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on

The role of science, technology and innovation to increase substantially the share of renewable energy by 2030

Advance Unedited Draft

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Prepared by the UNCTAD Secretariat[1]

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1. Introduction

The Sustainable Development Goals were agreed in September 2015, and cover seventeen related goals plus a larger number of specific targets. Goal 7 has the main aim of ensuring universal access to affordable, reliable and modern energy services by 2030. Within this, there is a target 'to increase substantially the share of renewable energy in the global energy mix' by 2030.

An expansion of renewable energy could also contribute to progress towards several other Goals. A study by the International Council for Science (ICSU, 2017) showed that achieving universal energy access and increasing renewable energy is likely to have largely positive impacts on other SDGs.

There are clear synergies with Goal 13 on climate action and Goal 9 on industry, innovation and infrastructure. The expansion of renewable energy is part of most national strategies to mitigate the greenhouse gases that cause climate change. As this paper will show in some detail, many national innovation policies and international initiatives include a focus on renewable energy technologies.

The reduction of poverty (Goal 1) requires, among other things, the development of modern infrastructures. Renewable energy can play an important role in the development of such infrastructures. Renewable energy can also contribute to Goal 3 by reducing the health risks associated with pollution by replacing the use of fossil fuels, e.g. for cooking and lighting in homes (IPCC, 2012). It is also relevant to Goal 5. By replacing traditional forms of energy such as wood fuel, modern forms of renewable energy can reduce the time spent gathering wood by women and girls in particular (Oparaocha and Dutta, 2011). Lighting through renewable energy systems can also provide greater time flexibility for domestic activities, especially for women (Millinger, 2012).

Some potentially negative interactions were also identified by the International Council for Science, which may need to be addressed. These include ensuring that any additional costs of renewable energy investments are not borne by the poor. As this paper will show, recent falls in renewable energy costs and the implementation of new business models have helped to mitigate this risk. Other examples include the impact of water supply infrastructure (particularly desalination) on energy demand and the impact of bioenergy on land use, especially if this leads to competition with land use for food.

This issues paper explores the role of science, technology and innovation to achieve a substantial increase in the share of renewable energy by 2030. The paper discusses the current status of renewable energy technologies and their contribution to global energy needs, and uses more detailed national case studies to explore the factors that have enabled or constrained the further growth of renewables. The issues paper also discusses different innovation pathways and policies, as well as recommendations for national policy makers and the international community.

The issues paper comprises six main sections that are structured as follows. Section 2 provides some further background on the role of renewable energy in the global energy mix. It briefly discusses recent trends and challenges for renewable energy. It also provides some illustrative scenarios for the expansion of renewable energy as part of strategies to meet the climate change mitigation targets in the Paris Agreement. It concludes with a focus on the status of some of the key renewable energy technologies and associated enabling technologies, and discusses some of the improvements that could occur in future.

Sections 3 to 5 discuss innovation pathways, key issues and policies for renewable energy in more detail. These sections draw on a range of national case studies of renewable energy innovation and deployment from both developed and developing countries. Section 3 focuses on the innovation systems, and the types of innovation that are relevant for renewable energy technologies. Section 4 discusses some more specific challenges for renewable energy – including technical challenges; market challenges; mini-grid and off-grid applications; and the use of renewables in households – especially in developing countries. Section 5 explores policies for renewable energy deployment, with an emphasis on policy mixes rather than individual policies in isolation. The section also discusses the role of international co-operation.

Finally, section 6 concludes with a set of recommendations for countries wishing to increase the role of renewable energy. It includes a particular focus on recommendations to the Commission on Science and Technology for Development, including the role of international cooperation.

2. Background and context

Renewable energy sources and technologies are diverse – and range from small scale solar photovoltaic panels to the use of biofuels for transport. The International Energy Agency (IEA, 2016) makes four distinctions between different renewable energy technologies that illustrate this diversity:

- Variable vs dispatchable renewables. Some technologies are weather dependent (e.g. wind and solar PV), with some unpredictability in their output, whilst others can be dispatched when required (e.g. bioenergy).
- Centralised vs distributed renewables. Solar home systems are highly decentralised, whilst large-scale hydro technologies are used in some of the largest power plants in the world.
- Direct vs indirect renewables. For example, solar thermal technology uses the sun to heat water directly whilst solar PV technology generates electricity which can then be used for a variety of energy services.
- Traditional vs modern forms of bioenergy. Traditional forms of bioenergy are still widely used in the developing world for cooking and heating using basic technologies, whilst more modern technologies are available (e.g. for improved cook stoves or for processing and burning biomass to generate power and heat).

It is therefore important to recognise the role that renewable energy can play across entire energy systems – and not just in electricity systems, which are often the main focus of discussions about technological change and innovation.

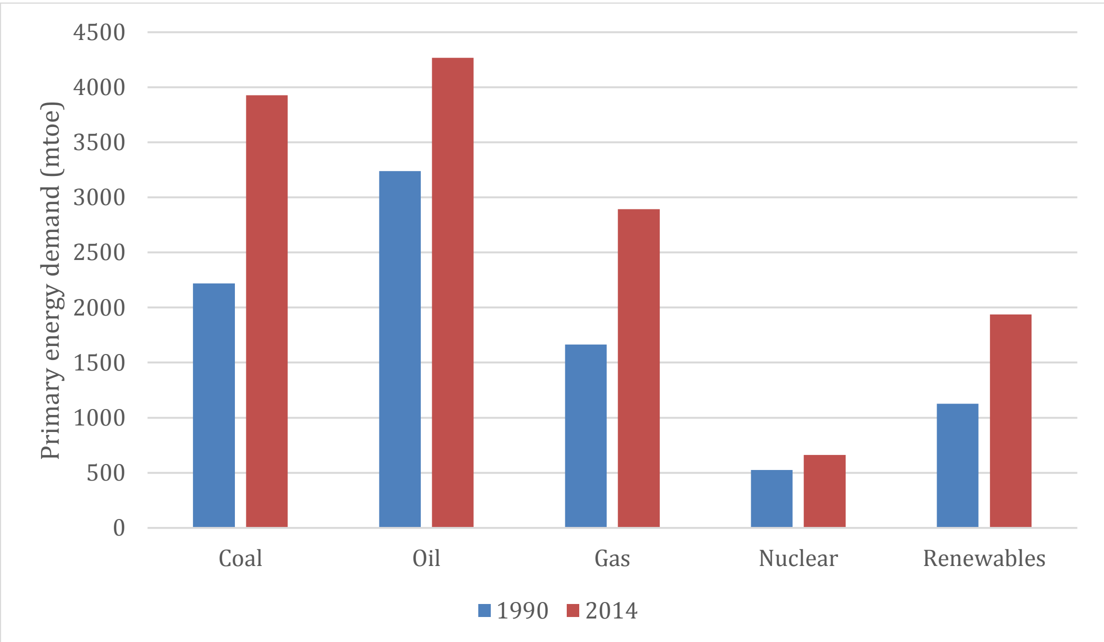
Renewable energy sources have been used for as long as energy systems have existed, and predated the use of fossil fuels (e.g. Grubler and Nakicenovic, 1991). Modern efforts to increase the use of renewable energy sources were originally spurred by the oil price shocks of the 1970s, and the desire for sources of energy that are less prone to geopolitical risks. More recently, the main driver of policies for renewable energy has been the need for increasing action to mitigate climate change – and the need to move away from the fossil fuels that dominate global energy systems. This led to a step change in the development and deployment of a range of renewable energy technologies. The rate of deployment of renewable electricity technologies has increased particularly quickly as a result of policy interventions in many countries. The costs of some of these technologies have fallen dramatically as a result.

2.1. Recent global trends in renewable energy deployment

According to the latest International Energy Agency (IEA) data, renewable energy accounted for 14% of the global primary energy demand in 2014 (IEA, 2016). If traditional forms of solid bioenergy are excluded, the share was 8%. Figure 1 shows the contribution of renewables to global primary energy demand in comparison with those of fossil fuels and nuclear power in 1990 and 2014.

Between 1990 and 2015, the average annual growth rate of renewable energy (2%) was slightly higher than the annual growth rate of primary energy (1.8%) (IEA, 2017a). This overall figure masks much higher rates of growth for some renewable technologies. For example, solar PV grew by an average annual rate of 46%, wind power grew at an annual rate of 24%, biogas grew by an average of 13% a year and solar thermal grew by 11% a year. By contrast, solid biofuels and charcoal – which accounted for 64% of renewable energy in 2015 – grew at an average rate of just over 1%.

Figure 1: Global primary energy demand by energy source



Source: IEA (2016).

The latest BP statistical review of world energy gives more up to date figures, albeit on a different basis: they do not include traditional forms of bioenergy. It states that renewable energy sources including hydroelectricity accounted for 9.5% of global primary energy consumption in 2015 and 10% in 2016 (BP, 2017a).

According to the IEA, 23% of electricity now comes from renewables world-wide (IEA, 2017a). The majority of this (16%) is from hydro power; with the remainder coming from bioenergy and waste (2%); and wind, geothermal, solar and tidal (5% combined). Over 50% of new power capacity investment went into renewables in 2015, overtaking the combined annual capacity addition for fossil and nuclear plants for the first time (IEA, 2016). In 2016, renewables capacity accounted for two thirds of additions – with a record 165GW being deployed in that year (IEA, 2017a). Wind and solar deployment has increased particularly rapidly in the last decade, driven by market creation policies in many countries. In 2016, 74GW of solar PV capacity and 51GW of wind capacity was installed.

In buildings, the IEA states that 12% of energy comes from renewables - plus a further 26% from traditional sources of biomass (IEA, 2016). 11.5% of industrial energy is from renewables, whilst the proportion in transport is much smaller (at 3%). Most of the latter is biofuels.

