Options cases

Case	Industry	Buildings	Transport	Power	DH
1	All possible fossil fuel capacity directly replaced with biomass	All possible fossil fuel capacity replaced with DH (biomass)	30% of fossil fuels replaced with biofuels	Nuclear capacity replaced with remaining biomass resource + hydropower	Fossil fuel capacity replaced with biomass
2	All possible fossil fuel capacity replaced with DH (biomass)	All possible fossil fuel capacity replaced with DH (biomass)	15% of fossil fuels replaced with biofuels, 15% with electrification	Nuclear capacity replaced with electricity production from DH CHP + hydropower	Fossil fuel capacity replaced with biomass
3	All possible fossil fuel capacity replaced with DH (biomass)	Same as Reference Case	All fossil fuels replaced with biofuels	All possible fossil fuel capacity replaced with DH (biomass)	Same as Reference Case
4	All possible fossil fuel capacity replaced with heat pumps	All fossil fuel capacity replaced with heat pumps	90% of fossil fuels replaced; 80% via electrification, 20% with biofuels	Nuclear capacity replaced with electricity production from hydropower + solar PV	All fossil fuel capacity replaced with heat pumps

Compared to the single REmap Options portfolio assessment of the 26 REmap countries analysed in 2013, the assessment of 4 cases for Sweden is an exception. This is due to the fact that Sweden can benefit from various technology strategies of renewable energy deployment (biomass, electrification, DH). Therefore the costs and benefits of different strategies are assessed separately to provide technology specific recommendations to policy makers. These four cases each focused on a key renewables deployment position, in addition to general renewables deployment.

Case 1: An approach focused on extended biomass use. Available biomass resources were allocated to the substitution of (i) all fossil fuels in industry (direct substitution), (ii) district heating (including a shift of building heating towards district heating), and (iii) partial substitution of fossil fuels in the transport sector.

Case 2: A structural change towards the use of district heating, with industry and building sector heating needs to be supplied by district heating in the place of the generation of heat (for example in CHP plants or boilers) by the end-use sectors; additional district heating demand will be supplied by the available biomass resources. This option was a result of the target for fossil fuel free heating in Sweden by 2020, where building sector heating is currently dependent upon a mixture of combustible fuels, district heating and electricity.

Given this target, a shift of the fossil-based fuels in building and district heating to biomass (in addition to the implementation of other renewable resources) could further improve the renewables share in the energy mix of Sweden. Remaining biomass resources were used as liquid biofuels to substitute fossil fuel dependence in the transport sector, in addition to a small push towards the use of electric vehicles.

Case 3: Allocating all available biomass resources to liquid biofuels production for use in transportation. This option was a result of the target for a 10% share of renewables in the transport sector by 2020, and a vision for fossil fuel free transport by 2030. Based on Reference Case projections, the transport sector has a 12 PJ deficit to overcome to reach 10% renewables[11], with an additional 284 PJ required in the 2030 Reference Case to reach 100% renewables. Given these targets and potential biomass requirements (assuming a biofuel transport sector rather than an electrified sector), a shift away from the fossil-dominated transport sector to biomass could significantly improve the renewables share in the energy mix of Sweden.

Case 4: A transitional shift to the electrification of the Swedish end-use sectors, with non-renewable energy consumption replaced with electricity consumption where technically feasible. Electrification focused on the shift of the transportation sector towards electric vehicles, with heating demand, in both the building and industry sectors, to be supplied by heat-pumps. All additional electricity generation demand was provided by additional renewable resources.

Table 3 highlights the prominent role played by biomass in providing a renewable source of energy in each of the 4 REmap Option cases. Given its importance in further developing the renewable energy mix in Sweden through 2030, care was taken to ensure that the biomass consumption in each of the cases took place at a sustainable level (based on the resource availability outlined in Table 1), with the rates of biomass consumption for each case given in the case analysis results in Table 3. Finally, a complete overview of the background and assumptions of each of the four cases is given in Appendix A, with the following portion of the REmap Options section focusing on the analysis results and findings.

Table 3 - REmap Options cases biomass resource consumption in 2030 TFEC

Case	Biomass Resource Potential in 2030 [PJ][a]	Total Biomass Consumption [PJ][b]	Biomass in industry [PJ]	Biomass in buildings [PJ]	Biomass in transport [PJ]	Biomass in electricity generation [PJ]	Biomass in DH [PJ]
Reference	954 – 1,136	565	248	55	15	74	157
1		863	326	55	105	86	186
2		793	248	55	53	119	264
3		1,070[c]	248	55	268	74	157
4		683	248	55	74	74	157

[a] (IRENA, 2014c);
[b] assuming a conversion efficiency of 50% for liquid biofuels, in other words 1 PJ liquid biofuel requires 2 PJ of raw biomass;
[c] assuming 170 PJ of biomass import

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[11] This is based on the rough assumption of an average of 5% ethanol (by volume) in ethanol blend fuels and 5% biodiesel (by volume) in FAME blend diesel (SEA, 2013).

In addition to increased biomass consumption in the 2030 REmap Options projections, electricity usage was found to play a key role in developing the RE share of the energy mix due to its increasingly high share of renewable power generation through 2030. This increased RE share in REmap Options power generation, from 62% in the Reference Case to around 70% in all four cases in 2030, highlights the further potential for renewables to develop in Sweden compared to the Reference Case under business as usual conditions.

The results of each of these four cases, as outlined in Table 4 below, are highly dependent upon the assumptions and rationale behind each of the cases. These assumptions were based on the specific renewables development focus of each individual case, and this is discussed in more detail in Appendix A.

Table 4 - REmap Options cases renewable energy share of TFEC in 2030

Case	TFEC [PJ]	RE share of TFEC [%][a]	RE share in industry [%][a]	RE share in buildings [%][a]	RE share in transport [%][a]	RE share in electricity generation [%][a]	RE share in DH [%][a]
Reference	1,428	54.2	63.9	71.5	7.3	61.7	92.8
1	1,421	71.0	79.3	81.7	37.4	69.1	96.1
2	1,395	70.3	80.4	83.2	26.5	71.5	97.1
3	1,430	74.4	66.8	75.0	89.0	70.1	91.4
4	1,255	74.6	74.3	78.5	66.8	67.3	94.3

[a] including electricity and district heating

Figure 16 below shows a sectoral breakdown of the fuel use in each of the four cases. The main REmap Options findings are discussed below:

- It can be seen that the industry sector is heavily dependent on biomass and electricity in all of the cases, with the portion of fossil fuel used in the iron and steel sub-sector unable to be substituted by either biomass or district heating;
- Sweden represents an interesting case due to the prevalence of district heating consumption in the building sector, with the ability for DH to be used to substitute fossil fuels in the buildings sector and potentially in industry;
- Additionally, in all cases, substitution of transport fossil fuels is heavily dependent on liquid biofuels, indicating increasing importance of this resource in future efforts to move Sweden towards a fossil fuel independent transport sector in 2030. Moreover, biomass use across all three cases is close to exhausting the economic biomass resource potential (as shown in Table 3);
- Furthermore, it is apparent that electrification of the energy mix in Sweden results in considerable energy savings, resulting in a TFEC (1,255 PJ) roughly 150 PJ/year lower than the other cases. These savings are most apparent in the transport sector, where electrification results in a 33% reduction in TFEC (208 PJ versus 309 PJ in the Reference Case), whilst the industry and buildings sectors also benefit to a lesser extent;

Furthermore, in terms of the increase of the total RE share in TFEC, Case 4, focusing on the electrification of Sweden, results in the largest share at 74.6% of the 2030 TFEC of 1255 PJ. This suggests that in the case of

Sweden, due to the high preexisting share of renewables in the power generation sector (61.7%) and the increased energy efficiency from electrification (12% reduction in TFEC) in the Reference Case, it is better to focus energy mix development on the substitution of fossil fuels with electricity. Such a focused use of electricity, which is predominantly hydropower and nuclear (i.e. GHG emissions neutral), would also seem to fit with the Swedish vision of a zero net GHG emissions society by 2050.

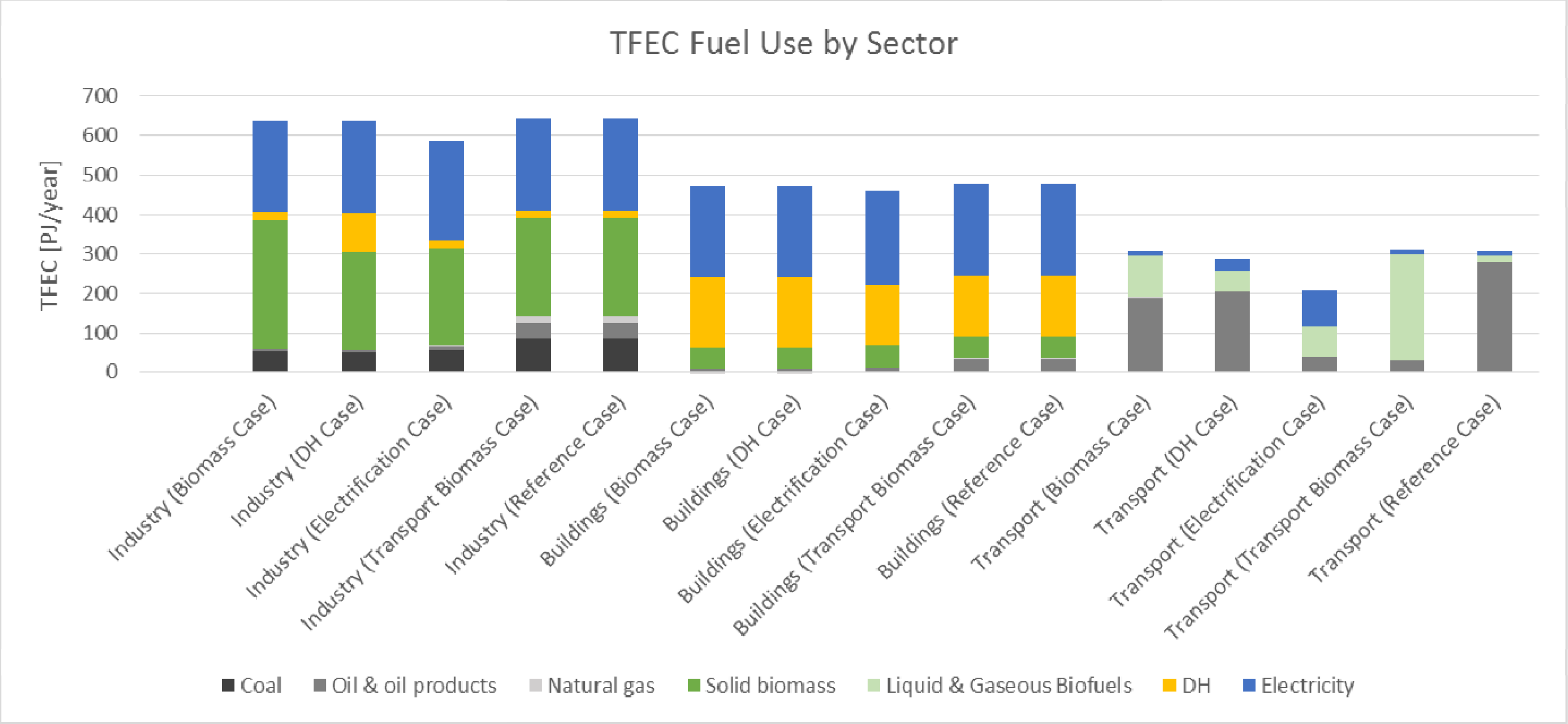

Figure 16 - Swedish fuel use breakdown in TFEC by sector

When looking at this sectoral fuel use from a renewable energy perspective, as shown in Figure 17, the pivotal role of biomass in the 2030 Swedish energy mix becomes even more apparent, representing more than 75% the TFEC of all renewables in all cases (from 75% in the Reference Case up to 81% in the DH case).

In all of the cases industry represents a sizeable share of total biomass consumption (from 31% in the transport biomass case up to 45% in the Reference Case), with DH the largest consumer of biomass in Case 2 (36% of total biomass consumption) and the transport sector the largest consumer in Case 3 the largest user of biomass (33% of total biomass consumption). However, Case 4, focusing on electrification, represents the lowest use of biomass in the four REmap cases (exploiting 72% of available resources compared to the highest consumption case, Case 3, which exploits 95% of economically feasible resources and requires additional imports), indicating that there are remaining biomass resources that could be exploited for power generation.

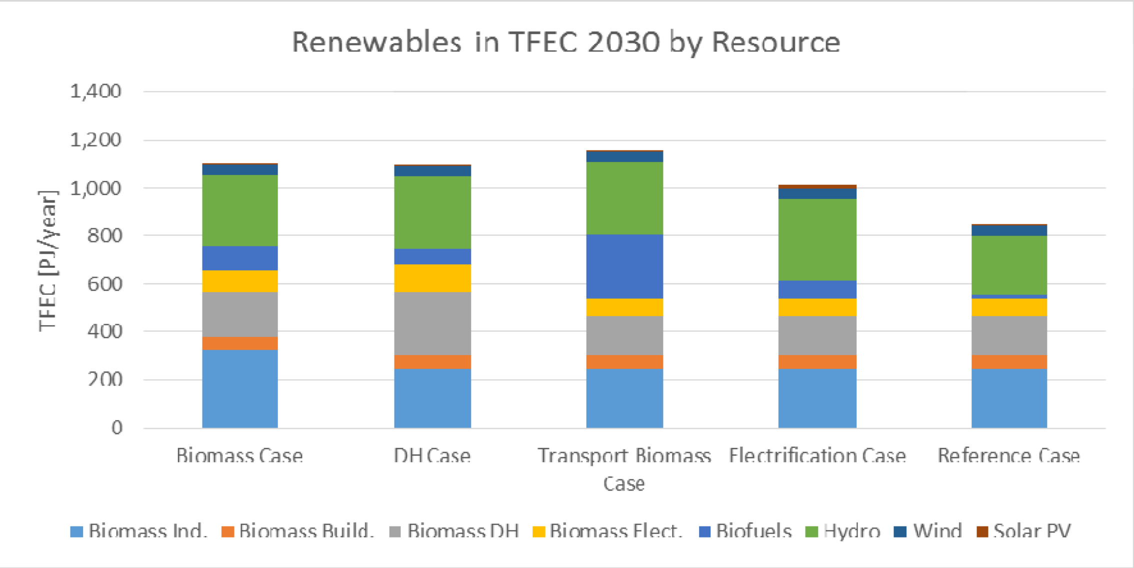

Figure 17 - Swedish renewable fuel use breakdown in TFEC

This increased use of biomass for electricity production in the electrification case (Case 4) would allow for an increased share of RE in the power sector, thus reducing the bottleneck issue in this case. More specifically, the overall RE share in TFEC in Case 4 is limited due to the exhaustion of renewable power generation resources (predominantly hydro) in meeting increased electricity production demand due to electrification, rather than in substituting non-renewable fuels. Further development of the comparatively small contribution of solar power production (currently 0.01 GW in all cases, except for electrification at 3 GW), and the untapped resources of ocean energy (with no current or projected commercial generation capacity) could also be deployed in the future to support electrification. Moreover, the net export of 90 PJ/year of electricity in 2030 could be redirected for domestic use, allowing for new renewables resources to substitute non-renewables power generation rather than solely being used to meet increased demand.

On the other hand, further increasing the use of biomass in the end-use sectors, resulting in Sweden becoming a net importer of biomass, could allow for Sweden to remain a net exporter of electricity, whilst further increasing the RE share in national 2030 TFEC. Finally, further increases in energy efficiency beyond that in the

Reference Case could result in a reduced TFEC, allowing for more renewable resources to be used to substitute non-renewable consumption.

In addition to assessing the final RE share in TFEC achievable with each of the four REmap Options cases, the cost of substituting non-renewable sources with renewables was analysed in order to determine the most cost effective REmap Options case. The substitution costs were calculated from two perspectives: the cost based on international prices for fuels and investment in capacity (perspective of governments), and the cost based on domestic (Swedish) prices including all relevant taxes (see Appendix B for detailed resource prices) (perspective of businesses), and are outlined in Table 5 below.

Table 5 - Substituion cost for Swedish REmap Options cases from government and business perspectives

		Substitution Cost [USD/GJ]					
REmap Option Case		Average of all sectors	Industry	Buildings	Transport	Electricity Generation	District Heating
Biomass Case	Government	-4.5	-1.9	-10.9	-5.0	-2.9	-5.2
	Business	-6.0	-11.9	-15.4	0.4	-0.1	-11.2
DH Case	Government	-7.6	-10.8	-12.6	-1.1	-2.9	-5.2
	Business	-8.7	-12.5	-14.9	-2.3	-0.2	-11.2
Transport Biomass Case	Government	-4.7	-	-	-5.1	-1.9	-
	Business	0.7	-	-	0.7	0.3	-
Electrification Case	Government	2.8	3.5	0.6	2.8	0.1	2.7
	Business	-5.8	-10.1	-4.0	-5.3	-8.9	-7.1

Note: In some cases, no substitution costs were estimated for the industry, buildings and district heating sectors, as no REmap Options were assigned for them.

From the summary of substitution costs in Table 5, it is apparent that the substitution of non-renewable resources by renewables in TFEC is cost effective, especially from a business perspective, i.e. based on local prices. More specifically, the negative average cost of substitution for most cases indicates that the substitution of non-renewables with renewables results in savings (on average). The lowest substitution costs are found in the buildings sector. This is because in all of the cases (except for Case 3 – transport biomass), fossil fuel-based space heating (consuming heating oil and natural gas) was replaced with district heating and its comparatively low cost biomass fuel-stock.

In terms of the average cost of substitution, the lower values in the local price cases (except for Case 3 – transport biomass) are primarily a result of this substitution of fossil-based heating fuels in the buildings sector, in addition to similar substitution of fossil fuels for cheap biomass in industry, due to the low estimated cost of biomass in Sweden in 2030 based on Swedish Energy Agency 2030 projections (2013). In contrast, the substitution cost for Case 3 is lower for international prices, because the estimated international price of liquid biofuels in 2030 is lower than that of local Swedish prices (relative to the cost of fossil-transport fuels).

Substitution of non-renewable technologies in the power sector results in similar, slightly negative substitution costs for all four cases, although the electrification case (Case 4) results in comparatively high governmental and comparatively low business substitution costs. This is due to the substitution of only a small quantity of nuclear capacity with cheaper solar PV instead of with hydropower, as occurred in the other three cases (all added hydro capacity contributed to new demand), because nuclear has low production costs compared to hydropower. The DH sector also results in very low costs of substitution for all cases. This is a result of the low cost of biomass (in Cases 1 & 2) and electricity (in Case 4) compared to the Reference Case use of fossil fuels in DH in addition to biomass. The lower substitution cost for business compared to government reflects the low estimated local price of biomass and higher fossil fuel prices in Sweden in 2030 (due to CO_2 and energy taxes for fossil fuels), representing a greater price difference than found in estimated international prices for biomass and fossil fuels in 2030.