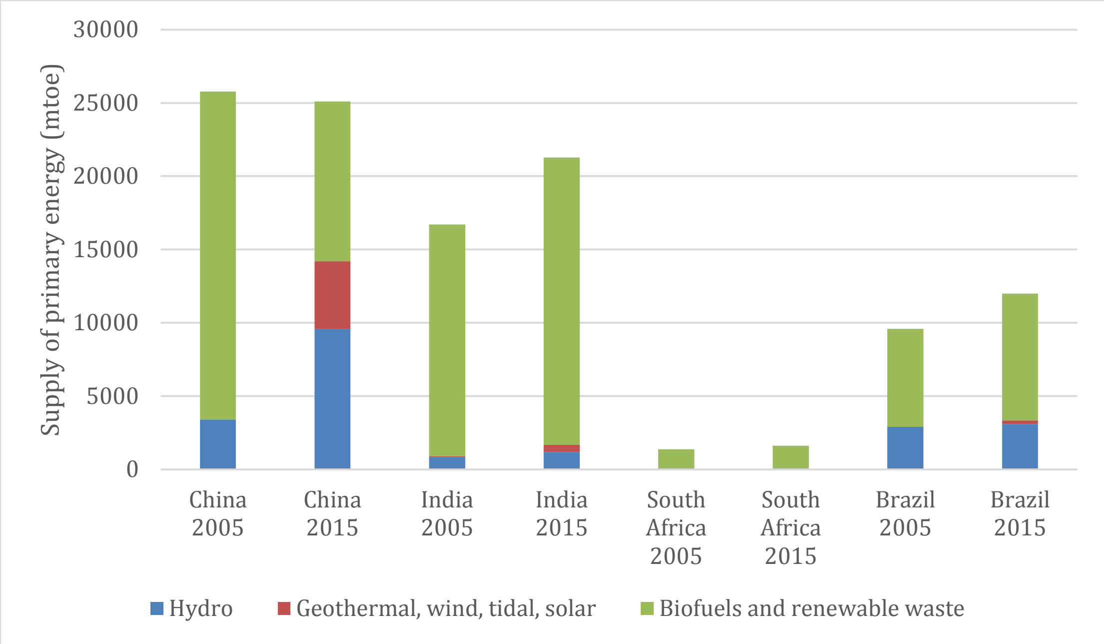
Regional figures from the IEA for the use of renewable energy show significant variation between different countries. In OECD countries, renewable energy plays a relatively minor role. The share of renewable energy in these countries grew from 3% in 1990 to 5.5% in 2015. The share of renewables in electricity generation grew from 17.3% to 23% during the same period. If hydro is excluded, the share of other renewables grew much more quickly – from 2% in 1990 to 10% in 2015.

In non-OECD Asia – a region that includes China and India – renewable energy accounted for 16% of primary energy in 2014. In Latin America and Africa, the share of renewable energy was much higher than in Asia – at 29% and 50% respectively. In each case, the use of renewable energy is dominated by bioenergy. Bioenergy alone accounted for 48% of primary energy demand in Africa in 2014, most of which was from traditional forms.

More detail on selected middle income and less developed countries is shown in Figures 2 and 3 below. In China, for example, the contribution of renewables to total primary energy supply was similar in 2005 (258mtoe) and 2015 (251mtoe). But the share of total primary energy fell from 15% to 8% during this decade as investments in fossil fuel infrastructure accelerated (IEA, 2007 and IEA, 2017a). However, the mix of renewable energy sources shifted markedly during that period. In 2005, 87% of China's renewable energy came from solid biofuels and waste, with the remainder coming from hydro power. By 2015, this share had fallen to 43% - with hydro accounting for 38% and wind, solar and geothermal energy accounting for 18%.

Whilst India and Brazil use less renewable energy than China, the share of renewables in their energy mix is much higher – 40% of primary energy in Brazil in 2015 and 25% of primary energy in India in the same year. The particularly high share for Brazil is partly due to the long-standing use of ethanol in road transport as well as significant amounts of hydro power generation.

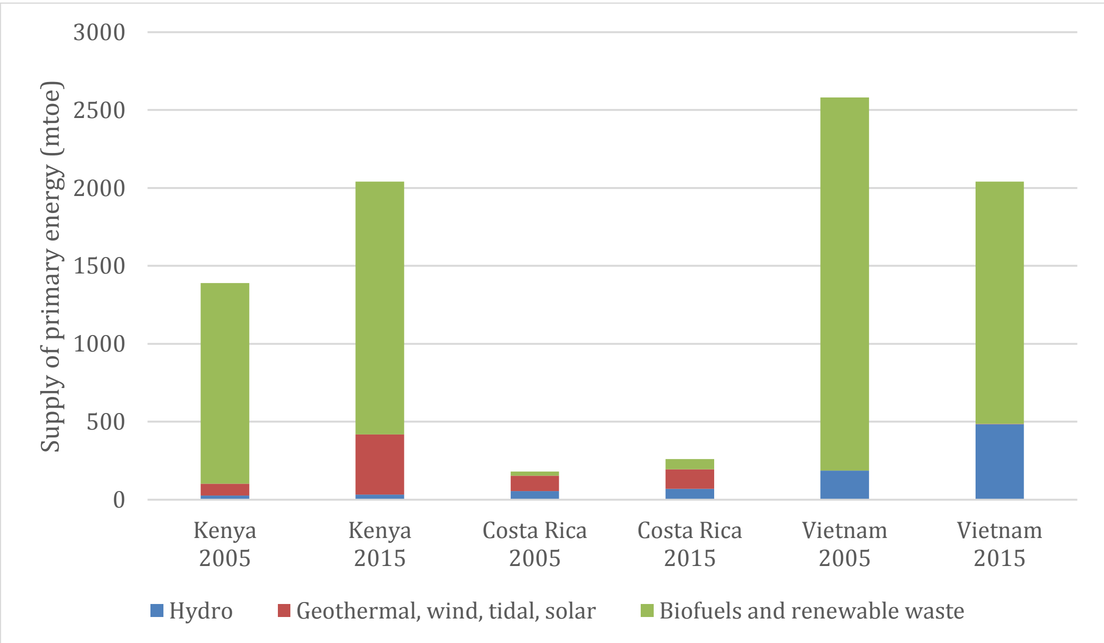
Figure 2: Renewable energy in China, India, South Africa and Brazil (2005 and 2015)



Source: IEA (2007 and 2017a).

As expected, the use of renewable energy in less developed countries is often dominated by traditional forms of bioenergy. However, the share of renewables in total primary energy supply varies considerably – from 28% in Vietnam in 2015 to 53% in Costa Rica and 81% in Kenya in the same year. In all three countries shown in Figure 3, this is complemented by a growth in other renewables including hydro, wind and solar.

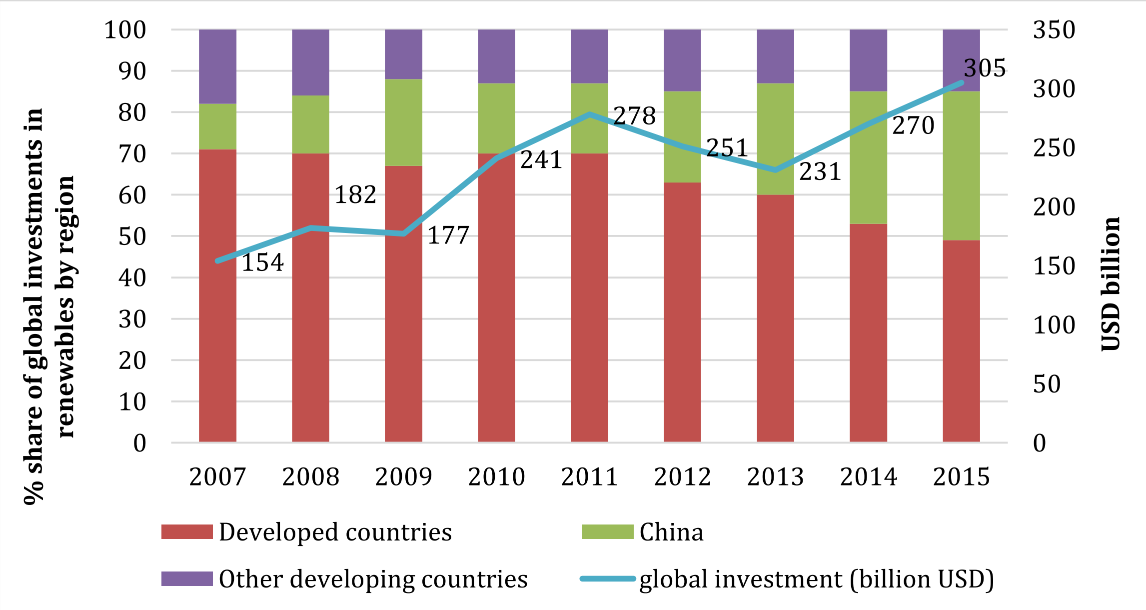
Figure 3: Renewable energy in Kenya, Costa Rica and Vietnam (2005 and 2015)



Source: IEA (2007 and 2017a).

In addition, investment in renewable energy has almost doubled from USD 154 billion in 2007, to USD 305 billion in 2015. Estimates of the investment levels needed to reach, for example, the target of 36 percent renewables of total final energy consumption, set by the Sustainable Energy for All (SE4A) initiative, is around USD 770 billion (IRENA, 2017a). According to the IEA (2017b), China and developing countries are experiencing the fastest growth since 2012. In 2015, global investment into renewable energy was mostly due to solar PV and wind, which accounted for around 90 percent (IRENA, 2017a). Figure 4 shows the recent development of global investment flows into renewable energy, as well as the regional share of these investments.

Figure 4: Global investments in renewable energy



Source: IRENA (2017a).

2.2 Breakthroughs and challenges

As noted above, there has been particularly rapid progress in some renewable electricity technologies in recent years. This has been driven by deployment incentives implemented in an increasing number of countries. These incentives have led to rapid cost reductions which, in turn, have made these technologies more cost effective. For example, cost reductions for solar PV have been in the range of 40-75% since 2010 according to the IEA. Similarly, onshore wind costs have fallen by a third between 2008 and 2015.

Auctions have been a particularly important policy for driving these cost reductions. In many countries, there has been a transition from government administered tariffs to auction systems during the past few years (IEA, 2017b). A review by the International Renewable Energy Agency (IRENA) concluded that the average contracted price for solar PV fell from almost $250/MWh in 2010 to $50/MWh in 2016 (IRENA, 2017b). Average wind contract prices halved in the same period – from $80/MWh to $40/MWh. Several recent auctions in Europe have driven down the costs of offshore wind much more quickly than expected. The United Kingdom's most recent auction in September 2017 resulted in contract prices for offshore wind that are 50% lower than the price of offshore wind in 2015 (BEIS, 2017). The IEA expects almost half of all renewable electricity capacity additions to be driven by auctions in the next five years, compared to just 20% in 2016 (IEA, 2017b).

As a result, several renewable technologies are now well established including solar (thermal and PV), hydro and wind. In many cases, public policy support is still required for these technologies. However, cost reductions have closed the economic gap between them and fossil fuels – and subsidies are not always necessary. Although they also require subsidies, bioenergy technologies for generating heat and power are also mature, as are first generation biofuels for transport. Yet, these biofuels are controversial due to concerns about life cycle emissions, resource sustainability and potential interactions with other uses of land (e.g. for food crops). New generations of biofuel are being developed. However, recent developments in electric vehicle technology and policy targets in many countries may mean that renewables play a more indirect role in transport. Many future scenarios now foresee a rapid expansion of electric (and sometimes hydrogen) vehicles, which could increase demand for renewables to generate clean electricity or hydrogen.

There is now an increasing emphasis on the technical and economic challenges of integrating larger shares of renewables into electricity grids. As the case studies in Section 2 will show, some countries now have high shares of renewables – including those such as wind and solar PV that are variable or intermittent. A recent systematic review of international evidence on the costs and impacts of increasing shares of intermittent renewables on electricity systems found a wide range of estimates for these costs and impacts (Heptonstall et al, 2017). It concluded that these costs will be higher if electricity systems are not flexible. Multiple sources of flexibility are now possible, including demand side response, interconnectors, conventional generation and storage (see section 2.3 below). One implication is that further increases in renewable electricity from variable technologies will partly depend on progress with developing and deploying these forms of flexibility. This may require reforms to electricity markets so that these flexibility options can be sufficiently rewarded for the benefits they provide.

In summary, a range of factors have driven or inhibited renewables development and deployment so far. Many of these will be discussed in more detail in section 4 of this paper. They include:

- Economics. Until recently, the costs of renewable technologies have usually been higher than those of fossil fuels. For some technologies, this economic gap has now started to close – particularly for electricity generation.
- Finance. This has been an important barrier to renewables deployment in many countries and has required policy intervention to provide greater certainty for investors. It remains a particularly important challenge in many developing countries.
- Technical maturity. Some renewable energy technologies are not yet ready to be widely deployed and still need significant development and demonstration so that they are reliable and cost effective enough.
- Integration into electricity systems. Renewable technologies sometimes present new challenges for electricity systems and markets. This includes bottlenecks in

electricity network infrastructure, limits to the ability of electricity systems to absorb variable renewables and markets that were designed for incumbent fossil fuel technologies.

- Environmental sustainability. Concerns about environmental sustainability have led to controversy about the use of some renewable energy sources. Examples include first generation biofuels, where there are questions about life cycle emissions and implications for land use; and large hydro, where there are important questions about impacts on regional ecosystems.
- Skills and capabilities. The deployment of renewable energy technologies and the design of policies to encourage this requires new skills and capabilities.

The Ernst and Young renewable energy country attractiveness index takes some of these factors into account in a regular ranking (Ernst and Young, 2017). The latest edition includes both developed and middle-income countries in the top 10. China is in first place in the most recent ranking on the basis of a continuing strong commitment to renewables deployment and the consequent deferment of coal fired power plant plans. India is second, Chile 8th and Mexico 9th. The OECD countries in the top ten include the United States of America (3rd), Germany (4th), Australia (5th), France (6th), Japan (7th) and the United Kingdom (10th).

2.3 Technology horizon scanning

Due to the need to transform energy systems world-wide to mitigate climate change and meet other policy goals, there are now many global and national scenarios that explore how this could be achieved. Most of these scenarios include an expansion of renewable energy alongside other measures such as energy and resource efficiency; energy demand reduction; and the expansion of other low carbon technologies such as nuclear power and carbon capture and storage. Technologies to remove greenhouse gases from the atmosphere, including combining bioenergy with carbon capture and storage, also play a prominent role in such scenarios – especially those that are designed to comply with the Paris Agreement.

In common with previous editions, the 2016 World Energy Outlook includes a '450 scenario'[2] which has a 50% chance of limiting the increase in global average temperatures to 2 degrees (IEA, 2016). In this scenario, the share of primary energy demand met by renewable energy increases to 27% in 2040 - an increase of over 3.5 times from the 2014 level. The most recent BP outlook report includes a similar Even Faster Transition Scenario in which 23% of global energy demand is met from renewables in 2035.

Some other assessments of the future are more optimistic about renewables growth. The IEA published a joint report with IRENA for the German G8 Presidency in 2017 (IEA and IRENA, 2017). This report explores two scenarios that are compatible with the Paris Agreement goal of limiting the average global temperature increase to 'well below 2 degrees'. The IRENA scenario specifically focuses on the extent to which energy

[2] The '450 scenario' refers to limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO_2.

efficiency and renewable energy can meet this goal. It therefore includes a much more ambitious share of renewables, which rises from 15% of global primary energy in 2015 to 65% in 2050.

This more optimistic future is echoed by some other assessments such as the Bloomberg New Energy Finance new energy outlook (BNEF, 2017). The 2017 edition of this outlook 2017 includes 34% of electricity coming from wind and solar technologies alone by 2040. For comparison, the IEA World Energy Outlook 450 scenario includes 27% of electricity from all renewable technologies by the same date.

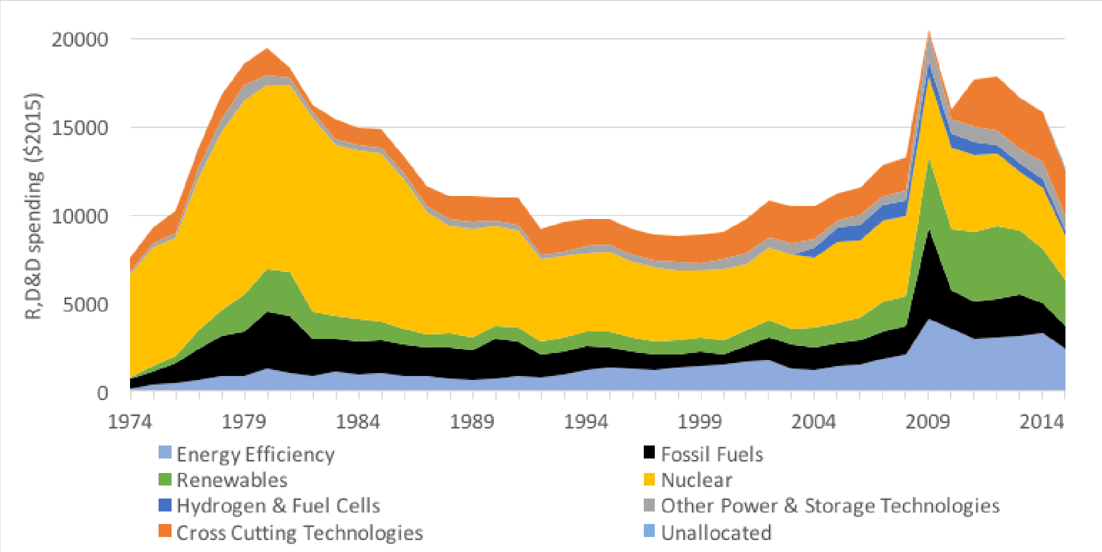
Many of these scenarios focus mainly on currently available technologies such as wind, solar and hydro - albeit with assumptions about further technological improvements and/or cost reductions. There remains significant scope for further innovation to reduce costs of these technologies, for example by increasing the size of offshore wind turbines or through new materials in solar PV. For example, Bloomberg New Energy Finance's most recent outlook projects a further 66% drop in the costs of electricity from solar PV by 2040 (BNEF, 2017).

However, even if these trends continue and the deployment of current technologies continues to grow, new technologies could have an important impact in the medium to longer term – not only in generating electricity, but also in providing renewable transport fuels and renewable heat. History shows that it can take decades for technologies to develop from early stage research to significant commercial deployment (Hanna et al, 2015).

Investment in research, development and demonstration (R,D&D) by the public and private sectors has been an important driver of renewable energy innovation, particularly since the oil price shocks of the 1970s. Figure 5 shows total R,D&D spending by IEA member country governments since 1974. It shows that for the early part of this period, the largest share of these public R,D&D budgets was directed to nuclear technologies. Renewable energy technologies, and associated technologies and vectors such as hydrogen and storage, have accounted for a larger share of these budgets in recent years.

A number of studies have made a strong case for increased levels of energy R,D&D investment by governments in future. In some cases, they have argued that budgets should be several times higher than current levels (e.g. Skea et al, 2013). Partly with this in mind, a coalition of over twenty countries formed Mission Innovation in the run up to the Paris climate change conference in 2015 (see section 5).

Figure 5: Energy research, development and demonstration spending by IEA countries



Source: IEA R,D&D Database.

Apart from improvements to established technologies, further innovation has the potential to commercialise less mature or less widely deployed renewable energy technologies including:

- Newer forms of solar energy such as concentrated solar power. A number of demonstration projects have already been constructed in Europe, the United States of America and North Africa.
- Wave and tidal energy technologies. These are diverse, with a wide variety of different designs. Countries such as the United Kingdom have spent significant resources of R&D, but they have not matured as quickly as some developers expected
- Geothermal energy. This is well established in a few countries that have relatively easy access to the resource – e.g. Iceland and New Zealand. Other countries such as Kenya have plans to expand their use of geothermal energy
- New wind power technologies such as floating offshore turbines or power kites deployed at high altitude
- More advanced biofuels that use non-food crops such as willow or miscanthus as feedstocks. They also include 'third generation' biofuels that use algae.

There is also a large emphasis on innovation in enabling technologies that can help to integrate variable renewables into electricity systems, including storage, smarter electricity systems that include the widespread integration of digital technologies and/or artificial intelligence, and technologies to increase the flexibility of energy demand. According to IRENA (2017a), the higher the share of variable renewable energy, particularly above 25%, the greater the need is for innovative solutions.

Electricity storage technologies are undergoing rapid development and cost reductions (IEA, 2016). This is partly driven by the growing market for electric vehicles, but also due to incentives for larger 'grid scale' electricity storage in some countries. In California, for example, the public utility commission has mandated that almost 2000MW of storage should be installed by utilities. It is important to note that storage technologies vary significantly in terms of their output, rates of charge / discharge and the length of time they can store energy for. Current battery technologies are unlikely to be sufficient to deliver large-scale seasonal storage - e.g. so that solar electricity can be stored in summer to heat buildings in winter. Therefore, there is also a need for advances in other types of heat or energy storage that can operate over longer timescales (IRENA, 2017c).

The use of renewable energy for heat and transport could also be facilitated though the use of hydrogen. Like electricity, hydrogen is an energy vector that needs to be produced. Low carbon hydrogen can be produced by steam methane reforming (e.g. using natural gas with carbon capture and storage), gasification of coal or biomass, or electrolysis of water (using renewable or other low carbon electricity technologies). Current estimates of hydrogen production costs indicate that electrolysis is relatively expensive when compared to other production methods such as biomass gasification and stream methane reforming (Speirs et al, 2017).