As part of the REmap Options process, these costs of substitution were collated in a cost-supply curve for improved comprehension, looking at the substitution costs (local and international) in terms of a breakdown by renewable technology and by sector. The following figures outline the substitution 'cost curves' for each of the four cases based on local prices, which includes national taxes and subsidies. The full-set of cost curves (local and international prices; breakdown by technology and by sector) have been omitted from this report for the sake of brevity. These technology options are shown individually based on their average costs of substitution, whilst the horizontal (black) bar to the far left of the figures shows the growth of modern renewables according to the Reference Case. Added to this are the REmap Options, which provide the solution for additional increases of renewables in 2030 TFEC in Sweden achievable through the use of individual technologies (represented by individual vertical bars), and the subsequent cost that arises due to the substitution of a specific fossil fuel technology with a specific renewable energy technology (y-axis).

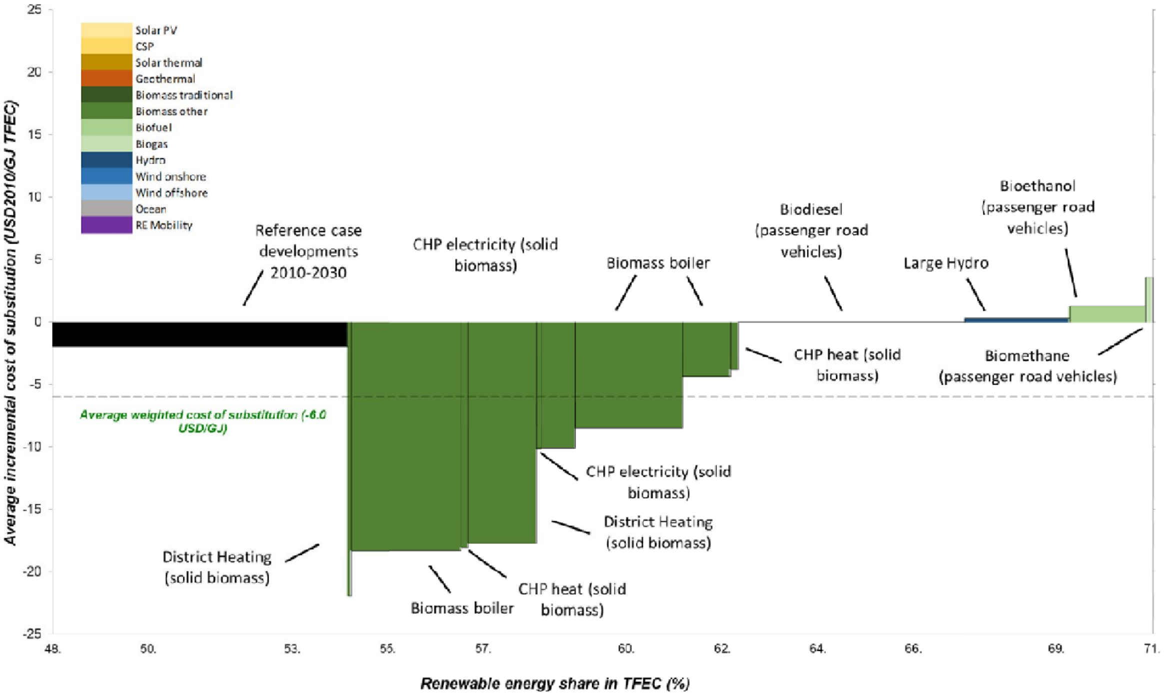

Figure 18 - Case 1 cost-supply curve (business perspective) for Sweden, 2030; breakdown by resource

Figure 18 highlights the substitution costs of specific technologies in Case 1. With a focus on the substitution of fossil fuels with biomass for heating, the most cost effective measures involve the substitution of fossil fuel space heating in the building sector with district heating (heat only and CHP heat production) and the substitution of fossil fuel boilers in industry with biomass fuelled boilers. The negative substitution costs for these technologies indicate that they have an economic case. Such savings arise from the local cost of biomass in Sweden in 2030 (SEA, 2013), which is estimated to be significantly cheaper per GJ than the fossil fuels which are being substituted.

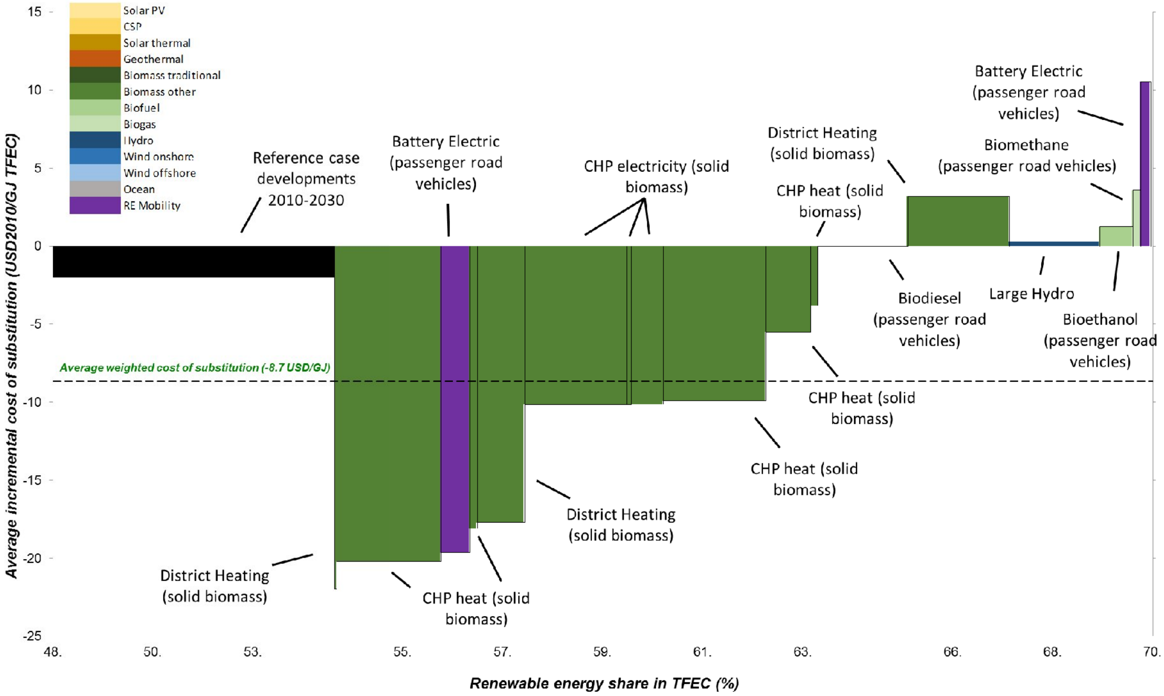

Figure 19 - Case 2 cost-supply curve (business perspective) for Sweden, 2030; breakdown by resource

Similar to Case 1, Case 2 (Figure 19) focuses on the substitution of fossil fuels with biomass for heating, substituting fossil-based heating in the industry and buildings sectors with biomass-based district heating. The most cost effective measures involve the substitution of fossil fuel space heating in the building sector and fossil fuel boilers in industry with district heating (heat only- and CHP heat production). Additionally, the substitution of 15% of the total diesel road transport fleet with battery electric vehicles also represents a negative substitution cost (i.e. potential financial saving). Such a negative substitution cost is due to the low estimated cost of refueling an electric vehicle with electricity (due to the low consumer electricity price in Sweden compared with much of Europe), and the comparatively high estimated cost of fossil transport fuels in Sweden in 2030.

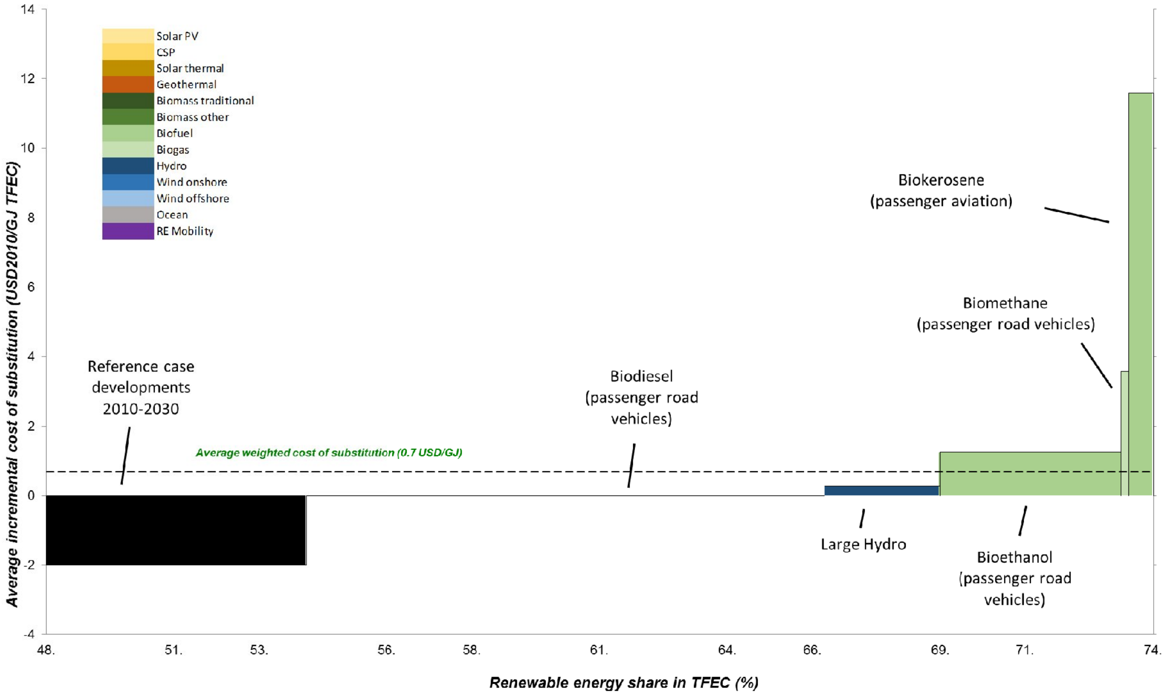

Figure 20 - Case 3 cost-supply curve (business perspective) for Sweden, 2030; breakdown by resource

From a local (Swedish) price perspective Case 3, whilst still resulting in a low average cost of substitution of 0.7 USD/GJ TFEC, is less financially appealing than REmap Options Cases 1 and 2. This situation (as outlined in Figure 20) is a result of the focus of this case on the substitution of fossil fuel in the transport sector. Whilst the estimated 2030 costs of biodiesel result in a substitution cost of zero for diesel-based passenger road vehicles, the substitution of gasoline with bioethanol, natural gas with biomethane, and jet fuel with biokerosene is estimated to incur positive substitution costs. High estimated costs for biokerosene in 2030 are a reflection of the currently immature production technologies and uncertainty surrounding its future development (Ramboll, 2013). Similarly, switching from natural gas road vehicles to biomethane results in a positive substitution cost due to the comparatively high estimated cost of production of biomethane from animal slurry (Murphy, 2010) which is the predominant source of biomethane in Sweden (IRENA, 2014c).

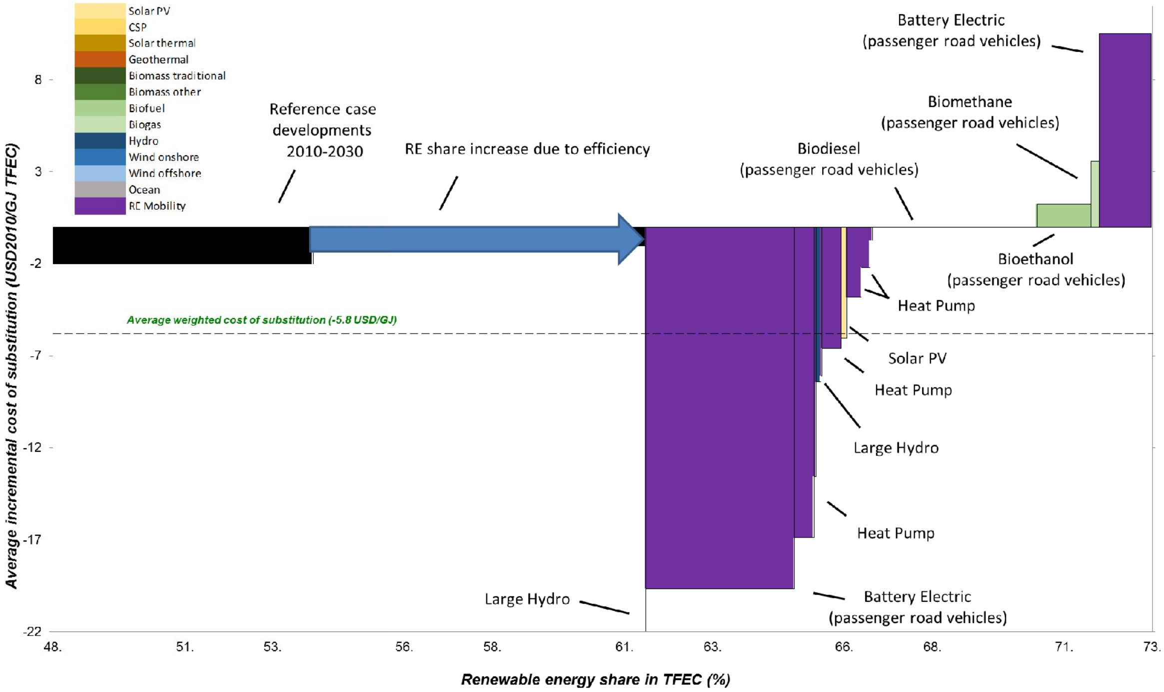

Figure 21 - Case 4 cost-supply curve (business perspective) for Sweden, 2030; breakdown by resource

Substitution of fossil fuel technologies with electrification technologies results in a substantial increase in the share of renewables in TFEC (approximately 8% from 54% to 62%, represented in Figure 21 by the blue arrow) due to the contribution of higher energy efficiencies. This electrification of energy consumption is the focus of Case 4 (predominately through the use of heat pumps and battery electric vehicles) takes advantage of the low estimated price of electricity (both residential and industrial) compared to fossil fuels in Sweden in 2030. These low estimated electricity prices are a result of the prevalence of hydropower and nuclear power in Swedish power generation, in addition to the low level of taxation applied to electricity-use in the industry sector. Given the uncertainty of nuclear power and hydropower generation developments in Sweden through 2030, the low estimated price of electricity in 2030 Sweden (compared to neighbouring European countries such as Denmark and Germany) needs to be carefully monitored. Changes to this estimated 2030 electricity price in future could have a significant impact on the supply cost of electrifying Sweden, as is highlighted by the sensitivity analysis in the following sub-section of the report.

Given the very low substitution costs in all of the REmap Options cases, especially for local prices, it was decided to complete a basic sensitivity analysis, in order to determine the reason for these low substitution costs. This sensitivity analysis focused on the local prices of key energy resources substituted in all four cases, namely solid biomass, liquid biomass and electricity. The analyses compared the estimated local Swedish prices in 2030 with those of other northern European countries, namely Denmark and Germany, with the key prices under comparison shown in Table 6.

Table 6 - Key sensitivity analysis local resource prices

	Price of Biomass [USD/GJ]	Ind. Price Electricity [USD/kWh]	Res. Price Electricity [USD/kWh]	Price of Biodiesel [USD/GJ]	Price of Bioethanol [USD/GJ]	Gasoline [USD/GJ]	Diesel [USD/GJ]
Sweden	9.7	0.09	0.28	48.4[a]	51.3[a]	51.3	48.4
Denmark	13.5	0.13	0.38	93.9	67.6	101.8	65.3
Germany	18.7	0.12	0.42	35.8	70.3	59.1	54.6

[a] due to a lack of available projection data, the 2030 price of biodiesel and bioethanol was linked to the price of fossil transport fuel

These results are outlined in Figure 22 below, and highlight the significant impact of electricity prices, solid biomass and liquid biomass prices on the average cost of substitution. More specifically, the very low projected cost of biomass in Sweden in 2030 (SEA, 2013), the low price of industrial electricity due to production from hydropower and nuclear, and low taxation, result in a potentially distorted cost of substitution when compared with local prices in other northern European countries. Given the difficulty of projecting commodity costs through to 2030, it is believed that the cost of substitution in Sweden should be monitored carefully and updated when more accurate projections become available in future.

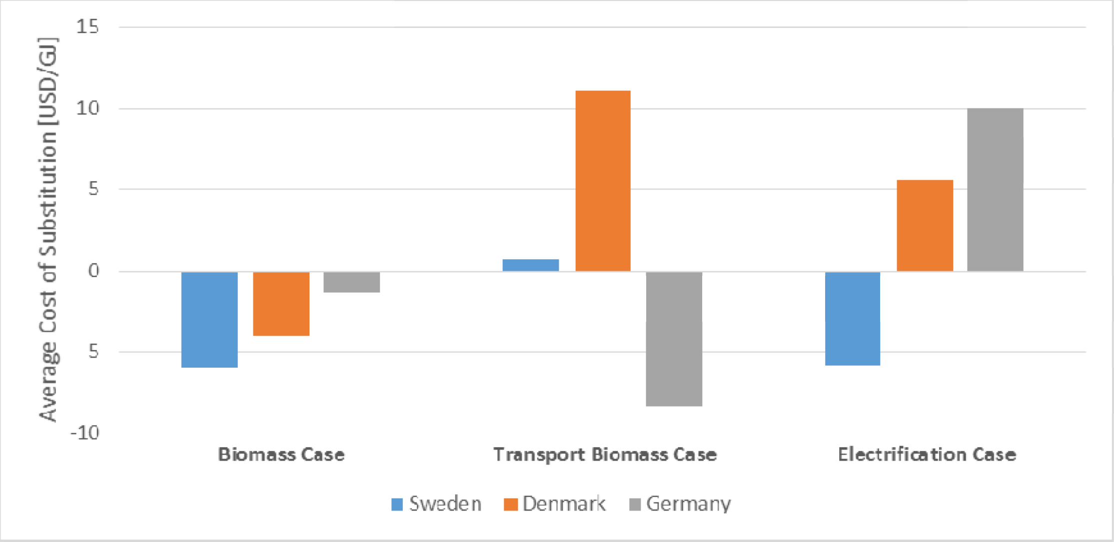

Figure 22 - Sensitivity analysis of the effect of local price on average substitution cost

9.2.5 Policy and barriers

From the four REmap Options cases it is apparent that there is significant, economically viable potential for Sweden to further the share of renewables in national energy consumption in 2030 beyond that proposed in the Reference Case projections. However, this future development and deployment of renewables in Sweden hinges on the attitudes of policymakers and influential industrial/societal stakeholders, each of who has their own agenda to support. This is highlighted by the 15%-20% difference between the Reference Case provided by the Swedish Energy Agency and the REmap Options cases in terms of projected renewables share of TFEC in

2030. In 2012 the share of renewables in Swedish TFEC already reached 51%, suggesting that, based on the Reference Case projections this share will only increase by 3.2% over 18 years (to 2030), which is very low given the increase in RE share from 48% in 2010 to 51% in 2012. The conservative nature of the Reference Case projections suggests that in spite of the potential barriers, the ability for Sweden to significantly increase its share of renewables in TFEC beyond 70% by 2030 appears quite feasible.