3. Innovation pathways to meet the challenges

This section provides a general overview of the challenges of renewables innovation, and how renewables pathways may differ between different countries. First the systemic nature of innovation processes is considered, which involves both technological and non-technological dynamics. Second, it follows from this that policy mixes are required in order to govern these processes. Third, because renewable energy systems exist within the socio-technical systems and economic contexts of particular countries and regions, it follows that different countries will have different resources available to them, and different priorities, and as such may make different choices as to the pathway of renewables innovation that they pursue.

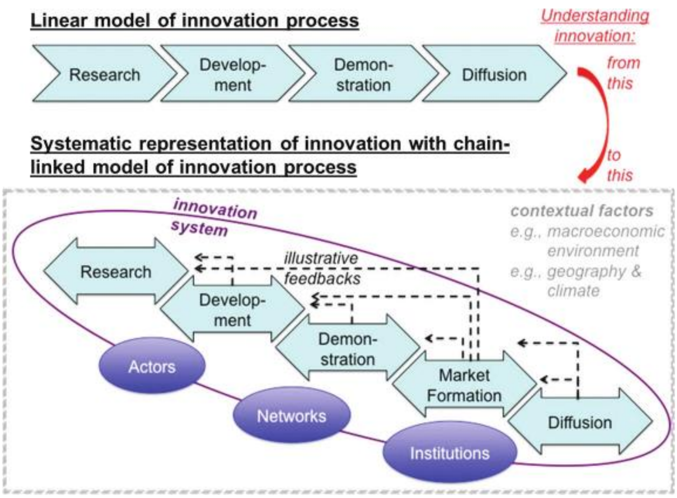
3.1 The systemic nature of renewables innovation

Early views of technological innovation presented the process as straightforwardly linear – beginning in research, moving through development and demonstration, and ultimately into diffusion, as shown in the top half of Figure 6. Whilst the essential features of this journey are still valid, accumulating evidence from studies of innovation processes reveals that the innovation process is more complex and dynamic than the linear model might suggest. In particular, as illustrated in the lower half of Figure 6, there are important feedbacks between different stages, for example as increased diffusion encourages or creates cash-flow for more investment in research and development. Further, the innovation chain occurs in a system context. Each stage in the innovation chain includes actors whose activities create the innovation dynamics, as well as economic activity, and who must successfully interact with each other in order for innovation to flow. There is also an institutional context, with for example formal institutions such as policies and market incentives, and informal institutions such as investment culture, and other practices and customs. Broader contextual factors such as the macroeconomic environment, geography and climate also affect the direction and success off innovation (Figure 6).

The scale and scope of innovation varies widely. Chris Freeman (Freeman, 1992) drew attention to the contrast between incremental innovations that lead to improvements in existing technologies, and radical innovations that yield new inventions and/or methods of production. Both types are relevant to the case of renewable energy. Whilst incremental innovation has important for the improvement of specific renewable energy technologies (e.g by scaling up the size of offshore wind turbines), more radical innovations such as the development of smarter, more flexible electricity systems can help to integrate variable renewable technologies in greater proportions or at a lower cost than was previously thought possible.

However, non-technological factors, such as the institutional and regulatory environment, are also a crucial part of the technological innovation story (as shown in Figure 6). Furthermore, non-technological innovations can also be significant to the diffusion of renewable energy. Non-technological innovations could include process and organisational innovations, social innovations, market and policy innovations, and business model innovations, such as the evolution from product based to service based models. This paper includes examples of several of these types of innovation.

Figure 6: The evolution of thinking on innovation processes – moving from a 'linear' model to a 'systematic' model



Source: Grubler et al. (2012).

3.2 The importance of policy mixes in governing innovation systems

There are some important implications of this model. One is that policies acting in isolation are likely to be less successful than portfolios of policies that account for each stage of the innovation chain, and for the contextual factors in which innovation systems are embedded. This includes the coordination of the actors, institutions and networks that comprise the innovation system, and the broader macroeconomic and geographical context. For example, in a review of Latin American countries, Banal-Estanol et al argue that it is through a combination of policies that electrification has increased coverage in Latin America (Banal-Estañol et al., 2017).

Recent literature on *policy mixes* includes a specific focus on their application to sustainable innovations such as renewable energy. For example, Rogge and Reichardt (2016) contend that the general literature on such policy mixes tends to be too narrow, with a focus on three features: strategic policy goals; interactions between individual policy instruments; and the need for a dynamic perspective to account for policy change. Based on a study of the policy mix for the German energy transition, they also argue that policy mixes for innovation need to take a systems perspective – and should take into account policy strategies that provide long term direction, policy processes that influence innovation and characteristics such as policy stability.

3.3 Different national renewables pathways

A further important implication is that renewables innovation systems are embedded within country and regional contexts, and as such will be enmeshed within particular contextual factors such as geographical and environmental conditions, macroeconomic conditions, socioeconomic and development priorities, cultural and institutional conditions, and policy and regulatory frameworks.

Some of these conditions are largely external factors which policy makers cannot change, but provide the boundaries or constraints within which renewables innovation must be managed. For example the geographical or environmental conditions which are an obviously critical factor in the availability of different natural resources, some of which could be used to derive renewable energy. Renewable energy policy has to take account of the natural availability of renewable resources. There may be also cultural factors within particular local contexts that must be taken into account.

Other conditions are more internal factors over which policy makers have a greater degree of control. For example, the policy and regulatory frameworks which apply to renewables can to large extent be managed and adjusted by policy makers and governments. In these areas there is significant potential to learn from the successes and challenges experienced by other countries. However, for some countries, there are clear limits to this due to constraints on the availability of finance from consumers, taxpayers or investors – and due to limits on institutional capabilities.

Other conditions have a greater bearing on the aims and priorities that policy makers have in attempting to deploy renewables. As discussed in Section 1, an expansion of renewable energy could have a positive impact on a number of goals. As well as delivering the global benefit of reducing or avoiding emissions of carbon dioxide from the combustion of fossil fuels, expansion of renewables can contribute to local or national level goals, such as invigorating industrial, manufacturing and commercial sectors associated with the production and deployment of renewables, and creating jobs as a result; increasing income generating opportunities for communities whose access to energy is hitherto limited or intermittent; increasing equality of opportunity for women and girls by reducing time spent gathering fuel, or increasing access to education; improving health through reducing indoor pollution or improving the provision of health centres for example through the refrigeration of vaccines; improving the productivity of agriculture for example by enabling pumped irrigation.

Thus, policy makers have different resources, constraints and priorities when it comes to deployment of renewables. For example, policy makers could choose to focus on the utilisation of domestic resources and of building up domestic industries and supply chains. Alternatively they could work with neighbouring countries to pool access to natural resources, and to internationalise supply chains to allow national specialisation according to comparative advantage. Policy makers may choose to focus on scale up of large scale renewable technologies connected to demand centres through extensive transmission and distribution infrastructures. Alternatively they could focus on decentralised small-scale energy technologies that avoid the need for transmission and distribution infrastructure – or a combination of centralised and decentralised approaches. The difference between centralised and decentralised approaches is not purely about the end-use energy service that is ultimately provided – they differ in terms of the wider socio-economic impacts of their supply chains, and in terms of the timing with which different benefits are received by different sectors of the population. As such, there is not one single optimal renewable deployment path, but rather a range of possible pathways. Choosing how to construct a renewables deployment pathway is not a one-size-fits-all exercise, but is rather dependent on a clear understanding of contextual factors and priorities.

In the following section we discuss a range of important considerations that are likely to be of significance, either as challenges or opportunities, in negotiating a renewables pathway. In each case we discuss country specific examples of how these challenges or opportunities are being addressed or negotiated.

4. Key issues in the innovation and deployment of renewables

In this section we focus on particular issues in the innovation and deployment of renewables. However, throughout each discussion it should be borne in mind that each of the issues is not isolated but inter-related with each of the others. As discussed in Section 3, renewables deployment involves an innovation system, comprising of technological as well as non-technological contextual factors, and this demands a mix of policies as nations identify the most appropriate renewables deployment pathway to their conditions.

4.1 Technical challenges: infrastructure, intermittency and storage

Energy systems are comprised not only of supply and demand technologies, but of infrastructures that connect them. Infrastructure is particularly significant in electricity systems, as even electricity generated close to demand requires a wire to transmit the power to the end use device, and in cases where generators are located distantly from demand, many hundreds of kilometres of power transmission lines may be required.

Such infrastructures are significant investments, and as such, once in place, have a considerable constraining and directing influence on the evolution of the supply and demand balance in the power system. They are thus highly relevant examples of the concept of 'lock-in' (Arthur, 1989; Unruh, 2000; 2002).

The future of the power grid infrastructure therefore becomes a major issue in countries that have historically invested in a power grid based around the locations of supply and demand in a largely fossil-fuel based system, but whose plans to transition to a renewables-intensive system means that the location of power generation will substantially change (Box 1).

Box 1: Adapting grid infrastructure for renewables

Germany's electricity transmission network is experiencing a challenge due to the fact that there is significant wind power potential in the north of the country, but major demand centres in the south. This means that deploying wind power in the windiest northern regions will entail a huge power flow from north to south during times of high wind and high demand. As a result, Germany's 'Energiewende' (energy transition) also includes plans to upgrade the grid infrastructure. There is a 10 year Grid Development Plan, which is revised every two years. Public acceptance of new transmission infrastructure is identified as a challenge, requiring participation and consultation to define routes. It has been decided to use underground cables for the 'electricity superhighways', which has improved public acceptance. However, this will come at increased cost, as underground cables are significantly more expensive per kilometre than overhead lines.

The United Kingdom also has a similar geographical challenge, as its prime renewable resources are located in more rural areas of the country which historically had lower capacity connections to the national grid, due to lower population and power demand. For many years, the country's National Grid company has used a forward looking 10-year grid development plan, the 'Ten Year Statement'. More recently, this has been complemented by an annual Future Energy Scenarios process to engage a range of stakeholders and to help identify potential upcoming network investment needs in a timely fashion. The challenge is to ensure that grid constraints do not hinder the deployment of renewables, whilst at the same time avoiding the risk of over-investing in network capacity that is ultimately under-utilised, because the generation actually built is less than predicted. The rapid growth of renewable electricity in recent years and the prospect of a rapid future adoption of electric vehicles has also led the regulator (Ofgem) and government to consider a range of regulatory and policy changes. These are designed to make the electricity system more flexible, and to encourage system innovations such as storage, demand side response and new business models.

Source: Contribution from the Government of Germany.

Other countries, like the United States of America, are also making efforts to modernise their grids. In the United States of America, the Department of Energy (DOE) has developed the Grid Modernization Initiative, with activities focusing on the integration of energy efficiency, renewable power, and sustainable transportation technologies into the electrical power system. The technologies and techniques required for successful grid integration include improved renewable power forecasting; energy storage technologies; advanced power electronics; "grid responsive" building technologies; vehicle-to-grid technologies; and new grid sensing, control, and operations approaches. The role of the DOE is to foster engagement and collaboration with and among industry, regulators, and other stakeholders.[3]

Some regions have particularly high potential for renewables, that if harnessed could exceed the demands of the country in which they are located. Further, the offset diurnal

[3] Contribution from the Government of the United States of America.

and seasonal timing of renewable outputs of different regions can mean that the renewable outputs of such regions could effectively complement each other, if they were linked up into an integrated cross-national network. In Europe there is interest in a European supergrid, extending as far as North Africa, which would pool the regions renewable energy resources (EEF, 2017). A part of Japan's Fukushima innovation coast framework is to expand power lines to gain access to wind rich areas (ANRE, 2017).[4] The success of such projects depends upon effective regional cooperation.

In China, the wind rich areas are distant from the main coastal demand areas, which presents an interconnection challenge. China has had problems with grid connection delays, and resulting curtailments to renewable produced power (Gosens and Lu, 2013). According to Gosens et al (2013), grid companies are now reluctant to purchase wind power because it is more expensive and intermittent.

In some countries, the lack of sufficient, or sufficiently reliable grid infrastructure is a major impediment to increasing electricity access. The lack of electricity infrastructure, especially outside of urban and semi-urban areas, is an issue raised in Uganda's Energy Policy (MEMD, 2002).

Even if grid infrastructure is present, grid reliability and losses can be major issues. Average losses in the South African Development Community (SADC) region for both transmission and distribution electricity networks are 19% (SADC REEESAP, p. 11, citing REN21, 2015 SADC Renewable Energy and Energy Efficiency Status report).[5] In comparison, the typical figures in the United Kingdom would be around 2% for transmission and 7% for distribution.

However, countries that do not currently have an extensive power grid, also have the opportunity to avoid 'lock-in' to grids not suited to renewables, and instead to design their new grids to be consistent with the system they wish to aim for in decades from now. Achieving this successfully will require careful consideration of future demographic trends, which will dictate future energy demands, and of the location of renewable resources. Again, a regional approach to this grid planning may enable countries to pool resources in a mutually complementary way. For example the Africa Clean Energy Corridor (ACEC), launched by IRENA, is trying to look at shared cross border resources and transmission lines (REEESAP p. 40). Another important option for countries without significant power grid coverage is to consider decentralised or micro-grid systems. These will be discussed further in Section 4.4.

The temporal balancing of renewables is also a major issue as renewables achieve a greater share of electricity generation. However, this depends on whether the renewable resources are variable or dispatchable. For example, Norway has for many years operated with a share of renewables in its power mix of higher than 95% - this is largely enabled by the fact that its major renewable resource is hydro, the output of which can be effectively controlled. Denmark has relied on decentralised combined heat and power (CHP) plants and interconnections with neighbours, especially Norway, to help manage high proportions of wind power. Hydro plays a significant role in

[4] Contribution from the Government of Japan.

[5] Contribution from the Government of Austria on the SADC Renewable Energy and Energy Efficiency Strategy and Action Plan (REEESAP).

Portugal's power mix, along with wind. Renewables now provide on average more than 60% of Portugal's electricity mix over a year, and there was a period in 2017 of six consecutive full days during which renewables provided 100% of the country's electricity.[6]

All of these examples show that systems are already accommodating high proportions of renewables. A recent United Kingdom Energy Research Centre (UKERC) report into the costs and impacts of intermittency finds that the costs of accommodating high proportions of variable renewables can be manageable especially in systems optimised with high levels of flexibility. Estimates of very high costs associated with variable renewables are typically due to assumptions of very inflexible systems.

As was discussed in Section 2, and concluded by the UKERC report, such increased proportions of renewables are likely to require attention to demand side flexibility, and renewables may stimulate innovation in supporting technologies. Smart grid technologies may have a key role in managing and shifting demand loads in order to help balance the variable output of renewables.

The IEA (2017) has indicated that here is an important potential convergence here of electricity systems with digital and information technologies. Such technologies may have a crucial role in enabling a system in which demands can flexibly respond to the conditions of the grid – for example responding to signals that renewable output is low by delaying flexible demands, to avoid putting pressure on the system; and conversely by responding to signals that renewable output is high by carrying out flexible demands at that time, to take advantage of the plentiful (and therefore cheaper) renewable electricity. Examples of demands which could be time flexible in this way could include washing machines – which could be programmed to run their cycle at the most optimal point during the day, provided the cycle is finished by a given time (say the end of the working day); or electric vehicles, which could be programmed to exert their charge during the most optimal hours, provided they have completely re-charged by morning. In 2016, the approximate investment on infrastructure and software for digitalization of the electricity sector in order to enable a more flexible network operation, accurate demand response management systems, and the integration of variable renewable energy resources was $47 billion (IEA, 2017). Digital infrastructure will be a key enabler to a smarter and more responsive electricity system. However, also crucial will be policy and market incentives that create the frameworks for such technologies to operate. There is no incentive for a consumer to allow devices flexible charging patterns if they are not rewarded by the prospect of seeking out lower cost electricity at times of over-supply – this means market structures that allow the price of electricity to vary over time (and potentially by location too). Furthermore, a smart and flexible grid will also require public engagement – the prospect of allowing personal companies access to high resolution data about personal energy using habits, and control over appliances, may raise privacy concerns.

Storage is also a key enabling technology. As discussed in Section 2.3 a range of storage technologies are in development, with applications ranging from small scale to grid scale, and for rapid discharge through to inter-seasonal storage. In rural and off-grid

[6] Contribution from the Government of Portugal.

contexts, a key supporting technology is battery storage, where the challenge is to reduce costs while increasing lifetime and robustness.

4.2 Market and policy challenges

As discussed in Section 3.1, the systemic nature of renewables innovation requires the creation of a clear market demand for renewables, but also a mix of supporting policies to stimulate research and development, coordinate actors and infrastructure, align regulations and incentives and mobilize funding.

As discussed in Section 2.3, it has often been the case that governments have played significant roles in funding, organising or driving early-stage research, testing and product development. This is because innovative products often are unlike any that currently exist in the market, or there is no market value for them, which means that revenues from the market are unlikely to be dedicated to such kind of research by private companies. Even if private companies can see the long term market potential of a certain piece of lab-scale technology, the experimental nature of this end of the innovation chain can make it too risky for private companies to invest in directly. Hence, government activities in either directly funding research, coordinating research activity, or presenting itself as a guaranteed and large customer for an innovative technology if it is successfully developed, can be critical.

One of the most well-known examples in the research and development end of renewable technology innovation chains is the Danish Risø National Laboratory for Sustainable Energy (see Box 2).

Box 2: The Risø test laboratory

The Risø test laboratory, was established in 1958 primarily as a nuclear power testing centre. However, in the 1970s it moved into wind turbine testing. The laboratory made a significant contribution in its sponsoring and acquisition of knowledge about early turbine designs, which then became a public asset. It conducted rigorous and independent tests, the results of which were made public for private actors in the Danish wind industry to benefit from. This meant that the most successful designs were proliferated much more quickly than would have been the case with individual companies working individually, meaning that the Danish industry as a whole moved quickly ahead of other national industries. (Grubb et al., 2014, Maegaard et al., 2013). Wieczorek et al. note that the Danish Riso National Laboratory for Sustainable Energy (and the Dutch Delft University of Technology) still excels in the number of journal articles per institute. The Danish turbine company Vestas is amongst the companies internationally submitting the highest numbers of patents (the others being the American GE and the German company Siemens). However, the authors note that knowledge produced by companies is often not patented or published.

Sources: Grubb et al. (2014); Maegaard et al. (2013); Wieczorek et al. (2015).

As shown in Figure 6, innovation systems include a range of activities, from product research and development, as already discussed, as well as manufacturing, construction, operation and maintenance. Each of these stages is populated by actors, who through their activities add value to themselves or the economy. Although such an innovation system could be contained within one country, there is nothing in principle problematic for an innovation system to be international, within which national-level specialisation occurs. However, from the national perspective, the weak points in a value chain may create vulnerabilities depending on socio-political factors. For example, Wieczorek et al (2013) examine the European offshore wind innovation system, observe that 'the United Kingdom does not have such a strong national industry and is very dependent on foreign actors to fulfil their national ambitions.' The authors continue by suggesting that 'a too strong dependence on foreign actors may result in a loss of legitimacy and political support, as domestic incentives for offshore wind primarily lead to the building up of an offshore wind industry abroad.' It might be added that while the manufacturers of offshore wind components are not primarily United Kingdom companies, nonetheless it is possible for them to locate manufacturing plants in the United Kingdom, thereby creating jobs in the United Kingdom, as Siemens and Dong Energy have started to do. In a later paper it is acknowledged that 'by using the domestic market and wind potential of the United Kingdom, foreign companies provide the domestic innovation system with access to foreign knowledge and skilled personnel… and contribute to national employment creation' (Wieczorek et al., 2015). However, emerging political issues could create further vulnerabilities for the United Kingdom in this regard – for example the effects on investment decisions of manufacturing companies if and when the United Kingdom leaves the European Economic Area. As such this aspect of the United Kingdom's innovation system may constitute a long term vulnerability. Given that the generation of wider economic benefit can be an important part of 'legitimacy creation' as discussed in Wieczorek et al, the lack of a domestic value chain may be seen as a risk factor in the United Kingdom's ambitions in deploying renewable energy.

International interactions within the innovation chain of a particular renewable technology can allow economic specialisation, resulting in efficiency benefits for all countries involved. It might also enable countries without a fully developed innovation chain to begin activities further along the chain – such as manufacturing and deployment – more quickly, if they can join in an international innovation chain and rely on capacities and capabilities of other countries with established activities further up the chain – such as fundamental research.

On the other hand, the internationalisation of the innovation system can create tensions given that competition is a key feature of international trade, such that the success of a sector in one country can spell demise for the same sector in another country. From the perspective of a particular country it is worthwhile to give some consideration to the balance between domestic and international activity in the innovation chain it aspires to develop and be part of. Each section in the chain is associated with different economic activities which add value to the economy in different ways. The greater the internationalisation of a country's innovation chain, the greater the potential risk of missing out on productive economic activities and resulting contributions to economic growth, from stimulating domestic activities.