With a legislative target of a 40% reduction in GHGs by 2020 compared to 1990 levels, and the vision of zero net GHG nationwide emissions by 2050 (Swedish Government, 2010), the current political mandate in Sweden appears to focus on the pragmatic reduction of net greenhouse gas emissions rather than on renewables. This is highlighted by recent comments by the Swedish Prime Minister (Hellberg, March 2014) reaffirming the 2010 reversal of the decision to phase-out nuclear power in Sweden and indicating the future low-emissions energy development will not involve the displacement of nuclear power. Furthermore, from a power generation perspective, the largest renewable electricity source (hydro) faces resistance to the future development of large-scale hydropower capacity due to environmental concerns (Renofalt, Jansson and Nilsson, 2010). This governmental stance, combined with the challenges facing future hydropower deployment represent significant barriers in moving towards a renewable power sector mix.

From the end-use energy perspective, the future development of renewables also faces some challenges, due to the dependence of Sweden on biomass resources. More specifically, biomass already provides nearly 30% of TFEC (in 2010), reflecting the historically increasing trend of bioenergy use in Sweden (Ericsson, 2011). This increase in biomass consumption has led to concern from major utilities and forest industry companies (e.g. pulp and paper) that increasing demand for biomass from both sectors will lead to increased biomass prices, however, given the projected increase in the demand from heat and electricity utilities and from the industry sector (pulp and paper), domestic biomass prices could increase dramatically. In the past such concern has led to increased import of foreign biomass in order to keep the domestic supply price low (Hektor, 2011). However, the increasing end-use demand for biomass and the projected modal shift to DH (reliant upon biomass) through 2030 suggests substantial increases in biomass import would be required if these low domestic biomass prices were to continue in the future.

Hansson, Berndes and Borjesson (2009) suggest that future increases to biomass import into Sweden should remain economically viable (i.e. biomass imports will cost equal to or less than domestic production), but that this is highly dependent on the future global demand for biomass. Given this uncertain import future, increased consumption of domestic biomass through 2030 is likely. This poses a challenge to future biomass production due to the current restrictions which result in more than half of the current biomass production of 1.36 EJ being left at the forest sites due to market restrictions (Hektor, 2011). However, given that this 1.36 EJ of biomass is being harvested each year (but only half is consumed), and that the maximum biomass consumption from any of the REmap Options Cases is 1.07 EJ in 2030, the challenge in ramping up biomass production through 2030 appears less daunting than having to commence exploitation of virgin forests. It should be noted that this ramp-up would require the involvement of a large number of stakeholders, due to the diversified ownership of Swedish forests: private individuals (50%), private companies (25%), state owned companies (14%), other private owners (6%), state (3%), other public (2%) (Ericson, 2011).

Well-established best practices in Sweden for biomass resource harvesting allow for significant expansion of the current Reference Case biomass exploitation, and represent an opportunity to continue the historical trend of domestic biomass utilisation in total final energy consumption. Such a combination of current technical expertise and increased biomass exploitation would ensure Sweden remained at the forefront of biomass harvesting practices, allowing for both an increase in renewable in TFEC and also for Swedish biomass best-practices to be used as a model for other countries seeking to expand biomass production. Furthermore, current best practices for district heating in Sweden could be combined with this increase in biomass resource harvesting to allow for a modal shift towards district heating in Sweden. Such a transition would further increase the renewable energy share in Sweden's TFEC and would help to eliminate the use of fossil fuels for heating, as per the 2020 national target.

Whilst there are significant opportunities and some barriers to future renewables development in Sweden through 2030, there is certainly some room to maneuver. With very low projected average cost of substitution for renewables in each of the four REmap Options cases, there is still room for the future cost of renewable resources to rise, whilst the average cost of fossil fuel substitution by renewables would still be economically positive in Sweden.

9.2.6 Summary

This IRENA REmap analysis of Swedish energy consumption through 2030 proposes four cases through which Sweden can build on its Reference Case projections to 2030 of a total final energy consumption of 1,428 PJ comprising 54% renewables. In terms of further developing this RE share, a transitional shift in Sweden towards electrification (Case 4) results in the largest final renewables share of 75%, with a local average substitution cost of -5.8 USD/PJ. This occurs through the increased capacity of heat pumps in buildings and industry and the use of EVs for transportation, supported by a portfolio of renewable power generation technologies including hydro, wind, solar and biomass. From an economic perspective, the least costly method of substituting fossil fuel consumption for renewables is to commence a structural change towards district heating, with a local average substitution cost of -8.7 USD/GJ resulting in a final RE share of 70% (the smallest RE share in TFEC of the four REmap Options cases).

Whilst the difference between the Reference Case provided by the Swedish Energy Agency and the REmap Options cases in terms of projected renewables in 2030 is quite large, the conservative nature of the Reference Case projections suggests that in spite of the potential barriers, the potential for Sweden to significantly increase its share of renewables in TFEC beyond 70% by 2030 appears quite feasible.

9.3 Developing Nation - Kenya

9.3.1 Present energy situation

With a total final energy consumption (TFEC) of approximately 0.54 exajoules (EJ) in 2010, Kenyan energy consumption (see Figure 23) 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). This TFEC contributes to 2.5% of the total African TFEC, and over 15% of East African TFEC (IEA, 2012a; World Bank, 2014a).

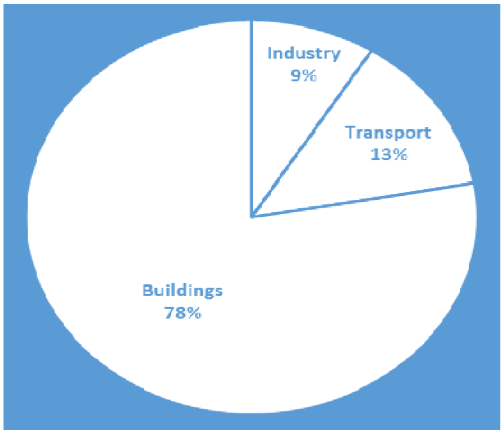

Figure 23 - Kenyan total final energy consumption 2010 by sectoral share

Representing the smallest share of Kenyan TFEC at 9%, the comparatively small energy consumption of 48 petajoules (PJ) in the industry sector is widely spread amongst various sub-sectors. With a lack of bulk materials production such as iron, steel, pulp & paper and chemicals (USGS, 2013), energy consumption is highest in the 'non-metallic mineral' sub-sector which focuses on the production of cement and soda ash, constituting 14% of industry TFEC. The second largest sub-sector consumer is 'food and tobacco', at close to 2% (IEA, 2012). The remaining 84% of industry TFEC can be attributed to a large informal sector, which is estimated to represent 34% of GDP and accounts for 77% of total employment (IEA, 2012b). This sub-sector of industry is comprised of a wide-variety of small and medium enterprises, including small-scale consumer goods manufacturing and building & construction. Industry is dominated by the use of oil & oil products, representing 58% of industry TFEC, whilst there is a total absence of biomass consumption in this sector despite its large share of TFEC.

Comprising the residential and commercial sub-sectors, the buildings sector constitutes the highest share of Kenyan TFEC at 419 PJ. Residential energy use dominates this sector, consuming over 99% of buildings TFEC (IEA, 2012). Whilst residential TFEC has increased by close to 70% over the last 20 years (1990-2010), residential per capita energy consumption (including electricity) has remained steady at around 10.2 GJ/person (see Table 7).

Table 7 - Historical Development of Kenyan Residential Energy Consumption

	1990	2000	2010
Fuel (excl. electricity) [MJ/Capita]	10247	10190	9943
Traditional Biomass [MJ/Capita]	9903	9684	9598
Oil & Oil Products [MJ/Capita]	344	506	345
Electricity [kWh/Capita]	33	26	42
Total [GJ/Capita]	10.37	10.28	10.10
Residential TFEC [TJ]	**243,071**	**321,681**	**412,997**

(IEA, 2012)

This constant rate of per capita energy consumption in the residential sub-sector is marginally influenced by the limited access of individuals to electricity, with 23% of the population having access to electricity in 2010 up from 10.9% in 1990 (World Bank, 2014a). This electrification has resulted in a minor increase in per capita oil consumption in addition to a slight decrease in the per capita dependence on traditional biomass for over 95% of residential TFEC (IEA, 2012). Nevertheless this traditional biomass dependence remains, with a significant expenditure of time and household income spent on the collection of fuel-wood to meet the subsistence needs, cooking and water heating, of approximately 90% of rural and 10% of urban households (Gathui, 2010). This dependence on traditional biomass to meet residential energy needs, of which only 37.3% is estimated to be from sustainable supplies (Githiomi & Oduor, 2012; MOE, 2002) has resulted in widespread national deforestation at roughly -12 000 hectares (ha) per year between 1990 and 2010, with total forest cover decreasing from 3.71 million ha in 1990 down to 3.47 million ha in 2010 (FAO, 2010), which continues to hamper residential access to energy through scarcity of supply and increased fuel prices, leading to continuing low levels of per capita energy consumption.

Finally, with a TFEC share of 13% and yearly energy consumption of 71 PJ, the Kenyan transport sector has experienced an 85% increase in final energy use over the ten year period to 2010 equating to annual growth of approximately 6.4% per year (IEA, 2012). This growth represents the fast growing motorisation of the economy, with the number of vehicles registered in the country doubling over the last five-year period (Kenya National Bureau of Statistics, 2013).

Providing a minor contribution to industry and buildings sector TFEC at 27% and 2% respectively, electricity consumption represents approximately 4% of TFEC (IEA, 2012). This reflects the low level of electrification in Kenya at 23% – 5,612,055 (58.2%) people in urban and 2,532,586 (8.1%) people in rural areas – with grid infrastructure predominantly limited to major urban areas in the south (as shown in Figure 24). The 7.5 terawatt-hours (TWh) of electricity generation is provided by three main technologies – hydropower (3.4 TWh), geothermal (1.5 TWh) and oil-based fuels (2.3 TWh comprised predominantly of grid connected medium-speed diesel power plants) – with smaller contributions from biomass (0.3 TWh) and wind power (0.02 TWh). This generation is distributed between the industry and buildings sectors (as shown in Figure 25) (IEA, 2012), with the energy use of the commercial sub-sector 100% reliant upon electricity. Such historically low levels of electrification and the concentration of transmission infrastructure in the south of the country has given rise to a well-established set of 15 mini-grid and off-grid solutions (see Figure 24), five of which have been operating for more than 30 years (Gichungi, 2013). This experience with mini-grid and off-grid solutions, and the high cost of expanding the transmission network into rural areas suggests there is room for further growth in distributed generation in Kenya.

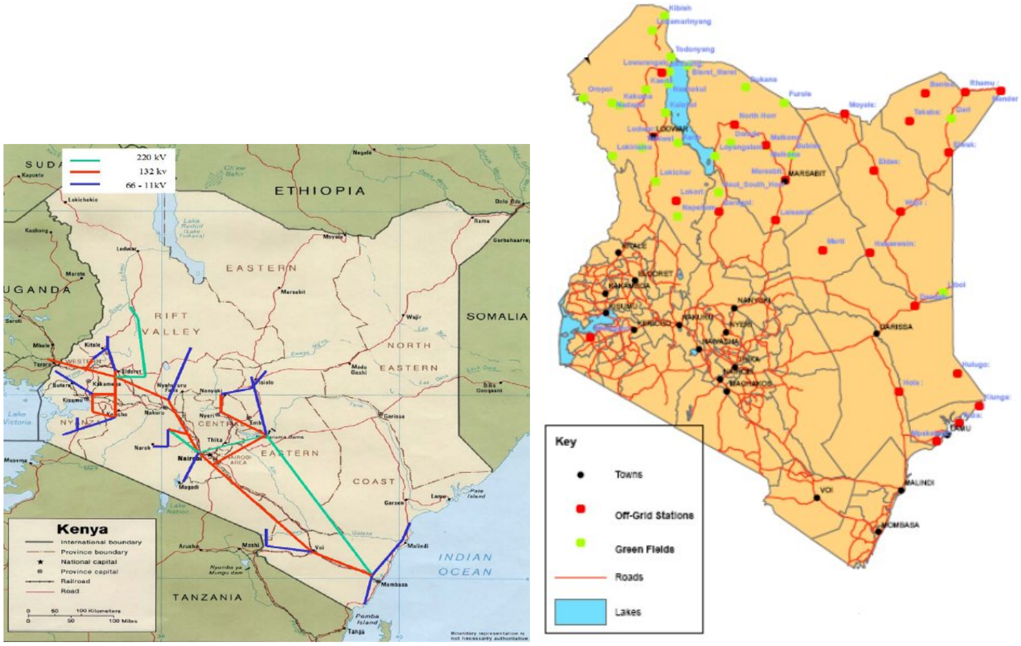

Figure 24 - Kenyan electricity transmission network (left) & off-grid & mini-grid systems (right) (Gichungi, 2013)

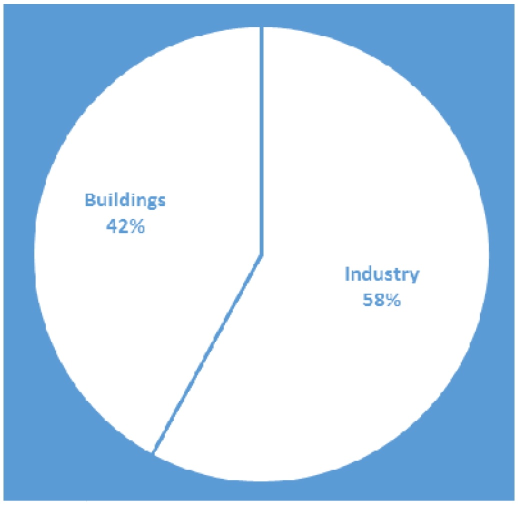

Figure 25 - Share of electricity consumption by sector 2010

Whilst Kenya is endowed with substantial renewable energy resources, especially geothermal, 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 it represents 65% of all electricity generation. Of this renewable share of the 7.5 TWh of electricity generation, hydropower is the largest contributor, also in terms of total generation, representing almost 46% of electricity production (IEA, 2012). Geothermal also contributes to the high level of renewables in the power sector, generating over 19% of all Kenyan electricity. However, limited development of these geothermal resources and fluctuations in yearly hydropower availability due to droughts, which have historically resulted in acute electricity shortages, has led to the dependence of the power sector on imported oil for over 30% of total generated power (UNEP, 2006).

9.3.2 Energy resource potential

With the current situation befalling Kenyan energy consumption outlined in the previous section, the next step in exploring the potential for Kenya to increase its renewable energy share by 2030 is to assess the potential for growth and structural change of energy consumption through 2030. Examining this potential in terms of available resources and relevant legislation allows for a comparison of the 2030 Reference Case projections for 'business as usual' (see Section 9.3.3) and the realistic potential for renewable energy development in addition to the Reference Case (i.e. the REmap Options case outlined in Section 9.3.4).

Whilst the renewable resource potential of Kenya is substantial, much of the available renewable sources (see Table 8) are currently underexploited. This is predominantly due to financial and technological restrictions, in addition to a lack of understanding of the exact resource potential due to 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. If Kenya is to work towards a 2030 energy supply with a greater renewables share, then these currently underexploited renewable energy resources will need to be further developed. Furthermore, given the historical impact of droughts on hydropower production, capacity growth is likely to be limited due to uncertainty surrounding future production capabilities (UNEP, 2006). In the short-term, growth in wind and solar is also likely to be restricted due to the suspension of new licence issuances for wind and solar projects through 2017 due to a governmental push for lower electricity prices through the development of cheaper fuel-based thermal production (Doya, 2013). Given the unsustainable levels of biomass consumption, the limited feasible potential for future hydropower development, and short-term restrictions on solar and wind deployment, Kenya will need suitable planning if it is to increase its renewables share of TFEC.

Table 8 - Kenyan Energy Resource Potential Estimates

Resource	Technically Feasible	Economically Feasible	Environmentally Feasible	Currently Exploited[f]
Biomass[a] (PJ/year)	250-380		▨	393[12]
Wind (onshore) (wind speed 6m/s at 50m)[b] (TWh/year)	90 000km^2	▨	▨	0.018
Solar PV[b] (TWh/year)	638 790	▨	▨	▨
Solar Thermal (GWh/year)	?	▨	▨	▨
CSP[b]	6000km^2	▨	▨	▨
Geothermal[c] (MW)	7000-10 000	▨	▨	▨
Hydro (>10MW)[d] (MW)	3000	▨	▨	741
Hydro (≤10MW)[e] (MW)	3000	▨	▨	

[a] (IRENA, 2014c);
[b] http://kerea.org/wp-content/uploads/2012/12/Kenya-Solar-Wind-Energy-Resource%20Assessment.pdf;
[c] http://kerea.org/geothermal-energy/;
[d] http://nrec.mn/data/uploads/Nom%20setguul%20xicheel/Water/badrakh%20china/Kenya.pdf;
[e] http://kerea.org/renewable-sources/small-hydro/;
[f] Kenya energy usage in 2010 (IEA, 2012).

The future exploitation of the renewable energy resources outlined in Table 8 above (outside of biomass) is dependent on the ability for the energy production to be transmitted to consumers throughout Kenya, thus typically relying on the presence of a transmission network in those areas with natural renewable resource availability. Figure 26 below outlines the location of planned transmission lines (indicated as yellow lines) and the comparative location of geothermal resource sites. From the figure it can be seen that future exploitation of geothermal resources is likely to be possible to due to the presence of an electricity grid for transmission of the generated electricity. Similarly, Figure 27 below outlines the solar and wind resource potential in Kenya, which when compared with the planned electricity grid infrastructure in Figure 26, suggests that much of the areas of high resource potential will be able to be connected to the grid for future exploitation.