For many countries there could be trade-offs, the balance of which may vary depending on whether a long-term or short-term perspective is taken. For some countries, the near-term priorities may be to provide energy access in order to improve peoples' health, well-being and opportunities for income-generating employment. The benefits of providing this access as soon as possible may present very compelling reasons for accessing international innovation value chains in order to use technology and IP already developed, so that technologies can be rolled out quickly, rather than waiting several years for the innovation chain to be built up domestically. On the other hand, a longer term perspective might consider the economic and industrial strategy of the country over decadal time frames, and might consider that building up more elements of the innovation supply chain domestically in order to provide this demand, would in the longer term release greater benefits for the economy as a whole, through employment creation and associated macroeconomic stimulus.

In general, then, for countries with plans to scale up deployment of renewable energy, it is worthwhile to consider what the balance between domestic and international actors will be in its supply chain, whether such balance will enable the country to sufficiently capture economic opportunities such as job creation and industry development, and what the effect of this balance will be on the broader political legitimacy and public acceptance of the deployment policies and targets.

One example of a country that has intentionally tried to increase its domestic presence within its supply chains is China (See Box 3).

Box 3: Wind power in China

Gosens et Lu (2013) identify 3 periods of wind power development in China (see Table 3 in (Gosens and Lu, 2013). The first, from 1985-2000, was dominated by government organised transfer programmes. Manufacturing of wind turbines started using foreign technology, and national teams were set up as joint ventures for Chinese engineers to be trained by foreign engineers. From 2000-2007 Chinese manufacturers emerged, sourcing turbine designs in private licensing deals with foreign companies. From 2007, leading Chinese firms have begun to develop their own ownership of turbine designs. This has either occurred in collaboration with foreign firms, or through the acquisition of a foreign designing company, or designs have been developed independently (Gosens and Lu, 2013).

A structure of targets and import taxes has been used to encourage domestic production, and reduce imports. This has encouraged manufacturers to seek domestic suppliers. However, in some cases foreign manufacturers have simply moved bases to China, to avoid the import taxes. A small number of high value components are still imported. For other components Gosens et al suggest that Chinese firms compete with lower quality but much lower cost. Strong competition has driven down prices but this has squeezed profits, which reduces R&D budgets (Gosens and Lu, 2013).

There has been rapid growth in wind in China – annual instalments doubling every year between 2003 and 2009. The Chinese domestic market has been the largest in the world since 2009. Until 2000 most turbines were foreign brands, but now 90% are Chinese brands. Per kW prices in China are 35-55% lower than in foreign markets, partly due to lower production costs but also because customers are more interested in quantity than quality. This is driven by the fact that the renewable portfolio standard is measured in kW of installed capacity, not kWh of energy. Long delays in grid connection have resulted in high curtailment – this also creates disincentive to pay for high efficiency turbines. Also wind resource-rich areas happen to be sparsely populated, making land prices low, which allows the industry to focus on larger numbers of smaller capacity turbines. The market is dominated by 1.5 MW turbines. Chinese exports are limited, partly due to this lower efficiency, which is an effect of its domestic market conditions (Gosens and Lu, 2013).

China has gone to considerable efforts to re-domesticate its wind energy supply chain, having begun from a position of government organised transfer programmes. However, even now, with many foreign owned firms it is not clear how truly 'domestic' the Chinese supply chain is. Policies to demand components only sourced from domestically owned companies would be against WTO rules.

Source: Gosens and Lu (2013).

The Chinese wind power case study presents an interesting example of a country starting from a position behind other countries, building up a supply and innovation chain with significant involvement of foreign investment and knowledge, but then over time trying to domesticate its supply chain. This follows a pattern of industrialisation that has been previously followed by other countries such as South Korea and Japan. Strategic intervention of government, with a view to building up supply chain and skills, was significant in the early stages, with the establishment of technology and knowledge transfer programmes. The case study also shows the importance of contextual factors involving actors, institutions and networks, and of feedbacks between different stages in the innovation chain. One notable feature is the role of market formation and of infrastructure in affecting the dynamics further up the innovation chain. A key policy instrument that creates domestic market demand for wind power is the renewable portfolio standard. However, due to the fact that this is measured in units of installed capacity, not of energy produced, it does not provide a direct incentive to maximise the quantity of energy produced from a given installed capacity. This is compounded by the fact that grid access is lagging behind the pace of turbine construction, which means that some projects experience delays in being able to produce energy and receive payment for it. These factors reduce the incentive for companies to invest in the highest efficiency turbines, and mean that the Chinese market is driven by a preference for low cost, even if this entails lower quality and lower efficiency. This in turn effects the ability of Chinese manufactured turbines to compete in the international market.

The solar PV innovation system is also highly international in nature, and China's role is significant within it. However, in this case Chinese manufactured products have been highly successful in reaching international markets. Demand for solar PV was driven by market incentives provided in a number of countries, including Germany (Box 4) Spain, France and the United Kingdom. Thus a number of countries were creating strong market demand for solar PV with very favourable incentives.

Box 4: Solar PV in Germany

Germany's investment in research and development of solar PV began in the 1970s initially in the context of the oil price shocks and a resulting desire to find alternatives to fossil fuel, and subsequently in the context of major accidents at nuclear power stations prompting an interest in alternatives to nuclear power (Jacobsson and Lauber, 2006). The R&D programme involved research institutes, universities and industry, and was supported by Federal and regional funding. As well as direct grant funding, further support was provided in the form of reduced interest loans, and public guarantees to secure bank loans. Production costs of solar PV in Germany decreased from $6.8 /Wp in 1992 to $2.9 /Wp in 2008. (Yu et al., 2016).

From the early 1990s Germany also acted to create a market for the technology, initially through subsidy schemes and 'soft loans' for rooftop installations, with the scheme broadened to include larger scale installations after a slow take up. (Polo and Haas, 2014, Yu et al., 2016). Germany introduced feed-in tariffs in 1990, in an early example of a market creation policy for renewable energy (Jacobsson and Lauber, 2006). The policy was reformed in 2000 with the implementation of the Renewable Energy Sources Act (Polo and Haas, 2014).

Sources: Jacobsson and Lauber (2006); Polo and Haas (2014); Yu et al. (2016).

Meanwhile China was focusing on developing a PV manufacturing industry (Box 5). In large part due to the activity of Chinese manufacturing, a rapid fall in the global cost of PV modules took place.

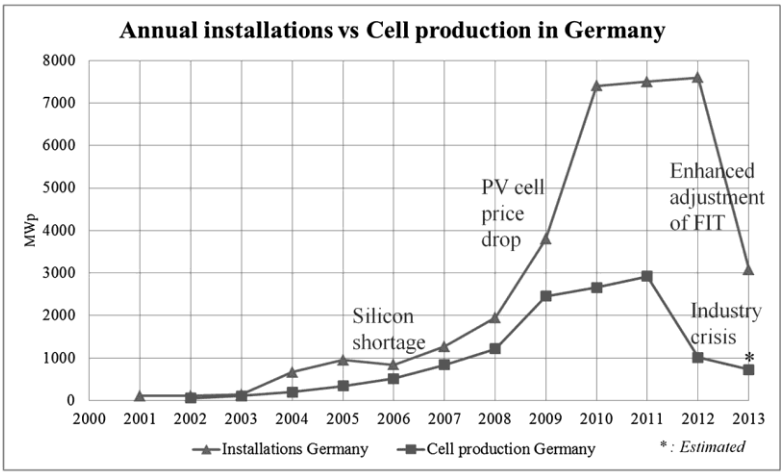
Box 5: Solar PV in China

As with wind, China did not start by owning designs, but focussed on labour intensive downstream manufacturing, rather than R&D. Low labour and energy costs enabled Chinese manufacturers to keep production costs low. During the 2000s China's approach to PV was production based and export driven, aiming at markets which provided strong PV incentives. China exported 97.5% of its modules in 2006 and 96% in 2009. It supported PV manufacturing through innovation funds, regional investment support policies, loans and 'easy credit'. (Yu et al., 2016). More recently China has begun to deploy solar PV at extremely large scale, as well as manufacturing.

Source: Yu et al. (2016).

This resulted in a rapid uptake of installations in Germany, as shown in Figure 7, as well as a similar story in other European markets that had feed in tariffs which now looked generous in relation to the much lower global market price for cells. In these countries, concerns about the spend on subsidies now being much greater than had been expected, led policy makers to substantially and suddenly reduce feed in tariff rates, or in some cases to suspend them entirely. This led to a boom and bust dynamic, where the domestic industries of some countries greatly reduced. Germany responded to the falling costs in 2008 by introducing a degression rate so that the 20 year fixed tariffs now decrease year on year. From 2009, the degression rate was adjusted according to the annual installed capacity (Polo and Haas, 2014). Figure 7 shows the effect on German installations of these measures, with a significant flattening out from 2010, and then a substantial fall in 2013. It also shows the effect on German domestic cell production, which dropped significantly from 2011. Germany's production of PV cells is now much reduced. However, it has still maintained capacity in other areas of the PV supply chain, such as production of inverters and other components used to manufacture PV cells (Hoppmann et al., 2014).

Figure 7: Annual installations and PV cell production in Germany, 2000-2013



Source: Yu et al. (2016).

These case studies describe a changing position of China in the renewables sector. Gosens et al comment that China aims to be 'a leading nation in innovation and scientific development by 2020 (State Council of P.R. China, 2012). Renewable energy, including wind power, was designated a 'strategic emerging industry' in 2010. Within these, China aims to 'seize the historic opportunity [..] to occupy a favourable position in future international competition'' (Gosens and Lu, 2013).

Thus, a number of internal policy drivers as well as international factors can contribute to the formation of supply chains related to renewable energy within a country. There are also important considerations to bear in mind in the way that renewable electricity technologies can impact upon the structures of the electricity market itself, and the policies that govern this. The operational characteristics of renewables can require different market designs appropriate to these characteristics. As discussed in Section 4.1, flexibility will be a characteristic of increasingly critical importance in electricity markets, the greater the penetration of variable renewable sources. For example, in Germany a new Electricity Market Act included measures to 'incentivise greater flexibility in the electricity system'.[7] As mentioned in Section 4.1, one way of using market signals to incentivise demand side flexibility is to allow the price of electricity to vary by time and location. This would send users a clear signal as to the true cost or value to the system of using, or not using, electricity at a given time and place, taking account of the generation on the system at that moment, and of any transmission constraints that may restrict the user's access to that power. Similarly, to increase flexibility in the system through market instruments, Japan has introduced measures to build 'negawatt' trading and virtual power plants (VPP) into the market – measures that place a value on demand response and load shifting as a means to help balance the system (ANRE, 2017).[8]

Such market structures are worth considering as a possible means of smoothing the transition towards high penetrations of variable renewables within electricity systems.