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[12] It should be noted that the currently exploited biomass resources cannot be directly compared to the 'potential biomass resources', as this potential represents only sustainable resources, whilst the currently exploited biomass includes fuel which is unsustainably sourced

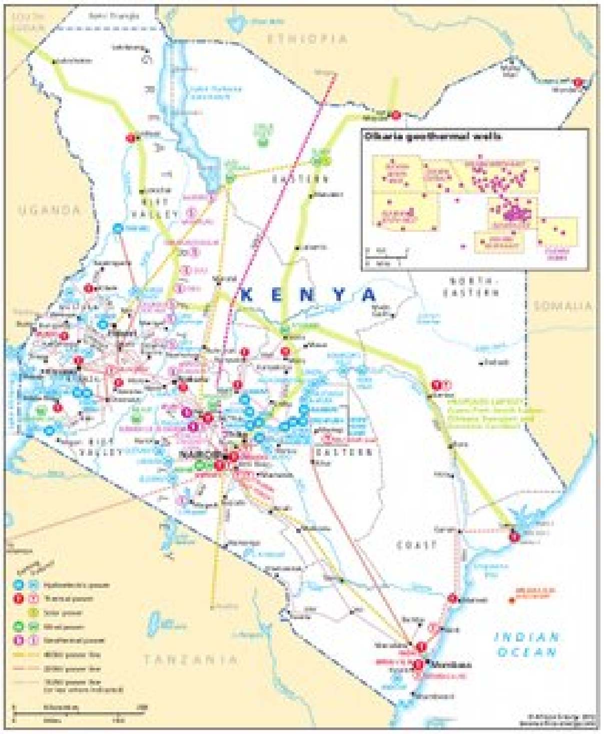

Figure 26 - Planned transmission grid (yellow lines) & geothermal resources (pink circles) (African Energy, 2012)

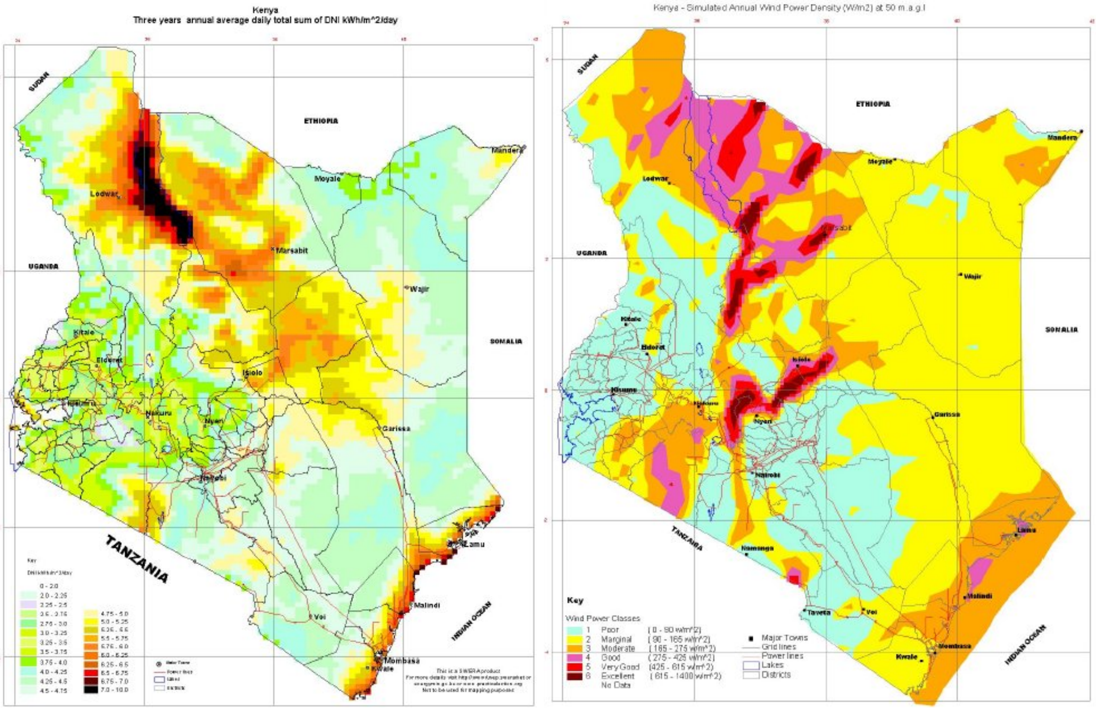

Figure 27 - Kenyan solar (left) and wind (right) resource potential (SWERA, 2008)

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' (Government of Kenya, 2007), strives to make Kenya a "middle-income country providing a high quality life to all its citizens by the year 2030". As part of this plan, rapid economic growth is expected to be linked to substantial growth in the power sector through 2030, with the projected generation and capacity requirements outlined in Table 9 (Government of Kenya, 2011). This strong vision for the power sector and the electrification of the nation is exemplified by the current energy policy targets and feed-in tariff (FIT) initiatives (see Table 10) set forth by the Kenyan government. With the overarching objective "to ensure sustainable, adequate, affordable, competitive, secure and reliable supply of energy to meet national and county needs at least cost, while protecting and conserving the environment", more quantitative objectives include (Government of Kenya, 2014):

- To achieve 100% electricity connectivity by 2020;
- To grow and sustain national tree cover to about 10% (of total land area);
- To reduce transmission and distribution system losses to 15%;
- Government vehicles to use at least 5% biodiesel blend and all isolated power generation plants to use 100% biodiesel, and;
- All gasoline vehicles in the country to be using at least 10% ethanol-gasoline (E-10 Mandate) blend.

Table 9 - Vision 2030: Least Cost Power Production Plan

	Capacity [GW]	Production [TWh]
Coal	2.42	8.23
Oil	1.64	0.16
NG	1.98	0.97
Nuclear	3	21.4
Hydro	1.04	3.34
Geothermal	5.11	41.8
Wind	2.04	6.36
Total	17.22	82.25

(Government of Kenya, 2011)

In addition to the FITs outlined in Table 10 below, the Government of Kenya also aims to promote the uptake of solar hot water systems (SHWSs), with retroactive regulations requiring all premises with hot water requirements exceeding 100L/day being required to install a SHWS within 5 years (i.e. by 2017) (KEREA, 2012).

Table 10 - Kenyan RE feed-in-tariff rates

	Installed Capacity (≤ 10 MW)	Installed Capacity (> 10 MW)
Wind (US$/kWh)	0.11	0.11
Hydro (US$/kWh)	0.105 – 0.0825	0.0825
Biomass (US$/kWh)	0.10	0.10
Biogas (US$/kWh)	0.10	-
Solar (grid) (US$/kWh)	0.12	0.12
Solar (off-grid) (US$/kWh)	0.20	-
Geothermal (US$/kWh)	-	0.088

(Government of Kenya, 2014)

It should be noted, that there has been little in the way of legislative focus by the Government of Kenya on the future energy use of the end-use sectors as of the writing of this report.

9.3.3 Business as usual: energy trends to 2030

In order to assess the potential to which the future Kenyan 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 Kenyan energy mix landscape in 2030 under a ‘business as usual’ (BaU) (referred to as the ‘Reference Case’ throughout this study) first needed to be achieved. The development of the Reference Case allowed for the assessment of what renewable energy resources could be developed in addition to those already projected to have occurred by 2030 (see section 9.3.2). Future energy consumption in the Reference Case through 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. However, a second Reference Case was also developed to provide a comparison of future energy use in the event that Kenyan economic development does not proceed as is expected through 2030. In light of this, the BaU analysis resulted in a ‘high’ Reference Case predominantly based upon the Vision 2030 economic growth projections (Government of Kenya, 2011), but focusing on the impact of GDP growth on end-use energy consumption rather than on power generation. The ‘low’ Reference Case also focused on GDP growth effects on end-use energy consumption, but was based upon a more constrained economic growth.

The use of Vision 2030 in the ‘high’ Reference Cases provided a detailed outline of the projected gross domestic product (GDP) and population growth rates, but with regards to energy consumption, focused predominantly on the development of the power sector, rather than on TFEC. Given the lack of focus on the development of end-use sector energy consumption through 2030, levels of consumption were estimated from an internal analysis based on data collected from available literature. This process involved the analysis of the individual end-use sectors, namely industry, buildings (residential, commercial and public), and transport, followed by the analysis of the power sector. These analyses applied an indicator-based approach, with individual indicators developed for different sectors, which were then combined with the estimated growth in gross-domestic product (GDP) to arrive at the ‘high’ and ‘low’ Reference Case TFECs for Kenya in 2030. For the ‘high’ case, GDP growth was based upon Vision 2030 (Government of Kenya, 2007): 6.5% in 2011, 7.8% in 2012, 8.9% in 2013, 9.4% in 2014 and 10% 2015-2030 i.e. growing from 2005 USD $23.5 billion to $144.9 billion at roughly 9.5% per annum between 2010 and 2030. In contrast, for the ‘low’ case, GDP growth was extrapolated based on historical trends, estimated as a yearly annual growth in GDP of 3.6% from 2010 through 2030 i.e. growing from 2005 US $23.5 billion to $47.3 billion at roughly 3.6% per annum between 2010 and 2030. This growth is roughly in-line with Greenpeace (Teske et al., 2012) and IEA World Energy Outlook (IEA, 2013) GDP yearly growth projections for Africa through 2030, at 4.4% and 4% respectively.

Using these growth values and additional sectoral indicators, the TFEC for each end-use sector was estimated, including electricity consumption. This electricity consumption was combined with the projected power generation capacity per technology outlined in Vision 2030 in order to determine the ‘high’ and ‘low’ case power sector composition under BaU through 2030. These Reference Case estimates were also compared with African and East African 2030 Growth Studies (Teske et al., 2012; IEA, 2013) in order to provide a gauge from which to measure the accuracy of the Reference Case estimates.

It should be noted that the objective of these 2030 Reference Case TFEC estimates is not meant to represent a scenario analysis and energy use projections for Kenya, but rather to provide a base from which to complete the REmap 2030 analysis as detailed later in this report.

Industry

Historical Energy intensity for the industry sector (MJ/USD; 2005 USD constant value of national GDP, including electricity) was found to remain quite constant, fluctuating at around 1.7-2.1 MJ/USD from 1970-2010, with the contribution of industry to national GDP remaining steady at around 19%. It was also found that the total growth from 1970 to 2010 for industry TFEC and for Kenyan GDP was similar at 4.9 and 4.8 times respectively (IEA, 2012; World Bank, 2014a). Given this historically steady relation between industry energy consumption and GDP, the Reference Case assumed a frozen efficiency growth from 2010 through 2030. However, it was assumed that an increase in industry efficiency of approximately 15% (Saidi, Wuertenberger & Stiebert, 2012) would result in a decrease in energy intensity from 2.03 MJ/USD in 2010 to 1.73 MJ/USD in 2030.

TFEC in 2010 is 48 PJ; for the low-case it is projected to rise to 82 PJ in 2030, an increase of 71% at approximately 2.9% per year, and for the high-case it is projected to rise to 250 PJ in 2030, an increase of 424% at approximately 8.6% per year. The increase of energy consumption in industry is seen to correspond to the estimated increase in GDP for each case, in addition the projected rise in total population from 40,909,194 in 2010 to 60,500,000 in 2030 (an increase of approximately 1.98% per year) (Government of Kenya, 2011). This combination of growth in GDP and population growth is projected to increase the output, and subsequently energy consumption, of preexisting sub-sectors such as the 'non-metallic minerals' with cement production to meet increasing domestic consumption due to rising population and the projected increase in Kenyan urbanisation from 23.6% in 2010 to 33.2% in 2030 (World Bank, 2014a) and soda ash production to meet the growing push for exports by the government. The future increase in population is also estimated to increase the energy consumption of the informal sector, including small-scale consumer goods manufacturing (e.g. vehicle manufacture from kits) and building and construction, which represented 84% of industry TFEC in 2010 and whose production and thus energy consumption is directly influenced by population growth rates and the subsequent increases/decreases in demand.

The estimated industry TFEC growth of 71% low-case and 424% high-case is somewhat higher than the 57% growth to 2030 predicted for industry in Africa as a whole by Greenpeace (Teske et al., 2012) or the 66% growth in industry to 2030 predicted by the IEA World Energy Outlook 2013 for Africa as a whole (IEA, 2013). However, whilst the low-case is roughly consistent with Africa-wide trends, the high-case reflects the strong push by the Government of Kenya to reach their Vision 2030 economic development goals (Government of Kenya, 2007).

The push by the Kenyan government for rapid economic growth through 2030 was seen to increase the share of industry TFEC in total Kenya TFEC from 8.9% in 2010 to 10.8% in the low-case and 19.1% in the high-case in 2030. Historically industry share of TFEC has gradually increased from 6.2% in 1971 to 7.5% in 1990 to 8.9% in 2010 in spite of sluggish economic development (IEA, 2012). Excluding electricity use, 2010 industry in Kenya exploits no renewable energy (RE). It is estimated that low-temperature heat requirements in Kenya, specifically in the food processing sub-sectors which represent 7% of industry TFEC could partially be provided by RE solutions. Specifically, it is projected that solar thermal technology could be used to meet 5% of the food sub-sector thermal energy requirements under BaU conditions (Kisero, 2014; GDC, 2014).

This results in an industry RE share (including electricity consumption) of 15.4% in the low-case and 19.7% in the high-case from 19.0% in 2010. This reduction in RE share in the low-case is a result of the estimated reduction in RE share in the power sector from 69.5% in 2010 to 56.9% in 2030 in concert with an increase in coal consumption. Whilst in the high-case, the level of electricity consumption grows faster than the increase of fossil fuel consumption resulting in in an increase in RE share (despite a reduction in RE share in the power sector from 69.5% in 2010 to 56.1% in 2030). Compared to Africa as a whole, this estimated RE share is quite low, predominantly due to the absence of any biomass use in Kenyan industry compared to other African nations who typically exploit modern biomass. This higher RE share for African industry as a whole in 2030 is reflected by Greenpeace (Teske et al., 2012) who project an RE share of 36.9%, and IEA WEO 2013 (IEA, 2013) who project an RE share in industry of 45%.

Buildings

Estimations for 2030 buildings TFEC predominantly focused on the residential sector (99% of buildings TFEC in 2010) and were based on a combination of population growth, future estimated rates of urbanisation (and the subsequent shift in energy consumption from traditional biomass to LPG and electricity), future governmental push for 100% electricity access in Kenya by 2030 and a governmental push towards clean cook stoves (estimated to replace 20% of the existing inefficient traditional stone fires by 2030).

Based on the rate of urbanisation through 2030, it was estimated that the energy consumption habits of the urban and rural population would remain fairly constant (outside of the aforementioned changes in efficiency), with the change from rural to urban settings reflecting a substitution of traditional biomass consumption for cooking and water heating by liquid petroleum gas (LPG) (at an efficiency level assumed to be twice that of a traditional biomass-based stone fire system). It was also assumed that the new mandatory push towards the nationwide installation of solar hot water systems for new dwellings (KEREA, 2012) would result in solar thermal consumption reducing the traditional biomass used for water heating by 10%. It was estimated that residential per capita energy consumption (excluding electricity) would decrease from 9.9 MJ/capita in 2010 to 8.04 MJ/capita low-case in 2030 and increase to 10.33 MJ/capita low-case in 2030, with changing demand resulting from population growth and urbanisation (i.e. resulting in switching from biomass to LPG consumption). The decrease in the low-case consumption was a result of traditional biomass substitution due to urbanisation and slight improvements in efficiency, whilst the increase in the high-case was due to an estimated increase in per capita demand reflecting economy-wide growth fuelled by Vision 2030.

This resulted in an increase in energy consumption (excluding electricity) from 407 PJ in 2010 to 489 PJ low-case and to 627 PJ high-case in 2030 i.e. an increase of 20.1% and 54.1% respectively compared to an increase in population of 62%. With regards to residential electricity consumption, it was assumed that the government push for 100% electrification by 2030 would be reached from a level of 23% in 2010 (Government of Kenya, 2007). This 4-fold increase in electrification was also assumed to result in a slight increase in the intensity of electricity usage i.e. approximately 4% more lighting and appliance usage per person, based on historical trends between 2000 and 2010. These increases were then combined with the estimated increase in per capita electricity consumption resulting directly from electrification (IEA, 2012) in order to estimate the 2030 per capita electricity consumption for the low-case. For the high case, growth in buildings electricity consumption was based on estimates from the Least Cost Power Development Plan (part of Vision 2030), which projected yearly increases in consumption of 15.3% between 2010 and 2030 (Government of Kenya, 2011).

From this it was estimated that residential per capita electricity consumption would increase from 42 kWh/capita in 2010 to 192 kWh/capita low-case and 452 kWh/capita high-case in 2030 as a result of a national shift to 100% electrification (from 23% in 2010; 58.2% urban, 8.1% rural). This resulted in an increase in residential electricity consumption from 1.7 TWh to 11.6 TWh low-case and 27.3 TWh high-case i.e. an increase of 6.8 and 16.1 times respectively in comparison to an increase in population by 1.62 and an increase in electrification by 4.3 times. TFEC in 2010 is 413 PJ; projected to rise to 530 PJ low-case and 725 PJ high-case in 2030, an increase of 28.4% and 75.7% respectively. This growth is relatively similar to the 38% growth to 2030 predicted for industry in Africa as a whole by Greenpeace (Teske et al., 2012) and the 32% growth in industry to 2030 predicted by the IEA World Energy Outlook 2013 for Africa as a whole (IEA, 2013). The low-case reflects a comparatively conservative level of energy consumption growth, whilst the higher level of growth in the high-case reflects the strong push by the Government of Kenya to drastically modernise society and subsequently energy access through 2030 (Government of Kenya, 2007).

The RE share (excluding traditional biomass) in the residential sub-sector is estimated to increase to 42.2% low-case and 43.9% high-case including electricity consumption (40.8% and 41.6% respectively excluding electricity) up from 2.8% in 2010 (0% excluding electricity). This increase in RE share is a result of the legislated uptake of solar hot water systems, in addition to the estimated uptake of 20% of clean cook stoves due to governmental programs, and an estimated increase in electricity consumption (substituting biomass and oil products) due to widespread electrification in spite of the reduction in RE share in the power sector from 69.5% in 2010 to 56.9% in 2030. Compared to Africa as a whole, this estimated RE share is lower, with Greenpeace (Teske et al., 2012) projecting an RE share (including all biomass consumption, some of which is likely unsustainably sourced) of 72.6% and IEA WEO 2013 (IEA, 2013) projecting an RE share (including all biomass consumption, some of which is likely unsustainably sourced) in the building sector of 81.6% for Africa as a whole in 2030.

With regards to the commercial sub-sector, whose energy consumption is solely reliant on electricity and whose contribution to the building sector TFEC is 0.8%, it was assumed that energy consumption was linked to GDP, with the energy intensity estimated to remain constant at 0.15 MJ/USD. This resulted in an increase in consumption through 2030 to 7.1 PJ low-case and 21.7 PJ high-case, all of which was electricity-based.

Transport

Energy consumption in 2030 for the low-case was estimated based on the combination of projected growth in vehicles per 1000 population (including non-passenger vehicle stock) in comparison to other developing countries (Dargay, Gately & Sommer, 2007) and the future increases in vehicle efficiency due to the replacement of the aging vehicle fleet through 2030. From a comparison of developing countries with annual GDP growth rates similar to that of the 3.5% per year estimated for Kenya through 2030, and the projected growth rate of vehicles per 1000 population through 2030 (Dargay, Gately & Sommer, 2007), it was estimated that the number of vehicles per 1000 population would increase at a rate of close to 5% per year, from 35 per 1000 population in 2010 to 100 per 1000 population through 2030.

Similarly in the high-case, energy consumption was also based on the projected growth in vehicles per 1000 population (including non-passenger vehicle stock), but growth was tied directly to GDP growth, in addition to future increases in vehicle efficiency due to the replacement of the aging vehicle fleet through 2030. This resulted in the number of vehicles growing to 217.6 per 1000 population by 2030. This is higher than other estimates for sub-Saharan Africa as a whole (Greimel, 2014), but reflects the comparatively stronger push for development in Kenya due to the Vision 2030 (Government of Kenya, 2007).

In tandem with the increase in vehicles per 1000 population, it was estimated that the energy efficiency of the Kenyan vehicle fleet would increase through 2030 as the aging vehicle fleet is replaced. The average age of the Kenyan vehicle fleet is 15 years, with more than 70% of the vehicle fleet older than 10 years (Kenya Motor Industry Association, 2014). This vehicle fleet currently represents vehicle efficiencies from 10-15 years ago, which have improved by 20% on average when compared to new vehicle stock (Kenya Motor Industry Association, 2014). Given the historical trend of the vehicle stock in Kenya, it is assumed that the average age of vehicles (i.e. 15 years) will remain the same in 2030. As such, it is estimated that the total vehicle fleet from 2010 to 2030 will experience an increase in efficiency of approximately 20% due to the replacement of old vehicle stock.