[7] Contribution from the Government of Germany.
[8] Contribution from the Government of Japan.

Germany's Electricity Market Act also aims to 'integrate the electricity market more strongly into the European internal market – cooperation with neighbouring countries to achieve energy security at a better value on a European basis'.[9] Integration with neighbouring electricity system is also a useful strategy to increase overall system security, and to smooth and balance out renewable outputs in different geographical regions. The EU as a whole is aiming towards an integrated electricity market, which could increase the potential of the region as a whole to balance a large portfolio of renewables (Wieczorek et al., 2015).

The challenges of promoting renewables have uncovered a process of policy learning in relation to the most appropriate forms of market incentives to provide for renewables. REN21 (2016) found that at the end of 2015, the policy mechanism most frequently used to promote renewable energy was the feed-in tariff, having been adopted by 110 states, provinces or countries. The feed-in tariff guarantees a fixed price per unit of electricity sold over an agreed period of time. This is an attractive form of price support for renewables which are typically dominated by high capital costs, and then would otherwise have to compete in a market in which prices were set by fossil fuel generators – which would represent a risky investment proposition. Bulgaria, Germany, Hungary, Japan, Kenya, Portugal, Spain, Turkey and the United Kingdom are amongst the countries that have used feed in tariff based approaches.[10]

A clear risk of the feed-in-tariff however is that the government could lock itself in to paying too much for a given technology. In this context, the success of tendering or auction based approaches to identifying the price for renewable energy contracts in delivering substantial cost reductions in renewable energy, is a very significant story in recent years. By the end of 2015, 64 countries had held tendering rounds for renewable technologies (REN21, 2016), with noticeably low prices for solar PV being achieved in countries such as Mexico and Chile (Levey and Martin, 2016). Since then, a number of countries, including Portugal, Germany, Japan and the United Kingdom have revised their allocation of contracts or tariffs to be delivered on an auction basis. Recent auctions have continued to discover low prices in a range of technologies, as for example shown in the case of Figure 8.

A number of other actions by government can contribute to a supportive policy environment for renewables. One important element is to create confidence in a clear, long-term direction of travel for the industry. One example of this is Germany's Energiewende, or energy transition. 'The Energiewende is our overarching goal, and our pathway into a future that is secure, environmentally-friendly, and economically successful.' It includes the following energy-related targets for 2050: 80-95% reduction in CO_2 emissions; at least 80% renewables in electricity, 60% renewables in energy overall; 50% reduction of primary energy consumption. It is noted that these kinds of targets are essential to provide 'a long-term basis for planning and investment for stakeholders'.[11] Another example is the United Kingdom's overall target for reducing greenhouse gas emissions by 80% from 1990 levels by 2050.

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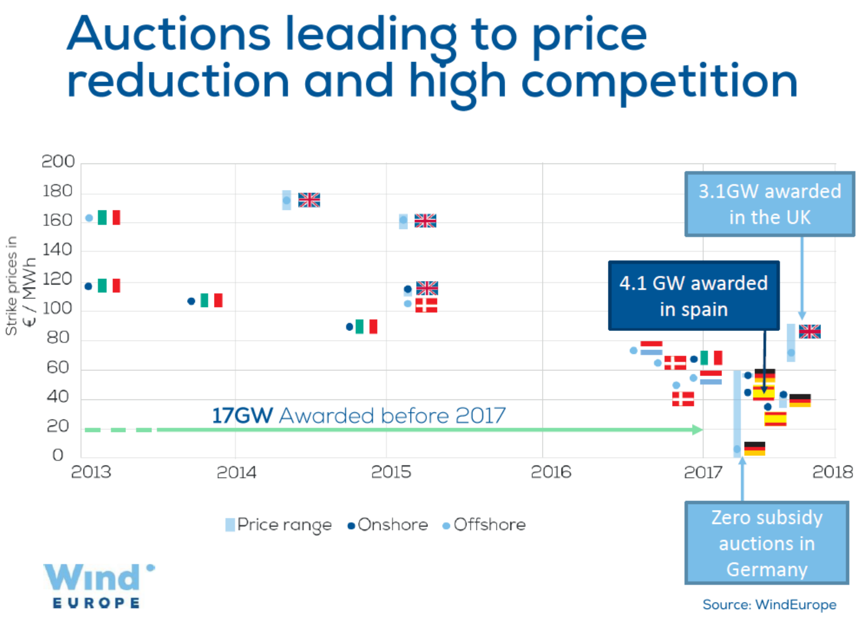
[9] Contribution from the Government of Germany.
[10] Contributions from the Governments of Bulgaria, Germany, Hungary, Japan, Kenya, Portugal and Turkey.
[11] Contribution from the Government of Germany.

Figure 8: Strike prices and capacities awarded for wind energy contracts in Europe



Source: Wind Europe.

However it is important that the goals are credible. A good way of demonstrating this is to include more detailed measures, or sub-targets, that can be used to demonstrate that progress is on track. For example, 'to meet the challenges ahead of us, the German government has developed a '10 points energy agenda' at the beginning of this legislative term…'.[12] Equally, the United Kingdom's 2050 carbon target is broken down into a series of five-year 'carbon budgets', which must not be exceeded in each five-year period, ensuring that genuine progress is being made, consistent with the long term target.

Other kinds of legal regulatory frameworks are also a key part of the supporting architecture for encouraging and enabling investments in renewables. These are crucial to ensure, for example, that investors have the confidence in the processes by which applications to construct power projects are considered, and how applications to connect to the grid are managed. They also need to have confidence in the transparency and stability of any payment support framework. Uganda's Scaling Up Renewable Energy Program Investment Plan identified barriers to deployment of renewables as inadequate regulatory, legal and institutional frameworks, including inadequate licensing for geothermal resource exploration (Uganda, 2015).[13]

The relative roles of the private sector and the state within the energy system is an issue that policy makers continue to grapple with. Latin American countries have been notable in their early activities with the privatisation and liberalisation of their energy systems. Macro-economic fluctuations in the 1970s and 1980s left many Latin-American countries with minimal ability to invest in public services including the power sector. This provided an incentive to privatise and liberalise the power systems. This was further encouraged by the tendency of World Bank loans to be made conditional on

[12] Contribution from the Government of Germany.
[13] Contribution from the Government of Uganda.

privatisation and liberalisation. In reviewing this period, Banal-Estañol et al (2017) suggest that the measures did improve quality of service and an increase in generation capacity. However, the measures did not necessarily extend coverage of the population – for private investors there was a clear incentive to focus on urban areas where there were higher income customers and greater economies of scale. Consequently, some LA countries, such as Bolivia and Venezuela have partially reversed these policies with renationalisations. In other countries, lack of investment in rural areas has prompted the development of specific rural electrification programmes (Banal-Estañol et al., 2017).

This experience, as well as other historical evidence suggests that the activity of the private and the public sector can have advantages in different ways and at different times. Private sector entrepreneurship can fuel greater creativity and innovation, and can in some cases leverage greater investment resources. Box 6 provides an overview of the different roles public, private and institutional investors can play in financing renewable energy.

Box 6: Changing landscape in financing renewable energy

Public finance institutions: Renewable energy has often had to rely on public finance institutions particularly in early stage project development. Public finance instruments are usually in the form of grants, subsidies, guarantees to facilitate renewable energy projects which are too risky for private sector support. For example, the South African government through the Renewable Energy Public Procurement Programme (REIPPP), has provided guarantees to power purchase agreements between its state own utility Eskom and independent power producers (IPPs). More recently, public finance instruments are being used as tools to crowd in' private capital (IRENA, 2016). These include:

- **International financial institutions** are usually multilateral development banks that are increasingly playing a leading role in renewable energy projects. These include the World Bank Group, the Asian Development Bank (ADB), the European Investment Bank (EIB), the European Bank for Reconstruction and Development (EBRD), the African Development Bank (AfDB), the Inter-American Development Bank (IDB), the Asian Infrastructure Investment Bank and the New Development Bank. As an example, the IDB, are providing loan guarantees in Mexico geothermal financing and risk transfer programme.
- **Development Finance Institutions (DFIs)** are usually bilateral development agencies, these AFD (the French Development Agency), KfW (the German Development Bank) and JICA (the Japanese International Cooperation Agency). Also, national development banks are key actors within individual countries, examples are: Brazilian Development Bank (BNDES), and the South African Development Bank (DBSA).
- **Climate finance institutions** are intermediary actors which mediate the implementation of donor funds towards developing countries initiatives. Examples include Global Environment Facility (GEF), the Climate Investment Funds (CIFs) and the Green Climate Fund (GCF).

As renewable energy projects are increasingly an attractive source of investment new capital markets instruments are emerging.

Private investors - new capital market instruments such as Green Bonds: Green bonds are gaining prominence as innovative mechanisms attracting finance for renewable energy projects in emerging economies. Green bonds are any type of bond instrument to fund projects with positive environmental and climate impact. They can be used to raise large-scale long-term financing from non-bank sources and at relatively low cost. According to IRENA (2016), nearly half of $41.8 billion green bond proceeds were invested in renewables. In 2016, more than $62 billion of green bonds were issued in the first 10 months (IRENA 2017). Despite the rapid growth, green bonds accounted for merely 0.3% of all bonds outstanding in 2015 (CBI and HSBC 2015). Green bonds have proven to have an important role in emerging economies, notably in India and China. In India, for example, first labelled green bonds were issued in 2015 by Yes Bank in February 2015. The India Rupee Linked Bond had $161.5m dedicated to financing renewable energy projects. In 2016, the Export Import Bank of India and the Industrial Development Bank of India issued a larger $500m green bond targeting renewable energy and transport projects.

Institutional investors – pension funds: Institutional investors are a major potential source of capital for renewables. The most active institutional investment in renewable energy has taken place in Europe reaching $7 billion in 2015 (BNEF 2016b). Institutional investors, notable pension fund, from developed economies show increasing interest in investing in developing countries. For example, three Danish pension funds (PensionDanmark, PKA and Lægernes Pension) joined forces with transport and logistics company A.P. Møller to launch a new infrastructure fund to invest in energy and transport projects in Africa. The four seed investors in Africa Infrastructure Fund I together committed USD 550 million (EUR 466 million) (Fixsen 2017).