TFEC in 2010 is 71 PJ; projected to rise to 136 PJ low-case and 296 PJ high-case in 2030, an increase of 91% and 317% respectively. The high level of dependence on traditional biomass and subsequent deforestation due to residential energy consumption, and the already overstretched electricity transmission network (AfDB, 2010) suggests that the Kenyan transport sector in 2030 will continue to be dependent upon imported oil to fuel transportation, with the transport sector RE share remaining at 0% in 2030 Reference Case. This growth is somewhat higher than the 51% growth to 2030 predicted for the transport sector in Africa as a whole by Greenpeace (Teske et al., 2012) or the 60% growth in transport to 2030 predicted by the IEA World Energy Outlook 2013 for Africa as a whole (IEA, 2013). However, these cases reflect the strong push by the Government of Kenya to reach their Vision 2030 economic development goals (Government of Kenya, 2007). In terms of RE share, the estimated share is quite similar, with Greenpeace (Teske et al., 2012) projecting a transport sector RE share of 0.4% and IEA WEO 2013 (IEA, 2013) projecting an RE share of 0.15% for Africa as a whole in 2030. This suggests the likelihood of a continued Africa-wide dependence on fossil fuels for transportation in the immediate future.

Power

From the power generation perspective, estimation of the overall electricity generation (and subsequent capacity requirements) was based on the Vision 2030 (Government of Kenya, 2011) least cost projections for the rate of electricity generation to consumption in 2030 and the predicted future technology mix in the power sector. Based on these projections it was estimated that the total electricity generated in 2030 would be around 22.5 TWh low-case and 65.8 TWh high-case. Due to the limitations imposed by reoccurring droughts in the region, it was estimated that hydropower production would not increase beyond contemporary levels of production, approximately 3.3 TWh, equal to the production level for 2030 taken from Kenya Visions 2030 (Government of Kenya, 2011). With recent discoveries of over 400 million tonnes of natural coal reserves in Kenya (Doya, 2013a), and plans for 1000 MW of nuclear power by 2022 (Kenya Engineer, 2014), thermal power production is projected to transition from oil to coal and nuclear. Coal power production is being brought online due to concerns surrounding the inability to bring geothermal plants online quickly enough to meet increasing demand (Muchira, 2014).

Based on the projected demands in the end-use sectors, electricity use in TFEC is estimated to increase from 7.5 TWh in 2010 to 19.6 TWh low-case and 57.4 TWh high-case in 2030, with the low-case increase of 2.6 times reflecting the push towards 100% electrification and the increasing population in Kenya, whilst the high-case increase of 7.7 times reflecting the objectives of Vision 2030. The RE share in the sector is estimated to decrease to 57% and 56% for the low-case and high-case respectively, from 65% in 2010. This decrease in RE share is a result of the inability to further increase hydropower capacity due to natural resource limits, whilst a ramp up of coal and nuclear thermal power stations due to concerns about the possible rate of geothermal deployment overshadows the increases in geothermal and wind capacity (as shown in Table 11 below).

This growth is slightly higher than the 2.1 times growth to 2030 predicted for the power sector in Africa as a whole by Greenpeace (Teske et al., 2012) or the 2 times growth in power generation to 2030 predicted by the IEA World Energy Outlook 2013 for Africa as a whole (IEA, 2013). However, these cases reflect the strong push by the Government of Kenya to electrify the country as part of their economic development goals (Government of Kenya, 2007). In terms of RE share in the 2030 power sector, the share of 57% low-case and 56% high-case RE in Kenya is also significantly higher than the projected RE share in Africa as a whole of 23% by Greenpeace (Teske et al., 2012) or 18.3% from IEA (IEA, 2013). However, given the high starting share of renewables in Kenya in 2010 due to the dominance of hydropower, and the high levels of renewable resources available, a roughly stead RE share through 2030 seems reasonable in spite of a growing and electrifying population.

Table 11 - Overview of power generation capacity in Kenya, 2010 & 2030

	2010	Low-Case 2030	High-Case 2030	Vision 2030
Coal	0	663	1937	2420
Oil	393	448	1309	1635
Natural gas	0	542	1585	1980
Nuclear	0	1000	3000	3000
Hydro	741	1039	1039	1039
Geothermal	198	947	3486	5110
Wind	5	557	1629	2036
Solar	0	0	0	2420
Biomass	26	0	0	0
Total (excluding imports)	**1363**	**5196**	**13984**	**17220**
Estimated total electricity generation	7501	22 520	65 828	82250
Share of RE in generation [%]	65.3	56.9	56.1	62.6

Reference Case TFEC in Kenya 2030

The combination of the Vision 2030 objectives with historical trends and indicators resulted in a final TFEC of growth from 535 PJ in 2010 to 755 PJ low-case and 1,307 PJ high-case in 2030. Based on the estimated growth through 2030 in the three end-use sectors, the sectoral TFEC breakdown for the high and low Reference Cases resulted in a decreasing share of TFEC in the buildings and an increasing share in the industry and transport sectors (as shown in Figure 28).

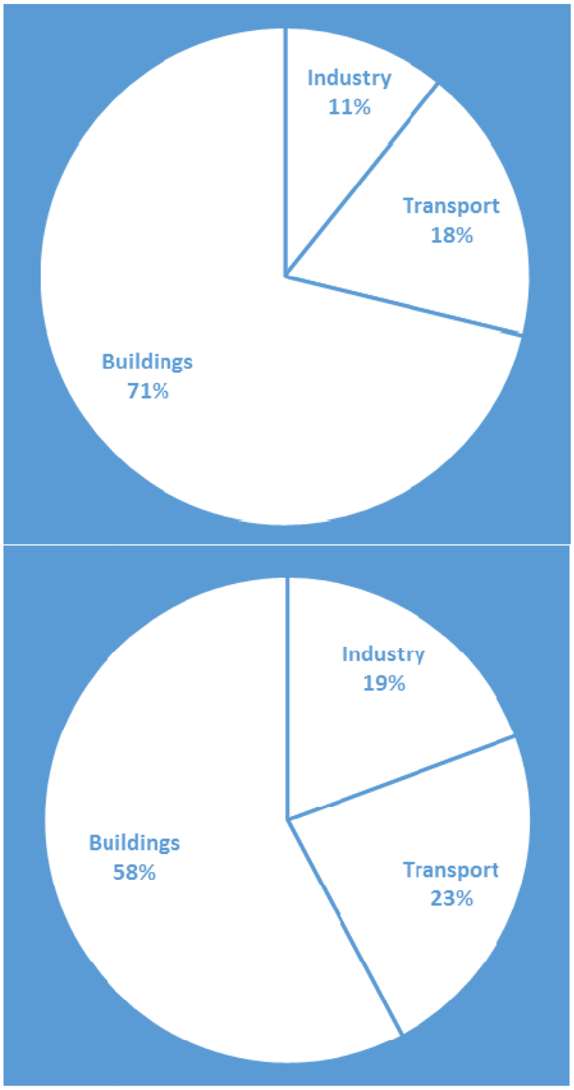

Figure 28 - Share of Kenyan TFEC 2030 (including electricity) low-case (left) and high-case (right) by sector

These two Reference Cases also resulted in an increase of the overall RE share in TFEC from **2.8%** (including electricity) in 2010 to **31.7%** low-case and **28.9%** high-case in 2030 (as outlined in Table 12).

Table 12 - Summary of TFEC breakdown in Kenya for 2010 and 2030 Reference Cases

		TFEC [PJ/year]	Electricity [PJ/year]	RE Share [%]
2010	Industry	48	13	19.0%
	Transport	71	0	0%
	Buildings	416	9	1.4%
	Total	**535**	**23**	**2.8%**
Low-Case 2030	Industry	82	22	15.4%
	Transport	136	0	0%
	Buildings	538	49	42.2%
	Total	**755**	**78**	**31.7%**

High-Case 2030	Industry	250	86	19.6%
	Transport	310	0	0%
	Buildings	747	120	43.9%
	Total	**1,307**	**78**	**28.9%**

Contributing to the overall growth of renewables in TFEC was intensive growth from 1.4% RE share in the buildings sector in 2010, to 42.2% low-case and 43.9% high-case. However, the RE share in industry decreased from 19% in 2010 to 15.4% in the low-case, but increased to 19.6% in the high case, whilst the transport sector RE share remained at 0% (as shown in Figure 29 & Figure 30).

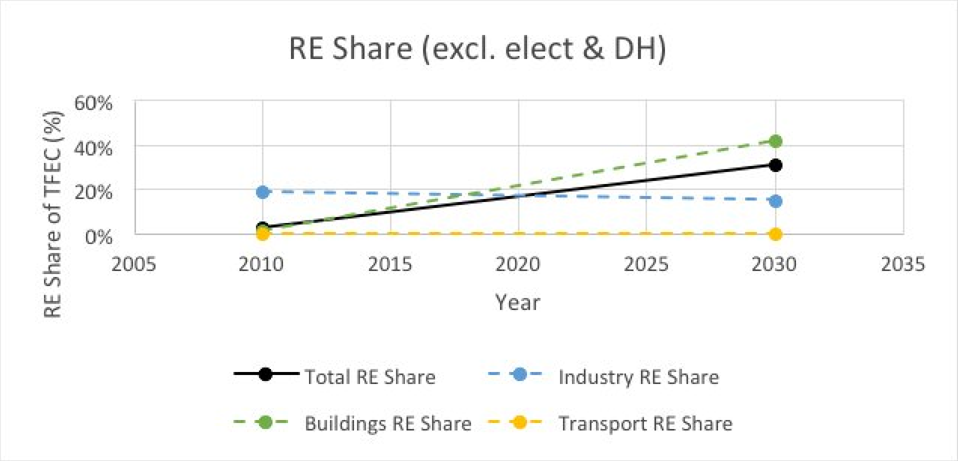

Figure 29 - TFEC share of RE by sector (including electricity) low-case

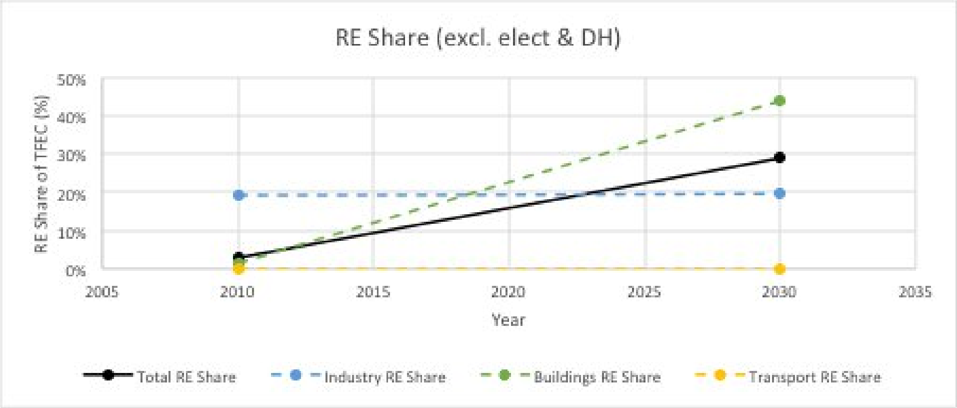

Figure 30 - TFEC share of RE by sector (including electricity) high-case

Whilst business as usual trends suggest that the RE share in Kenyan TFEC in both the low and high Reference Cases will increase significantly from 2010 through 2030, this is predominantly a result of the implementation of more efficient cook stoves rather than significant deployment of renewables. Furthermore, in spite of this increased sustainability in biomass consumption, the depletion of biomass resources will likely remain a key issue of interest for the Government of Kenya due to its continued importance in societal energy use. From

Table 13 below, it can be seen that in spite of a significant increase in the use of modern biomass through a partial transition to clean cook-stoves, total biomass consumption will likely rise through 2030, resulting in a continued deficit in sustainable biomass resource availability.

Table 13 - Comparison of Reference Case biomass consumption and available biomass resources

				Resources [PJ]	
Biomass Demand [PJ]	**2010**	**Low-case 2030**	**High-case 2030**	**Low**	**High**
Industry	0	0	0	250	380
Buildings	393	442	581		
Traditional Biomass	393	245	322		
Modern Biomass	0	197	259		
Transport	0	0	0		
TFEC	**393**	**442**	**581**		

Whilst there remains significant potential for the future reduction of non-renewable energy consumption in Kenya, this could be difficult outside of the power sector due to the critical levels of biomass consumption in 2010 and estimated in the 2030 Reference Cases, limiting its use for substitution of fossil-based resources. A push for end-use sector renewables will likely require the harnessing of alternative RE sources, in addition to the reduction of biomass consumption in the buildings sector (this is discussed further in Section 9.3.5).

9.3.4 REmap Options

With a defined understanding of the present situation, market potential and Reference Case projections of energy use in Kenya, the 'REmap Options' analysis can now be assessed. The REmap Options provide an analysis of the realistic potential for further renewable energy deployment in Kenya in addition to that set out by the Reference Case. When establishing the REmap Options for Kenya, the potential for fossil fuel substitution in the national energy mix was first considered from the perspective of the present energy policy situation, the available renewable resources, and the projected Reference Case growth. The maximum realisable potential (of any given RE source) is the same for both cases, regardless of the development in RE share in the two Reference Cases, but where possible, the achievable sectoral RE shares for both the low-case and high-case were kept the same. This was done in order to highlight the sensitivity of resource and economic requirements for increased RE deployment, to differing future energy consumption projections.

From an industry perspective, the already overburdened biomass supplies appeared to provide little opportunity for fossil fuel substitution outside of that used in power production (i.e. in the power sector). However, it was found that the Kenyan sugarcane industry provided a currently unexploited source of biomass in the form of the waste bagasse (34.8 PJ in 2030) generated during the sugar refinement process (Government of Kenya, 2011). This bagasse, after taking into account internal-demand at refineries and the potential for bioethanol production, can be used to meet the thermal energy demand (up to 16.9 PJ) in industry currently provided by coal. This results in the consumption of 12.2 PJ of bagasse in the low-case and 16.9 PJ in the high-case. Additionally, the importance of the food and tobacco sub-sector (7% of fossil fuel use in industry), and the location of firms in regions of relatively high solar irradiance (see Figure 27), gave rise to the possibility of further RE deployment. More specifically, given that nearly 40% of the total energy demand of the sub-sector is low temperature heat, it was estimated that half of this total (i.e. 20% of Food & Tobacco energy use) could be supplied by solar thermal solutions. This resulted in increased solar thermal consumption of 0.47 PJ low-case (150 MW) and 1.05 PJ high-case (334 MW). Combined with an increasingly renewable power sector (as addressed later in the report), the RE share of the industry sector increased to 41.6% in both the low-case and high-case.

Similar to industry, the transport end-use sector provided little opportunity for fossil fuel substitution. This was predominantly due to increasing levels of energy consumption in the sector, overburdened biomass supplies and a limited transmission network, which limited the extent to which biomass and electrification could be used to substitute fossil-based transport fuels. However, due to aforementioned lack of exploitation of sugar cane residue (bagasse), there is the opportunity to exploit this resource for biofuel production. More specifically, bagasse (16.9 PJ) can be converted into up to 8.5 PJ ethanol (Lewis & Mofor, 2013), with an estimated achievable RE share of approximately 2.7% in both the low-case and high-case reachable through the conversion of bagasse to bioethanol. In the low-case this results in the consumption of 3.7 PJ of bioethanol and 8.5 PJ in the high-case. From the perspective of the 10% blending targets for all gasoline-based road transport, the use of bagasse bioethanol allows for 78% of this target to be met, suggesting that additional sources of ethanol must be utilised to reach the 10% governmental blending target.

The buildings sector represents the most substantial share of national TFEC at approximately 71% low-case and 57% high-case, and presents the greatest opportunity for increased RE deployment in Kenya. The REmap Options in this sector focus predominantly on the transition from unsustainable traditional biomass use to the consumption of modern, sustainable biomass. Through the implementation of clean cook-stoves as per the Kenyan climate change action plan (Saidi, Wuertenbergy, & Stieber, 2012), in addition to the utilisation of sustainable biomass resources – biogas, biomass residues and wood fuels – 322 PJ of unsustainable biomass can be substituted by 116 PJ of modern biomass in the high-case and 245 PJ of traditional biomass can be substituted by 88 PJ of modern biomass in the low-case. In addition to this push towards sustainable biomass consumption, the solar hot water system (SHWS) regulations introduced by the Government of Kenya in 2012 (KERA, 2012) will likely contribute to an increase in RE share. More specially, projected yearly growth of SHWS uptake is estimated at 20% (Saidi, Wuertenbergy, & Stieber, 2012), resulting in the uptake of 245 MW of solar thermal capacity (making the buildings sector the largest source of solar thermal technology) and the substitution of electricity-based water heating by 0.9 PJ above the Reference Case in both the low-case and high-case. Together this deployment of modern biomass and solar hot water systems results in a buildings sector RE share of 88.4% low-case and 91.8% high-case for the REmap Options.

In comparison to the consumption of biomass and fossil fuels, electricity use in Kenyan TFEC is estimated to remain quite low, increasing from 4.2% in 2010 to 9.4% low-case and 15.8% high-case in the 2030 Reference Cases. In spite of this, the renewable energy resources available in Kenya (see Table 8) are conducive to a high RE share in the power sector. For the REmap Options, the development of the power sector was modelled after the Vision 2030 ‘Least Cost Power Development Plan’ (Government of Kenya, 2011). More specifically, the level of renewable generating capacity achieved by this plan was taken as the maximum potential RE capacity that could be deployed in the REmap Options, whilst the technology-specific capacity factors were applied to determine the quantity of electricity generated. For both the low- and high-cases, a mixture of solar, wind and geothermal was used to substitute estimated 2030 oil, coal, natural gas and nuclear capacity, with base-load nuclear being substituted predominantly by geothermal. This substitution resulted in a power sector TFEC RE share of 100% for both cases. It should be noted that no expansion to existing hydropower capacity was allocated due to the production uncertainty surrounding drought conditions and its impact on river flows in Kenya.

Table 14 highlights the prominent role that will continue to be played by biomass in the high and low REmap Option cases. Given its importance in the total Kenyan energy mix, and with a projected transition to more efficient usage methods and increasing electrification, the level of biomass consumption is estimated to decrease to high but potentially sustainable levels. However, it is estimated that not all of this biomass will be from sustainable sources, with the low-case still including 67 PJ and the high-case 123 PJ of traditional biomass use. This suggests that active governmental intervention to combat continued deforestation may be warranted to encourage the population to transition to modern forms of biomass use.

Table 14 - REmap Options cases biomass resource consumption in 2030 TFEC

Case	Biomass Resource Potential in 2030 [PJ][a]	Total Biomass Consumption [PJ]	Biomass in industry [PJ]	Biomass in buildings [PJ]	Biomass in transport [PJ][b]
Reference	250 - 380	442	0	442	0
Low-Case		304.6 (285)	12.2	285	7.4
Reference		581	0	581	0
High-Case		408.8 (375)	16.9	375	16.9

[a] (IRENA, 2014c) Note: this does not include the bagasse biomass resources available for use in the transport & industry sectors;

[b] assuming a conversion efficiency of 50% for liquid biofuels, in other words 1 PJ liquid biofuel requires 2 PJ of raw biomass

The results of each of this biomass and addition renewable energy usage in the low- and high-cases are outlined in Table 15 below, and suggest that a significant increase in renewables usage in Kenyan TFEC is possible through 2030.

Table 15 - REmap Options cases renewable energy share of TFEC in 2030

Case	TFEC [PJ]	RE share of TFEC [%][a]	RE share in industry [%][a]	RE share in buildings [%][a]	RE share in transport [%][a]	RE share in electricity generation [%][a]
2010	535	2.8	19.0	1.4	0	69.5
Reference low-case	755	31.7	15.4	42.2	0	56.9

Low-Case REmap Options	558	62.4	41.6	88.4	2.7	100
Reference high-case	1,307	28.9	19.6	43.9	0	56.1
High-Case REmap Options	1,070	55.3	41.6	91.8	2.7	100

[a] including electricity

Figure 31 below shows a sectoral breakdown of the fuel use in both REmap Options cases. The main REmap Options findings are discussed below:

- It can be seen that in 2030, Kenya is likely to remain heavily dependent on biomass to meet its energy needs. However, the transition from traditional to modern biomass, and the subsequent increases in the efficiency of biomass consumption can be seen to reduce resource exploitation in 2030 to high but sustainable levels (see Table 14);
- Sustainably sourced power generation will grow to play an even greater role in the 2030 Kenyan RE share, but continued low penetration (11.6% low-case and 18.7% high-case TFEC) will limit the beneficial impact of the large resource availability for sustainable electricity production. This suggests that there is significant opportunity to exploit these RE resources for export, or for these resources, such as geothermal and solar thermal, to be exploited directly in the end-use sectors to meet thermal energy demand;
- The transport sector is seen to remain the key obstacle to even greater RE uptake, experiencing little RE growth through 2030, and remaining dependent on fossil fuels for over 97% of its TFEC. With energy consumption in this sector seen to increase two- to four-fold, this represents both a significant opportunity and a significant challenge for the future sustainability of energy consumption in Kenya, and for decreased dependence on fossil fuel imports.

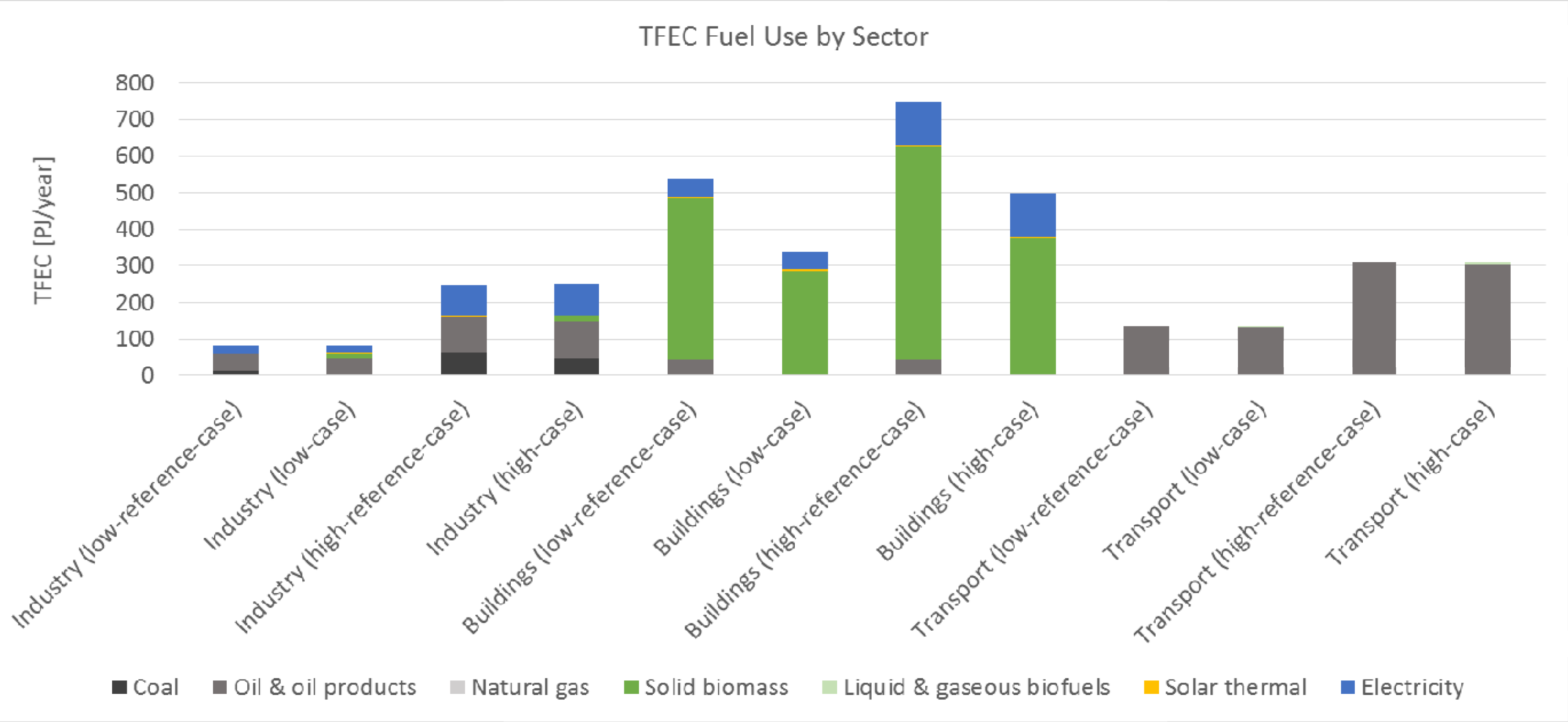

Figure 31 - Kenyan fuel use breakdown in TFEC by sector

When looking at this sectoral fuel use from a renewable energy perspective, as shown in Figure 32, it can be seen that biomass will continue to play a critical role through 2030. Similarly, tapping into the large geothermal resources available in Kenya will be critical for transitioning to a high share of renewables, especially in the power sector. However, despite estimates of nationwide electrification and increased per capita electricity use, much of this geothermal resource (5000 - 10 000 MWe) remains unexploited, with only 947 MWe in the low-case and 3486 MWe in the high-case being used. This suggests there is still plenty of opportunity for growth in electricity demand whilst maintaining 100% RE share in the power sector, in addition to the potential for the increased direct-use of geothermal for heating applications. Similarly, the current low levels of wind and solar resource exploitation suggests significant potential for uptake, especially for off-grid and mini-grid applications

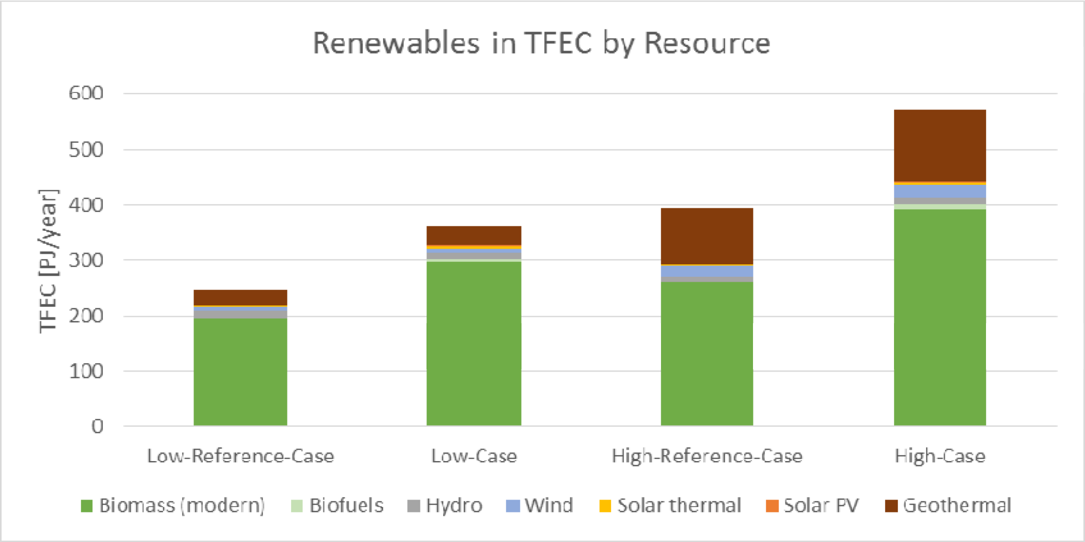

Figure 32 - Kenyan renewable fuel use breakdown in TFEC

From the comparison of renewable resource consumption in the high- and low-cases, it is apparent that the uncertainty surrounding the future economic development, and subsequent energy consumption trends of Kenya, has a dramatic effect on the level of RE share achievable with the available resources. From Figure 32 it can be seen that for the low-case, in spite using significantly less modern biomass and geothermal resources than the high-case, an RE share in TFEC of 62.4% is achievable compared to 55.3% for the high-case. This results in the potential for even further increases to the RE share in the low-case for the same level of available resources, and highlights the importance of preparing RE deployment strategies for a range of national economic and development growth eventualities.

In addition to assessing the final RE share in TFEC achievable for both the high and low REmap Options cases, the cost of substituting non-renewable sources with renewables was analysed in order to determine the financial implications of a transition to increased renewables deployment. The substitution costs were calculated from two perspectives: the cost based on international prices for fuels and investment in capacity (perspective of governments), and the cost based on domestic (Kenyan) prices including all relevant taxes (see Appendix B for detailed resource prices) (perspective of businesses), and are outlined in Table 16 below.

Table 16 - Substitution cost for Kenyan REmap Options cases from government and business perspectives

REmap Option Case		Average of all sectors	Industry	Buildings	Transport	Electricity Generation
Low-Case	Government	**-2.5**	-0.6	-0.8	-3.1	-17.4
	Business	**4.4**	1.8	5.8	33.8	-13.2
High-Case	Government	**-4.3**	-0.4	-0.7	-3.1	-18.7
	Business	**2.8**	2.3	5.9	33.8	-15.34

From the summary of substitution costs in Table 16 it is apparent that the substitution of non-renewable resources by renewables in TFEC in both the high- and low-cases is negative (results in savings) from a governmental perspective i.e. using international prices. Contrastingly, whilst still low, substitution of fossil fuels with renewables from a business perspective would require net additional expenditure in both REmap Options cases. This is primarily a result of the comparatively high local costs for modern/sustainable biomass (versus traditional biomass), and the high local cost of bioethanol production from bagasse in comparison to local gasoline prices. Interestingly, the transition to 100% RE in the power sector through the substitution of non-renewable technologies results in net savings from both a business and governmental perspective. Finally, it should be noted that the lower substitution costs in the high-case compared to the low-case are a result of the comparatively high electricity share in TFEC in the high-case. This higher level of electricity consumption resulted in comparatively higher levels of costly oil-based medium speed diesel capacity available to be substituted by cheaper RE alternatives in the high-case, thus resulting in lower average costs of substitution.

As part of the REmap Options process, these costs of substitution were collated in a cost-supply curve for improved comprehension, looking at the substitution costs (local and international) in terms of a breakdown by renewable technology and by sector. The following figures outline the substitution 'cost curves' for both the high- and low-case based on local prices, which includes national taxes and subsidies. The full-set of cost curves (local and international prices; breakdown by technology and by sector) have been omitted from this report for the sake of brevity. These technology options are shown individually based on their average costs of substitution, whilst the horizontal (black) bar to the far left of the figures shows the growth of modern renewables according to the Reference Case. Added to this are the REmap Options, which provide the solution for additional increases of renewables in 2030 TFEC in Kenya achievable through the use of individual technologies (represented by individual vertical bars), and the subsequent cost that arises due to the substitution of a specific fossil fuel technology with a specific renewable energy technology (y-axis).

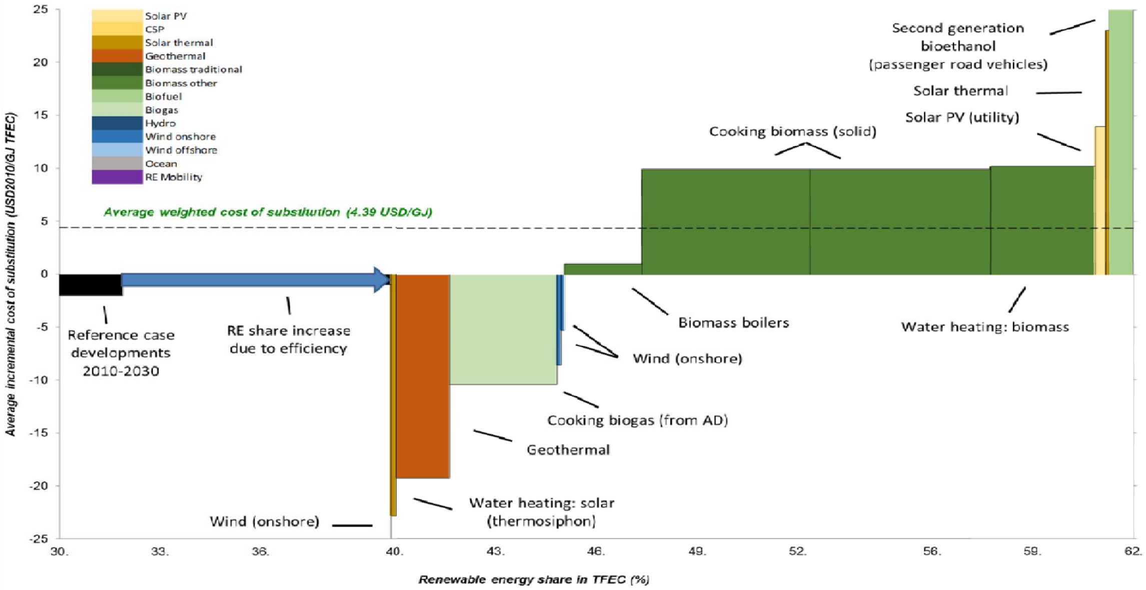

Figure 33 - Low-case cost-supply curve (business perspective) for Kenya, 2030; breakdown by resource

Figure 33 highlights the substitution costs of specific technologies in the low-case. The main focus of substitution was traditional, unsustainable biomass. This was substituted by more efficient modern biomass from sustainable sources, with positive costs of substitution a result of the ability for traditional biomass to be sourced at low to no cost in Kenya. In contrast, biogas sourced from the anaerobic digestion of crop residues provided a cost effective method of traditional biomass substitution for cooking. Similarly, the negative cost of substitution of imported fossil fuels by onshore wind, and the substitution of future base-load nuclear power by geothermal power highlight the high cost of electricity generation from predominantly imported, non-renewable fuels in Kenya.

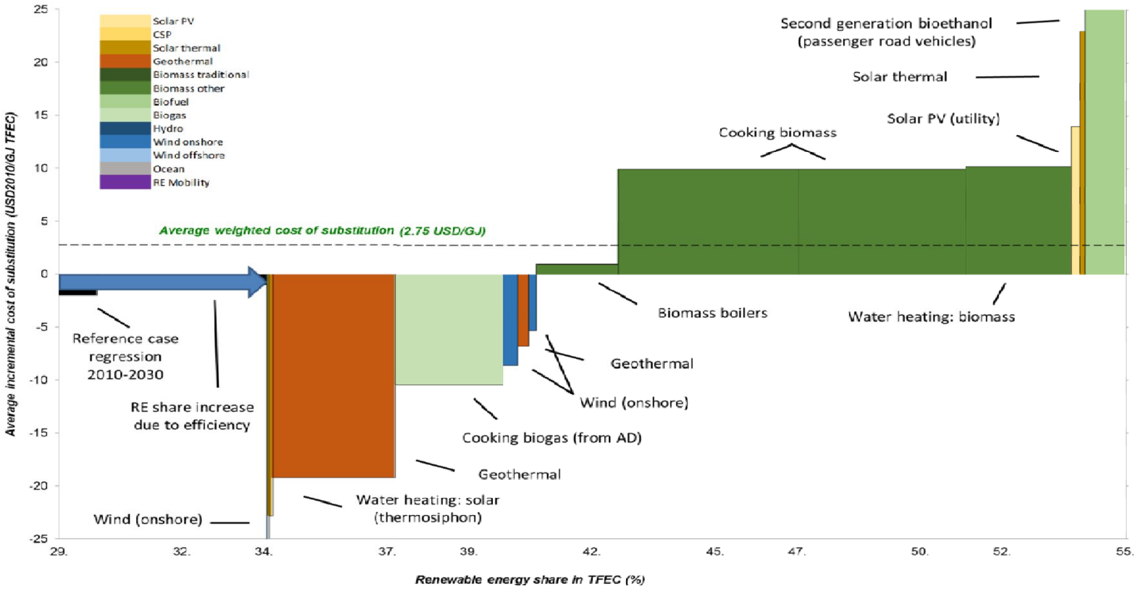

Figure 34 - High-case cost-supply curve (business perspective) for Kenya, 2030; breakdown by resource

Similar to the low-case, the high-case (Figure 34) focuses on the substitution of traditional, unsustainable biomass with more efficient, modern biomass from sustainable sources. The most cost effective measures involve the substitution of non-renewable power generation, predominantly oil and nuclear by wind and geothermal respectively. Additionally, in an attempt to reach the 2030 mandate of 10% ethanol blending in all gasoline, bioethanol sourced from bagasse was used to substitute gasoline in road transportation. However, this substitution was estimated to come at a high cost, and was estimate to only reach 73% of the 10% blending target (i.e. 7.3% of all gasoline was substituted). This high cost, despite the high price of gasoline in Kenya compared to other East African nations, resulted from the extremely high estimated cost of producing bioethanol from sugarcane bagasse.

9.3.5 Policy and barriers

From the high and low REmap Options cases it is apparent that there is significant, economically viable potential for Kenya to further the share of renewables in national energy consumption in 2030 beyond that proposed in the Reference Case projections. However, this future development and deployment of renewables in Kenya hinges on the attitudes of policymakers and influential industrial/societal stakeholders, each of who has their own agenda to support. This is highlighted by the difficulty in developing a Reference Case for total final energy consumption in Kenya in 2030. The focus of governmental policy and targets predominantly on the power sector (Government of Kenya, 2007, 2011) shows a distinct need to take a more holistic approach to energy policy, focusing on both the power sector and the end-use sectors.

In the same vein, the lack of clarity surrounding the existing RE policy and regulatory frameworks has made it difficult for private investors to enter the market and assist in the deployment of RE technology (Kilonzo, 2013). Similarly, recent governmental focus on the reduction of electricity prices through the exploitation of newly discovered coal-resources poses a threat to the future sustainability of the Kenyan power sector. Furthermore, this drive to reduce electricity prices has resulted in the deployment of any new wind or solar capacity being put on hold until 2017 in favour of the aforementioned cheap fossil-based capacity, setting a dangerous precedent for future renewables deployment. In the end-use sectors, the estimated future growth in the transport sector as the Kenyan population increases and becomes increasingly developed, from 71 PJ in 2010 to between 136 PJ and 310 PJ (97% of which is fossil-based) represents the greatest challenge to the future sustainability of Kenyan energy use. Adding to this difficulty is the high levels of biomass exploitation in the building sector in Kenya through 2030, making it difficult to substitute oil use in transportation or industry with biofuels due to lack of biomass availability.

However, this heavy biomass consumption, currently at unsustainable levels, can tie-in with the current governmental fight against deforestation (Saidi, Wuertenberger & Stiebert, 2012), to push for a transition from traditional to more efficient, modern biomass to reach high, but sustainable levels by 2030. Potential also exists with regards to the governmental push for significant power sector growth and 100% electricity access in 2030 in an effort to develop the economy (Government of Kenya, 2011). More specifically, this national push ('Vision 2030') towards economic and energy growth and development provides the perfect opportunity to leap-frog traditional, centralised fossil-based energy solutions in favour of more sustainable, more energy secure (i.e. fuel import independent) renewable solutions at both a large scale (e.g. geothermal) and a household level (solar hot water systems, modern biomass). Similarly, the push for 100% access to electricity could be facilitated by the existing 'mini-grid' and 'off-grid' renewables potential in Kenya (IED, 2013), which would likely also reduce the costs of future transmission and distribution infrastructure projects.

From a cost perspective, it is likely that future governmental drive and support will be required to achieve increased RE deployment due to positive average costs of substitution. This is highlighted by the greatest opportunity for fossil fuel substitution: a shift from unsustainable, traditional biomass use in the buildings sector to modern biomass. Allowing for increased renewables, decreased deforestation and decreased negative health effects, such a transition would provide many benefits, but is largely unaffordable for individual users or households. Whilst the average governmental cost of substitution is negative, such high costs to individuals at a local level drives home the need for a robust and holistic governmental approach to future energy use if Kenya is to achieve its future economic and development goals in a sustainable manner.

9.3.6 Summary and conclusions

This IRENA REmap analysis of Kenyan energy consumption through 2030 proposes a high- and a low-case through which Kenya can build on the estimated Reference Case usage through 2030 of a total final energy consumption of 755 PJ and 31.7% renewables (low-case) and 1307 PJ and 28.9% renewables (high-case). In terms of further developing this RE share, a transitional shift in Kenya from traditional to modern biomass is key (i.e. a shift to 100% sustainable biomass resources), in addition to the governmental push to 100% electricity access, resulting in a potential RE share of 62.4% (low-case) and 55.3% (high-case). From an economic perspective, this transition is dependent on the future level of national growth and development, with a local average substitution cost of 4.4 USD/GJ low-case and 2.8 USD/GJ high-case.

The uncertainty surrounding this future level of energy consumption is quite high due to the vigorous projected economic growth, and governmental focus predominantly on the power sector. However, in spite of such uncertainty and the potential barriers arising from this, the potential for Kenya to significantly increase its share of renewables in TFEC to 55%-62%, appears quite feasible based on the technology and resources available in Kenya.

10.0 Discussion

10.1 Introduction

The completion of the case study IRENA REmap country analyses provides 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, are 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 will be 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, will attempt to address the research questions outlined at the beginning of this report, in order to test the hypothesis given in section 1.3.

10.2 A Comparison of Case studies – Sweden vs. Kenya

From the case study detailed in section 9.2, it is apparent that Sweden represents a highly developed, urbanised and technologically progressive nation. Business as usual estimates, based on highly detailed and specific Swedish government planning and targets and resource availability, show that Swedish society has reached the limit of its need for increased energy consumption. That is, future TFEC of 1.4 EJ in 2030 is essentially the same as the total final energy consumption of 1.36 EJ in 2010. This rate of increase is also significantly less than the projected increase in population from 9.4 million in 2010 to 10.4 million in 2030, suggesting that minor increases in energy consumption due to population growth over the next 20 years will be effectively negated by increases in the efficient use of energy. Similarly, under business as usual conditions, the high share of renewables in TFEC in 2010 (47.7%) was projected to increase to 54.2% in 2030, predominantly due to more efficient use of energy. This resulted in reduced fossil fuel usage, rather than a significant increase in the deployment of renewables.

Such a conservative technological approach to energy consumption, focusing on efficiency improvements to a greater extent than fossil fuel substitution, was also reflected in the current legislative policy in Sweden. With the target of 50% RE share in TFEC by 2020, and no further long-term RE target, the political agenda in Sweden is quite conservative, in spite of its comparatively high RE share in TFEC. More specifically, this 2020 RE target was reached in 2012, suggesting that significantly more renewables could be deployed in Sweden by 2030. Furthering adding to this apparent hesitance to target significant future RE deployment is their approach to energy security. In spite of envisioning a fossil fuel independent transport sector by 2030, the exact definition of 'independent' is quite unclear, purporting a continued reliance on fossil fuels in the transport sector but somehow less dependent on fossil fuel imports (in spite of the lack of natural fossil fuel resources). Despite this conservative vision of a renewable future in Sweden, the analysis of the feasibility of increased deployment of renewable technology showed significant potential for a highly increased RE share in 2030 Sweden.

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. More specifically, the main resources available to substitute fossil fuel consumption outside of the power sector (i.e. direct fossil fuel use) were sustainable biomass substitution and electrification, both of which had significant levels of domestically available resources and were well-established technologies in Sweden. 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 (see section 9.2.4) to deploy significantly higher levels of renewables than under Reference Case conditions. Furthermore, this increased RE deployment at a **negative** cost of substitution does not take into account externalities such as reduced environmental and health impacts from reduced fossil fuel consumption, suggesting that a future transition from fossil fuels to renewables in Sweden is not only possible, but economically, socially and technically viable.

In contrast to Sweden, Kenya represents a country at a very low level of development. Kenya is a highly ruralised society with very limited energy technology development. This is highlighted by low per capita energy use and high levels of energy poverty, with 70% of final energy consumption still dependent on traditional biomass. Furthermore, due to a lack of energy planning outside of the power sector and an acute lack of resource availability data, business as usual estimates had to be extrapolated from a variety of economic and societal growth indicators in order to establish a 2030 reference case for energy use in the industry, buildings and transport sectors. These estimates show that energy consumption in Kenyan society is set to increase dramatically, with future TFEC of between 1 EJ to 1.3 EJ in 2030, more than doubling from the 0.535 EJ consumed in 2010.

Such an increase reflects the strong national push for economic growth (overly optimistic at 10% GDP growth per annum from 2010 to 2030), in a drive to increase national development and subsequently eliminate societal poverty. Alongside this high economic growth, the population is projected to increase from 41 million in 2010 to 60.5 million in 2030. Furthermore, the concentration of almost 80% of 2010 energy consumption in the buildings end-use sector suggests that future national TFEC will be heavily influenced by this population growth, and the increasing individual demand for energy as living standards continue to develop. Similarly, the low share of renewables in TFEC in 2010 (2.8%) was projected under business as usual conditions to increase to 28.9% to 31.7% in 2030, as a result of national development rather than a direct substitution of existing fossil fuels. More specifically, the level of fossil fuel consumption through 2030 is estimated to rise due to population and economic growth, but this was offset by an increased uptake of modern (sustainable) biomass use in the buildings sector and increased residential electricity consumption (in the place of fossil fuels or traditional biomass). This resulted in increased renewables deployment, rather than a decrease in the quantity of fossil fuel consumption.

This focus on increased energy consumption and its link to economic growth, rather than on the substitution of fossil fuels, is also reflected in the legislative policy in Kenya. With the overarching target of reaching ‘middle income status’ by 2030, the political agenda in Kenya is primed towards economic growth and societal development, with less focus on renewable energy deployment. More specifically, in spite of the low share of renewables in TFEC, there is little legislation in place to target significant increases in RE deployment in the end-use sectors. Furthermore, outside of minor fossil-based transport fuel reduction (10% ethanol substitution by 2030), all focus is on electricity generation and the power sector, despite electricity only contributing to 4% of TFEC in 2010. Such limited focus with regards to renewable energy deployment suggests a single-minded drive for economic growth and national development, and an effort to take after developed countries and their energy consumption models. Despite this marginalisation of renewables outside of the power sector and the limited technological and natural resources data for renewable development due to the development level of

Kenya, the analysis of the feasibility of increased deployment of renewable energy technology showed significant potential for a substantially increased RE share in 2030 Kenya.

The renewable energy roadmap options (REmap Options) for Kenya highlighted the societal, technological and economic potential for Kenya to substitute fossil fuel use for renewables. As a society with a low level of development and high levels of energy poverty, there were limited options available for the substitution of current (and future) fossil fuel consumption with renewable solutions. With national dependence on traditional biomass for 70% of TFEC (over 90% in rural Kenya) resulting in the continued overexploitation of biomass resources i.e. deforestation, and the limited levels of electricity consumption in spite of governmental pushes for 100% access by 2030, options for RE deployment were limited. The main feasible options for increased RE in 2030 was in the power sector, due to significant renewable resources available for electricity production, and through the improvement of existing traditional biomass consumption i.e. the use of more efficient cook-stoves, and obtaining biomass fuel from sustainable sources. Whilst the deployment of these options provides the opportunity for Kenya to increase its renewable energy share from 2.8% in 2010 to between 55% and 62% by 2030 at an average cost of 3 to 4 USD/GJ, this does not reflect the whole story. Given the focus of much of this RE deployment on the conversion from inefficient, traditional biomass use in the buildings sector to modern biomass, the individual cost of such a technological transition is close to 11 USD/GJ at an individual 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 benefits. This suggests the need for external intervention from those with technological expertise and an understanding of such a situation.

10.3 Comparing Renewables in Developed and Developing Nations

In the context of developed and developing nations as a whole, the nation-specific discussions outlined above in section 10.2 highlighted the generalised energy needs and RE potential of the two respective country groups. They provided insight into the key areas in which future renewable energy could most effectively be deployed, from the perspective of the developmental status of a given country. From these insights, a clearer picture of the needs of developed and developing countries can be extrapolated, highlighting the high-level challenges and opportunities that face future RE deployment in nations at different stages of development.

Developed countries represent nations that have typically reached the human-development index ceiling with regards to welfare benefits from increased energy consumption (Smil, 2004). This was apparent in the projected lack of energy consumption growth compared to population growth in the Swedish case study between 2010 and 2030. A lack of per capita energy growth reflects the stability of developed economies and their access to and expertise in the deployment of advanced energy technologies which offer increased efficiency (Toman & Jemelkova, 2002), such as Sweden’s global best-practice in biomass-based CHP. Economic stability, technological expertise and the widespread availability of detailed renewable energy resource potential data provides an ideal base from which to plan the transition from fossil fuels. This was evidenced by the multiple potential RE deployment pathways that were feasible for Sweden (see section 9.2.4), with these

REmap Options cases resulting in negative average costs of non-renewable energy substitution from both government and business perspectives.

However, the opportunities available to developed countries to transition to a high RE share was not without certain challenges. The main challenge relates to the high level of infrastructure development in highly developed countries, such as Sweden, 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). Such lethargy has recently been made apparent in Canada and Australia (Energy Business News, 2014), and even in the typically pro-renewables Sweden, with Swedish renewable electricity 2020 targets already reached in 2011 (with no 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.

Contrastingly, developing countries represent future sources of high economic and population growth. As evident in Kenya and estimated for developing countries in general (Garnaut, 2011a), per capita energy consumption is set to dramatically increase in the future as developing governments seek to address energy poverty and welfare issues through economic growth. This growth in future energy demand, and efforts by developing governments to decrease poverty through improved energy access represents both an opportunity and a challenge to the increased deployment of renewables in developing nations.

Governmental energy planning is often focused predominantly on the power sector, as apparent in the Kenya Vision 2030 report (Government of Kenya, 2007), with price distortions due to subsidies and potentially unrealistic energy capacity targets resulting in high levels of fossil fuels in future energy targets (Institute for Energy Research, 2013). This is due to the pressing need of governments to reduce energy poverty and increase societal welfare at the lowest cost, which does not take into account the environmental and energy security implications that result from fossil fuel dependence. Furthermore, governmental targets tend to marginalise non-electrical end-use sector energy consumption with regards to detailed development targets and legislation, and when combined with the lack of resource data availability and the uncertain economic climate in many developing countries, results in a hesitance from companies to invest in renewable energy projects (REN21, 2013). Finally, the average local cost of fossil fuel substitution in developing countries (i.e. the cost to individuals and businesses) is typically positive (i.e. it costs money), as highlighted in the Kenya case study. This is a result of the dependence of many developing countries on traditional biomass to meet their energy needs, especially amongst the most impoverished families. With traditional biomass typically available at low or no cost (IRENA, 2014) and the relatively high capital costs of more efficient, sustainable alternatives (such as clean cook stoves), the ability for developing countries to increase the deployment of renewables at an individual/household level is very restricted (UNEP, 2012).

Despite these challenges, developing countries represent a unique opportunity for the rapid uptake of renewable energy technology in both the power and end-use sectors. More specifically, developing countries have a low level of per capita energy consumption when compared to developed nations, and are also set to experience the vast majority of population growth through to 2030. When this population growth is combined with the aims of many developing nations to reduce poverty through economic and subsequently energy consumption growth (UNIDO, 2014), there arises a large quantity of energy demand that needs to be met between the present and 2030. 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). Furthermore, the correct implementation of renewables for new future demand rather than fossil fuels would allow for a more decentralised, fuel import independent economy. This would lead to reduced economic and health impacts (World Future Council, 2009), reduced energy infrastructure costs for developing governments such as Kenya who are targeting 100% grid access by 2030 (Johnson, 2013), reduced emissions and subsequent contributions to climate change, and finally, increased energy security due to independence from fossil fuel imports (Lovins & Lovins, 2001).

11.0 Implications and Recommendations

11.1 Introduction

The outline of the case study results and subsequent discussion highlights the significant potential for renewable energy deployment in both developed and developing. Generalisation of this potential, reflected in the opportunities and challenges facing nations of differing development levels, allows for the research questions and hypothesis posited at the beginning of this thesis to be answered. Subsequently, the answering of these questions gives rise to certain implications regarding the future role of developed and developing nations in the transition to sustainable energy consumption, in addition to future work that should be conducted to verify and expand these findings.

11.2 Summary and Findings

The completion of the REmap country analyses and subsequent discussion of the results as they pertained to developed and developing countries as a whole, allowed for the hypothesis and research questions posited at the beginning of this thesis to be answered.

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?

For developed countries, the key challenges facing the accelerated deployment of renewables are the issues of capacity lock-in, and conservative government targets. That is, current renewable energy targets in many developed nations are not very ambitious and do not take advantage of the technical expertise and resources available in these countries. In the case of capacity lock-in, renewables face the challenge of overcoming high levels of sunk costs in fossil-based energy investments with lifetimes of 20 to 60 years which results in governments and institutions unwilling to spend additional money on renewables after investing heavily in pre-existing or pre-planned projects. In terms of opportunities, renewables represent the chance to minimise the future negative impact of energy use on climate change and the environment, and provide increased energy import independence and subsequent security. Furthermore, developed countries have the opportunity to make this transition with low or negative substitution costs, with the opportunity to use their skills developed prior to and during this transition for economic gain in other countries.

For developing countries, the key challenges facing the accelerated deployment of renewables is the focus of nations on rising from poverty and developing their economies by the most direct means, in addition to a lack of renewables resource data availability, technical expertise and financial unaffordability at a household level. However, these challenges, especially with regards to national development, are partially offset by the clean slate offered by the underdeveloped levels of energy consumption in many of these nations. That is, the lack of development provides developing governments with the opportunity to leapfrog the fossil fuel dependent, centralised energy systems integral to current-day developed nations. Such an opportunity would allow developing governments to increase their energy consumption and economic growth, whilst preventing future environmental impacts that would arise if these future energy requirements were sourced from fossil fuels.

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?

From the generalisation of the case studies, it became apparent that developing countries provide the greatest opportunity for the future deployment of renewables. Whilst developed countries have greater technological capabilities for the deployment of renewables, they are hindered by their high level of development. More specifically, most developed countries have reached a fairly stable level of economic development, energy use and population growth, which means that the majority of the required energy infrastructure has already been constructed. This infrastructure, much of which comprises non-renewables which required initial investments that are locked-in and must be recouped over the lifetime of the investment, would need to be substituted by renewables in a transition to higher levels of RE. Such need for substitution results in significant resistance from stakeholders who face financial losses, as experienced in Germany by the large power generation firms (Ottery & Kahya, 2014). In contrast, much of the energy infrastructure required to meet growing demand in developing countries has yet to be built, representing a unique opportunity for developing countries to avoid the need to substitute fossil fuel technology at all, but rather to transition directly to the use of renewables.

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

From the developed nation perspective, developing nations have the opportunity to take advantage of the technological knowledge base of many developed countries. If developed countries took a more concerted, global approach to RE deployment, they could use their skills to help develop renewable projects where they are most feasible, and could profit whilst doing so.

From the developing nation perspective, developed nations could learn much about political decisions and targets with regards to renewables. Whilst these political visions may be overly optimistic, or even unrealistic, they reflect the concept of a government that is less concerned about remaining in office, in comparison to governments in developed nations which provide overly conservative RE targets that are easily achieved, and do not provide the global impact that could readily be achieved by these countries.

In summary, the findings obtained through the completion of the case studies of Sweden and Kenya and outlined in the research suggest that the hypothesis of this thesis was indeed correct:

"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."

However, in spite of this fact, there are great opportunities for renewable energy deployment in developed and developing nations alike, with the research findings merely having implications as to how this could most successfully be accomplished.

11.3 Implications

The research into the feasibility of the future deployment of renewables in developed and developing countries has raised significant implications for the sustainability of the planet and its 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 to 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 will need 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.

This would allow for the best allocation of technical skills, resources and finance where it would be most appropriate, leading in the long-term to a developed world with a high level of welfare and sustainable consumption that should solve the energy dependent issues of climate change and energy security. However, given the projected global population growth and dependence of the global economy on perpetual growth, there will eventually be a need to either stop growth, or to decouple economic and individual prosperity from growth (and subsequently from consumption).

11.4 Reflections on Engagement

The opportunity to work at the International Renewable Energy Agency (IRENA) in Bonn, Germany, provided the researcher with a greater appreciation of the workings of international organisations, and the challenges faced in promoting the increased use of renewables on the global stage. Similarly, work on the renewable energy roadmap (REmap) analyses provided an interesting perspective on energy consumption, promoting the need for energy engineers and countries to focus not solely on the power sector, but rather on the total consumption of energy in all sectors and all forms. Finally, the completion of the Sweden and Kenya case studies at IRENA starkly highlighted the difficulties in engaging countries in the need to transition towards increased renewables deployment. Due to the politically sensitive nature of energy discussions, and the lack of time available from government contact points, it became apparent that in spite of the best intentions, it is very difficult for a non-governmental organisation such as IRENA to influence the political mindset and focus of individual countries.

11.5 Recommendations for Future Research

Upon completion of the research, it became apparent that in addition to answering questions, the research raised a number of questions upon completion of this thesis. The following recommendations comprise the future work that the researcher would undertake or suggests be undertaken to further the work completed herein:

- Better engage with national experts from the respective case study countries in order to determine the accuracy of the reference case estimates, in addition to the realisable potential of the proposed increases to renewables deployment via the REmap Options.
- Compare and contrast the validity of the generalised conclusions for developed and developing nations, by completing 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 of implementation, which could be used as an example for developed and developing countries alike, and;

- In addition to the validation and testing of the conclusions made regarding the future deployment of RE solutions, it is also proposed that further work be done on looking at how to best engage governments with renewable energy deployment, as their willingness to engage with global institutes such as IRENA is limited, or at least slowed and delayed due to political vested interests.

11.6 Conclusions

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 national case studies, Sweden and Kenya, provided a glimpse into the similarities and disparities of energy use in developed and developing country, and the potential for such nations to transition to a future of energy use based around renewables. In generalising the Sweden and Kenya case study results to be more representative of all developed and developing countries respectively, the research was able to answer each of the proposed research questions, and provide a means to test and subsequently defend the hypothesis proposed at the beginning of this report. From the perspective of the initial objectives proposed for the research, the culmination of the research in two complete case studies and the subsequent discussions and implications surrounding the results represent the successful completion of the research.

The researcher believes that the initial personal vision behind the objectives and research questions was perhaps aimed a little too high for completion in a master thesis. However, in spite of personal reservations, the research has highlighted the need to focus on energy at a more interlinked, holistic level, rather than from a compartmentalised perspective, be it power production, emissions, economics, energy security or national development. The findings outlined above reiterate the need for, and benefits of global action from all nations with regards to a future of increased renewables deployment and fossil fuel substitution. Furthermore, the research highlights the advantage that developed nations have with regards to increasing the uptake of renewables, and the potential for these countries to use their best practice expertise to partner with other nations to deploy renewables at a global level, with economic, political, social and environmental benefits for all those involved.

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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Appendices

Appendix A – Sweden REmap Options Cases Assumptions

Case 1 – Biomass-centric renewables development

This case focused on the substitution of fossil fuels with biomass in the three end-use sectors and in district heating. In addition to the development of biomass resource consumption, additional hydropower capacity was developed to substitute a portion of the existing nuclear capacity.

Industry

Given the emphasis on biomass use in this case, thermal coal used for industrial heating (33.4 PJ) and fossil fuels used in the 'chemical & petrochemical', 'non-metallic mineral', 'food & tobacco', 'paper, pulp and printing' (14.3 PJ natural gas and 34.2 PJ oil & oil products) were substituted with 78 PJ of solid biomass. In this case the solid biomass is used as a direct substitute for fossil fuels in industry. This substitution of renewable biomass results in an increase in the 2030 RE share in industry from 63.7% in the Reference Case to 84.6% (excluding electricity and DH).

Buildings

In contrast to the direct use of biomass in the industry sector, fossil fuel use in the building sector due to space heating was substituted with biomass-fueled CHP in district heating. This resulted in a substitution of 27 PJ of oil & oil products and 1 PJ of natural gas in the buildings sector by 24 PJ of biomass in district heating. Subsequently the 2030 RE share in buildings increased from 60.2% in the Reference Case to 87% (excluding electricity and DH).

Transport

Due to the biomass resource limitations and high share of fossil fuels in the transport sector in Sweden, substitution of fossil fuels by liquid biofuels were projected to only substitute 30% of gasoline and diesel consumption in the transport sector. This represented a 21.7 PJ and 67.2 PJ reduction in gasoline and diesel consumption respectively, and a subsequent 1 to 1 increase in the respective consumption of bioethanol and biodiesel. After substitution, the RE share in the transport sector was found to rise from a Reference Case value of 7.3% in 2030 to 36.5% (including electricity). Furthermore, in conjunction with biomass consumption in other sectors (including electricity and DH), this increased liquid biofuels consumption results in a total Swedish biomass consumption of 894 PJ, nearing the limit of economically feasible supply potential.

District Heating

In addition to the 29 PJ increase of biomass-based CHP heat production from substitution in the buildings sector, 5 PJ (2 PJ natural gas and 3 PJ oil & oil products) of the remaining fossil fuel consumption in DH in the Reference Case was substituted with 4.6 PJ of biomass-based CHP heat production. Together this increased DH consumption results in an increase in the renewables in DH from an already high share of 92.8% in the reference case, to 96.1%, closer in line with the Swedish target of fossil fuel free heat production.

Power Generation

Based upon the 2030 Reference Case Swedish electricity in TFEC comprises almost 62% renewables (including CHP) in the Reference Case, with the remaining 38% comprised predominantly of nuclear. This 62% renewable power generation comprises 69 TWh hydro, 12 TWh wind and 21 TWh biomass. With the economically feasible wind resources exhausted in the Reference Case, and the limitation of biomass resources due to their allocation in other sectors in Case 1, it was assumed that further development of renewable power generation would come from hydro resources, in addition to the electricity generated from the district heating CHP. This increased renewable generation resulted in the substitution of 3000 MW of nuclear by 2900 MW of hydropower and 510 megawatt-electric (MWe) of CHP, with the renewable share in electricity generation increasing to 69.1%.

Case 2 – District heat-centric renewables development

Case 2 also focused on the substitution of fossil fuels with biomass in the three end-use sectors and in district heating. In addition to the development of biomass resource consumption, additional hydropower capacity was developed to substitute a portion of the existing nuclear capacity, and to provide extra electricity generation required for the partial electrification of the transport sector.

Industry

Similar to Case 1, thermal coal used for industrial heating (35.2 PJ) and fossil fuels used in the 'chemical & petrochemical', 'non-metallic mineral', 'food & tobacco', 'paper, pulp and printing' (15 PJ natural gas and 36 PJ oil & oil products) were substituted with 78 PJ of biomass-fueled CHP in district heating, much like in the buildings sector. This substitution of renewable biomass results in an increase in the 2030 RE share in industry from 63.7% in the Reference Case to 81.8% (excluding electricity and DH).

Buildings

In the same manner as Case 1, fossil fuel use in the building sector due to space heating was substituted with biomass-fueled CHP in district heating. This resulted in a substitution of 27 PJ of oil & oil products and 1 PJ of natural gas in the buildings sector by 24 PJ of biomass in district heating. Subsequently the 2030 RE share in buildings increased from 60.2% in the Reference Case to 87% (excluding electricity and DH) due to this substitution.

Transport

With a focus more on district heating and less on biomass (compared to Case 1), Case 2 reduced the pressure to exhaust the economically feasible biomass resources by equally substituting fossil transport fuels with liquid biofuels and electric vehicles (EVs). Liquid biofuels and EVs each substituted 15% of the 2030 reference case fossil fuel consumption, resulting in the substitution of 21.7 PJ of gasoline and 67.2 PJ of diesel consumption. This transport fuel substitution resulted in an increase in the consumption of bioethanol and biodiesel by 10.1 PJ and 27.9 PJ respectively, with electricity consumption in the transport sector increasing by 17 PJ. After substitution, the RE share in the transport sector was found to rise from a Reference Case value of 7.3% in

2030 to 25.6% (including electricity). This lower RE share in the transport sector compared to Case 1, in spite of the substitution of the same quantity of fossil fuels, is a result of the partial shift towards electric vehicles in a society with partially non-renewable power generation.

District Heating

In addition to the 102 PJ increase of biomass-based CHP heat production from substitution in the industry buildings sectors, 5 PJ (2 PJ natural gas and 3 PJ oil & oil products) of the remaining fossil fuel consumption in DH in the reference case was substituted with 4.6 PJ of biomass-based CHP heat production. Together this increased DH consumption results in an increase in the renewables in DH from an already high share of 92.8% in the reference case, to 97.4%, closer in line with the Swedish target of fossil fuel free heat production.

Power Generation

Based upon the 2030 Reference Case Swedish electricity in TFEC comprises almost 62% renewables (including CHP) in the reference case, with the remaining 38% comprised predominantly of nuclear. This 62% renewable power generation comprises 69 TWh hydro, 12 TWh wind and 21 TWh biomass. With the economically feasible wind resources exhausted in the Reference Case, and the objective not to fully stretch the limit of available biomass resources, in contrast to Case 1, it was assumed that further development of renewable power generation would come from hydro resources, in addition to the electricity generated from the district heating CHP. This increased renewable generation resulted in the addition of 1895 MWe of CHP and 3800 MW of hydropower, 1060 MW of which was to provide additional capacity to meet the partial transport sector electrification demand. The addition of this renewable generation capacity resulted in the substitution of 1755 MW of nuclear, with the renewable share in electricity generation increasing to 71.5%.

Case 3 – Liquid biofuels for transport-centric renewables development

In contrast to the previous cases, Case 3 focused on the substitution of fossil fuels with biomass solely in the transport sector. This case was used to evaluate the potential for the Swedish government to realise their vision of a fossil fuel independent transport sector by 2030, focusing on the substitution of fossil transport fuels with liquid biofuels. In addition to the development of biofuel-based transport sector, additional hydropower capacity was developed to substitute a portion of the existing nuclear capacity.

Industry

With a focus on deploying all available biomass in the transport sector, and no alternative renewable resources available in Sweden to provide industrial heating, with the 2030 RE share in industry remaining at the Reference Case value of 63.7% (excluding electricity and DH). It should be noted that heat pumps were not considered as a substitution option in this case due to the assumed focus of renewable development on the transport sector.

Buildings

In similar fashion to the industry sector, no alternative renewable resources were available in Sweden to provide building heating, with the 2030 RE share in buildings remaining at the Reference Case value of 60.2%

(excluding electricity and DH). It should be noted that heat pumps were not considered as a substitution option in this case due to the assumed focus of renewable development on the transport sector.

Transport

With a focus on achieving the Swedish government's vision of a fossil fuel independent transport sector by 2030, Case 3 devoted all available biomass resources to displacing fossil-based transportation fuels. Focusing solely on substitution via liquid biofuels resulted in a final RE share in the transport sector (including electricity) of 89% (up from 7.3% in the Reference Case), but required the import of additional biomass to meet the total biofuels demand. More specifically, in addition to consuming 900 PJ of Swedish biomass resources, 170 PJ of imported biofuels was required.

District Heating

With all available biomass deployed in the transport sector, and no alternative renewable resources available in Sweden to provide district heating, the 2030 RE share in DH remained at the Reference Case value of 92.8%.

Power Generation

With the economically feasible wind resources exhausted in the Reference Case (as addressed in Cases 1 and 2), and the available biomass resources already totally exploited by the transport sector, , it was assumed that further development of renewable power generation would come from hydro resources. This increased renewable generation resulted in the addition of 3690 MW of hydropower, resulting in the substitution of 2195 MW of nuclear, with the renewable share in electricity generation increasing to 70.1%.

Case 4 – Electrification

As an alternative to increased biomass consumption as a substitute for fossil fuel, Case 4 focused on the substitution of fossil fuels with electricity. For heating demand fossil fuels were substituted by heat-pumps, whilst the transportation sector was projected to move away from fossil fuels (gasoline and diesel) towards electrification. However, due to the REmap focus of increased renewables share in TFEC, it was assumed that all additional power generation capacity required to meet the increased demand would come from renewable sources. As such, the level of electrification in Sweden was limited by its access to economically feasible renewable resources that could be developed. It should be noted that air-to-air heat pumps were predominantly used due to their current prevalence in Sweden and their ability to function at adequate efficiency down to temperatures of -15C (Forsen, 2005), covering the vast majority of the temperature range experienced by inhabited Sweden (World Bank, 2014; Nordregio, 2011). For those areas experiencing colder temperatures, it was assumed ground-source heat pumps would be used in the place of air-to-air heat pumps.

Industry

In contrast to the biomass heavy development of the first three cases, Case 4 substituted thermal coal used for industrial heating (30.2 PJ) and fossil fuels used in the 'chemical & petrochemical', 'non-metallic mineral', 'food & tobacco', 'paper, pulp and printing' (12.9 PJ natural gas and 30.9 PJ oil & oil products) with heat pumps (19

PJ). The electrification of heating in industry results in an increase in the 2030 RE share in industry from 63.7% in the Reference Case to 78.6% (excluding electricity and DH).

Buildings

In the same manner as in industry, fossil fuel use in the building sector due to space heating was substituted with heat pumps. This resulted in a substitution of 23 PJ of oil & oil products and 1.1 PJ of natural gas in the buildings sector by 6.3 PJ of electricity. Subsequently the 2030 RE share in buildings increased from 60.2% in the Reference Case to 81.5% (excluding electricity and DH).

Transport

With a focus on achieving the Swedish government's vision of a fossil fuel independent transport sector by 2030, Case 4 devoted all available renewable power generation resources (excluding biomass) to displacing fossil-based transportation fuels. Focusing predominantly on substitution via electrification results in a final RE share in the transport sector (including electricity) of 65.6% (up from 7.3% in the Reference Case). However, given the limitation of power generation capacity to renewable sources, 59 PJ of fossil fuels were substituted with 59 PJ of liquid biofuels. Whilst the electrification of the transport sector results in an apparent final share of renewables that is lower than that achieved by substitution with liquid biofuels in Case 3, it should be noted that electrification resulted in a reduction of TFEC in the transport sector from 309 PJ to 208 PJ due to a substitution of 181 PJ of fossil fuels with electrification consumption of 80 PJ.

District Heating

Continuing with the electrification of energy consumption in Sweden, 5 PJ (2.5 PJ natural gas and 3.5 PJ oil & oil products) of the remaining fossil fuel consumption in DH in the Reference Case was substituted with 4.6 PJ of biomass-based CHP heat production. Together this increased DH consumption results in an increase in the renewables in DH from an already high share of 92.8% in the reference case, to 97.4%.

Power Generation

With the economically feasible wind resources exhausted in the Reference Case, and the objective not to focus on significant further development of biomass resources, it was assumed that further development of renewable power generation would come from hydro and solar PV resources. This increased renewable generation resulted in the addition of 2995 MW of solar PV and 5824 MW of hydropower. However, only 122 MW of hydro and 1 MW of solar PV was used to substitute 71 MW of natural gas, 15 MW of oil and 76 MW of nuclear, with the remaining additional capacity used to meet the transport sector electrification demand. The addition of this renewable generation capacity to meet increased electricity demand rather than to substitute fossil fuel generation results in a renewable share of 67.3% in electricity generation.

Appendix B – Key case study supporting Data

Energy prices in Sweden (local/international)

		International Prices		Local Prices	
		2010	2030	2010	2030
Crude oil	(USD/GJ)	14.58	20	32.48	38.46
Steam coal	(USD/GJ)	2.7	4.5	34.12	17.46
Electricity Household	(USD/kWh)	0.1	0.171	0.13	0.28
Electricity Industry	(USD/kWh)	0.1	0.12	0.04	0.09
Natural gas Household	(USD/GJ)	5	22.18	29.29	36.42
Natural gas Industry	(USD/GJ)	5	11.09	11.89	16.04
Diesel	(USD/GJ)	21	28.81	35.19	48.38
Gasoline	(USD/GJ)	21	28.81	42.56	51.28
Biodiesel[a]	(USD/GJ)	25	23	35.19	48.38
First generation bioethanol[a]	(USD/GJ)	18	27	42.56	51.28
Biomethane	(USD/GJ)	20	22	20	52
Primary biomass 1 (Industry)	(USD/GJ)	11.4	8.33	7.72	9.66
Primary biomass 2 (Residential)	(USD/GJ)	11.4	8.33	11.58	12.78

[a] Note: the local price of liquid biofuels (biodiesel and bioethanol) in 2030 was linked to the projected price of fossil-based transport fuels due to the unavailability of 2030 prices for liquid biofuels in Sweden.

2030 Capital costs in Sweden (local/international)

	International [USD/kW]	Local [USD/kW]	Capacity Factor [%]
Renewables			
Hydro (large)	5400	5400	50
Solar PV (utility)	1407	1407	18
Autoproducers, CHP electricity part (solid biomass)	500	850	75
Biomass boilers	580	1034	85
Heat Pumps	742	850	50
Autoproducers, CHP heat part (solid biomass)	231	850	75
Space heating: Air-to-Air heat pumps	780	1113	50
Biomass DH	512	512	30
Biodiesel (passenger road vehicles) [USD/vehicle]	30000	30000	-
Second generation bioethanol (passenger road vehicles) [USD/vehicle]	28000	28000	-
Biomethane (passenger road vehicles) [USD/vehicle]	30000	30000	-

Biofuels (passenger aviation) [USD/vehicle]	50000000	50000000	-
Battery electric (passenger road vehicles) [USD/vehicle]	32000	32000	-
Public CHP electricity part (solid primary biomass)	231	850	75
Public CHP heat part (solid primary biomass)	231	850	75
Non-Renewables			
Nuclear (OECD)	7500	7500	84
Coal (OECD)	3000	3000	80
Oil (power gen.)	1200	1200	80
Coal (steam boiler)	256	256	85
Petroleum products (steam boiler)	200	200	85
Natural gas (steam boiler)	153	153	85
Coal (furnace)	256	256	85
Petroleum products (furnace)	150	150	85
Space heating: petroleum products (boiler)	175	175	85
Space heating: natural gas (boiler)	128	128	85
Petroleum products (passenger road vehicles) [USD/vehicle]	28000	28000	-
Petroleum products (passenger road vehicles - Diesel) [USD/vehicle]	30000	30000	-
Natural gas (passenger road vehicles) [USD/vehicle]	30000	30000	-
Petroleum products (passenger aviation) [USD/vehicle]	50000000	50000000	-

Energy prices in Kenya (local/international)

		International Prices	Local Prices
		2030	
Crude oil	(USD/GJ)	20	18.1729
Steam coal	(USD/GJ)	4.5	3.4
Electricity Household	(USD/kWh)	0.171	0.225
Electricity Industry	(USD/kWh)	0.1196	0.15
Natural gas Industry	(USD/GJ)	11.09	7.6
Petroleum products	(USD/GJ)	16.4609	18.5
Gasoline	(USD/GJ)	28.8066	57.1
Second generation bioethanol	(USD/GJ)	25	89.5
Primary biomass 1	(USD/GJ)	8.33185	17.6
Biomass residues	(USD/GJ)	3.34505	3.38

Tradtional biomass	(USD/GJ)	3	3
Nuclear fuel	(USD/GJ)	0.86	0.86

2030 capital costs in Kenya (local/international)

	International [USD/kW]	**Local [USD/kW]**	**Capacity Factor [%]**
Renewables			
Hydro (large)	5400	5400	50
Solar PV (utility)	1407	1267	18
Wind onshore	1657	1508	38
Geothermal	3100	2956	80
Solar Thermal	656	656	10
Water heating: biomass	600	600	30
Water heating: Solar (thermosiphon)	250	630	12
Cooking biogas (from AD)	39	39	10
Cooking biomass (solid)	15	15	10
Second generation bioethanol (passenger road vehicles) [USD/vehicle]	28000	28000	-
Non-Renewables			
Nuclear (non-OECD)	7500	5028	84
Coal (non-OECD)	3000	2403	80
Oil (power gen.)	1200	1350	30
Natural gas (power gen.)	1000	1069	80
Petroleum products (steam boiler)	200	200	85
Space & Water heating: traditional biomass	100	100	85
Water heating: electricity	150	150	10
Cooking traditional biomass	10	10	10
Petroleum products (passenger road vehicles) [USD/vehicle]	28000	28000	-