Sources: CBI and HSBC (2015); contribution from the Government of South Africa; Fixsen (2017); IRENA (2016, 2017a).

On the other hand there are areas where the private sector is less well equipped. One example is the provision of public goods which are not immediately profitable, such as increasing energy access in rural areas, as discussed above. Situations where overall system performance would be improved through shared infrastructure can also leave private sector actors struggling with inefficient solutions, and requiring state-led coordination. Natural monopolies need careful regulation, and state involvement needs to ensure their regulation is in line with public policy priorities. As also noted above there is also a significant role for the state in supporting and coordinating R&D. As explored in Box 12, public sector coordination private actors has also helped to accelerate innovation by enabling mutually beneficial learning to take place between actors who would normally be competitors.

In general, even with significant private sector activity, there is an important role for government to provide legal and regulatory structure, which both ensures that private sector activities are being directed in a way beneficial for society, and provides clarity and confidence to private sector actors themselves. Banal-Estañol et al suggest that a significant element in the success of Latin America in increasing electrification has been the role of independent regulatory agencies providing 'policy stability and transparency', alongside the role of the private sector (Banal-Estañol et al., 2017). Governments can also play an important role in addressing situations where private sector investment is not occurring due to commercial risks. These and other important types of government intervention have been important lessons learned from Uganda's first rural electrification strategy and plan (Box 7).

Box 7: Lessons learnt from Uganda's first rural electrification strategy and plan

The Government of Uganda had its first Rural Electrification Strategy and Plan (RESP) for the twelve-year period of 2001-2012, and its second plan for 2013-2022. During this 10-year planning period, the Government's strategy is to achieve a rural electrification access of 22% by 2022 from the level of about 5% in 2013. When preparing the second Rural Electrification Strategy and Plan, Uganda made several conclusions that were derived from a systematic analysis conducted at the end of the first RESP. These include:

Rural electrification development needs to accelerate by adjusting the model. The simple fact is that the underlying economics of investing in electricity infrastructure in areas where people are poor and industrial development has not taken root bears considerable financial and commercial risk. The original model created a mismatch of short-term profit interest in a business that takes decades to develop. It is rather the other way around – government must lead, use patient and lowcost capital financing, build the initial organizational and infrastructure capacities for electricity services, promote electrification-related economic development and supportive measures to spur rural modernization and income growth. Thereafter it becomes feasible for private investors and commercial financing to take over.

Second, underlying renewable energy business risk should be addressed with appropriate solutions. Experience with the first RESP showed that the key risk factor that inhibited rapid expansion was commercial risk. New approaches were needed for the effective marketing of consumer electricity service to aggregate and build demand; for lowering barriers to rapid accumulation of customers and to increasing energy use in productive activities; and for enforcing discipline at the renewable energy "cash register" – commercialization functions, including policing electricity and materials theft. Local models such as cooperatives, if correctly developed and supervised, give the beneficiary populations and consumers direct responsibility for these things. The peer interest principle can work wonderfully in terms of making sure people are treated fairly and the service providers and customers alike live by the same rules.

Third, it needs to be ensured that the program scale was feasible. The previous set of rural electrification providers were struggling because they were too small. They were given the areas that are predominantly domestic and do not have the ability to balance this rural household customership with more developed service areas. Under the previous arrangement, it would take many years for these service areas to be viable, and in the interim, the costs felt by the consumers would be unaffordable and the consequent need for operating subsidy would extend far into the future. In short, the rural service territories must be sufficiently large to generate revenue levels as needed to meet service providers' financial cost requirements including cost of capital investment financing.

Fourth, planning and management for the renewable energy sector should be centralised and program implementation be simplified. The previous program was being implemented in a disaggregated manner with many players acting in overlapping and insufficiently coordinated roles. This flowed from the original "demand-response" model that assumed government would not need to plan and orchestrate renewable energy development, but merely top-up the capital needs of private sponsors, who would do all the planning and implementation management. Rethinking the model meant re-ordering the way the sector is planned and resources are allocated. The best way was to centralize authority in the lead entity responsible for the renewable energy sector and ensure that electrification is carried out in harmony with the broader scope of national economic and social development planning and that the rural aspect of the nation's electricity infrastructure development is adequately coordinated with the other power sector functions and entities.

Finally, there was a need to plan for long-term sustainability. The previous program did not dispose adequate planning and coordination of resources. It also implied an indefinite term of providing subsidy. Long-term program sustainability means developing internal mechanisms for financing and assuring that all other major functional requirements of rural electricity service and rural utility sustenance can, in time, be addressed independently of government support. The key features of the strategy and plan for the new ten-year period should guarantee that the program is put on a path to self-sustaining viability.

Source: Contribution from the Government of Uganda.

4.3 Extending electricity access – grid, mini-grid and off-grid solutions

Extensive electricity transmission and distribution networks, providing electricity access to the whole population, are common features of energy systems in developed countries. These infrastructures were developed during the last century, typically over several decades. In developing countries electricity access often remains much less extensive. The number of people in the world without access to electricity was 1.1 billion in 2016. This is 14% of the world's population, 84% of whom live in rural areas. In developing countries in Asia, 89% of the population have access to electricity, in the Middle East the proportion is 93%, and in Latin America 97%. In sub-Saharan Africa the rate of electricity access is 43%.

Increasing electricity access makes a critical contribution to the Sustainable Development Goals. One important contribution is by improving standards of education in schools and enabling greater study time in homes. IEA (2017) cites a range of evidence suggesting that access to electricity can also increase gender equality, for example increasing the likelihood of girls finishing primary school, increasing the incomes of self-employed women, and increasing employment opportunities for women by increasing the efficiency with which household tasks can be completed. The IEA also notes evidence that 'there are significant advantages in involving women from start to finish in the design of modern energy access technologies and programmes, and empowering women to become more involved in the provision of energy services' (IEA, 2017).

Electricity access is also crucial to health care provision, for the operation of medical devices and the storage of vaccines. Almost 60% of health clinics in sub-Saharan Africa have no access to electricity (SE4All Africa Hub, 2014, in IEA). Amongst health clinics with electricity access, it is estimated that 60% of refrigerators in health clinics in Africa are not provided with reliable electricity causing loss of almost half of vaccines, and 70% of electrical medical devices in developing countries fail, with poor power quality a significant contributing factor (UNEP, 2017; WHO, 2010 in IEA).

Electricity access can create new income generating opportunities and increase the productivity of existing activities. Sustainably managed irrigation can bring about a significant in agricultural yields, and electricity access is often needed to pump and move water. The use of electricity to drive mechanisation help to reduce losses in processes such as milling, and can also enable farmers to add greater value to their product before bringing it to market, for example by drying grain, de-husking rice or processing tea leaves (IEA, 2017).

Electricity access also assists the productive activities of shop owners and other businesses. Industrial activities may require higher power loads, hence can be 'anchor loads' to stimulate the extension of grid services which are not always viable for smaller demands, with domestic and small business connections following on (IEA, 2017).

Progress in increasing electrification is being made. The global total of 1.1 billion without electricity access in 2016 had declined from 1.7 billion in 2000, mainly due to the construction of fossil fuelled power plants and the extension of the grid. China achieved full electricity access in 2015. India has also made rapid progress in electrification in recent years, with electricity access rising from 43% of the population in 2000 to 82% of the population now. The Indian government has focussed on grid extension, and this has been the means by which almost those gaining access to electricity since 2000 have been connected. However the government published a draft mini-grids policy in 2016, which could help promote decentralised renewable energy (IEA, 2017).

Globally, from 2000 to 2012, 72% of the increase in electricity access was provided by fossil fuel generation, the remaining 28% coming from renewables, mainly hydropower. Since 2012 the contribution of renewable sources to electricity access has increased to 34%. The vast majority – 97% - of new electricity access worldwide since 2000 has been delivered by grid extension. Decentralised technologies currently account for less than 1% of those with access to electricity in developing countries (IEA, 2017).

Decentralised electricity solutions can take a number of forms. Small, off-grid systems for example comprised of a solar panel, battery and small appliances such as LED lamps, are relatively affordable and easy to install. Such 'pico' systems represented 94% of all off-grid solar sales in 2016. Such systems can provide valuable improvements to users' way of life, especially if the lighting provided is displacing unhealthy and dangerous lighting sources such as kerosene lamps. However they have limited potential beyond such basic applications, and the operation of loads such as refrigerators or televisions, or for the provision of loads for productive activities, would require larger arrays (IEA, 2017).

Larger off-grid generation sources could be harnessed through arrays of PV panels, wind turbines, or small to medium scale hydro (Box 8 and 9). The integration of several sources within a small network of loads would constitute a mini-grid. Such system would require a developer who would need to be able to see a clear return on investment. An enabling regulatory framework would also be required – for example, if and when the national grid arrives to the region, under what terms the mini-grid would be integrated into it (IEA, 2017).

Box 8: Harnessing the potential of micro-hydro power plants in the Democratic Republic of the Congo

In the Democratic Republic of the Congo (DRC), only 9% of people had access to grid electricity in May 2016. The lack of electricity in rural areas has forced people to use a variety of energy sources, including firewood, kerosene, charcoal, diesel for generators, vegetable oils and plant residues. The reliance on ligneous fuels (such as wood, charcoal and plant residues) for the basic energy needs was a major driver in destruction of the forests and the rise of GHG emissions.

The exploitable hydropower potential in the country is estimated to be in the order of more than 700 TWh/year or 66% of Central Africa's potential, 35% of the whole of the continent's, and 8% of the world's hydro potential. This is equivalent of 100GW expressed as firm power capacity. There is a considerable gap, however, between the potential and the reality on the ground: less than 3% (or 2.6GW) is currently being exploited, mainly via large Inga Dam (2.4 GW). The plans to construct a new mega dam on the Congo River (Inga 3 project) are still at blueprint stage and have met with technical, financial and political obstacles, as well as international criticism pointing to negative environmental and social impacts the project.

Developing decentralised micro and micro hydropower (MHP)-based mini-grid systems emerges as an economically viable, environmentally sustainable and climate-friendly power supply alternative to harness abundant hydropower resources of the country, especially in its remote and rural areas. The development and implementation of MHP is expected to benefit vulnerable groups by reducing their dependency on the expensive imported and polluting fossil fuels. MHP will also reduce the demand for biomass obtained from the local forests as well as cut pollution and greenhouse gas emissions.

In its Intended Nationally Determined Contributions to the UNFCCC, the government of the Democratic Republic of the Congo put rural and urban hydro-electrification as a top priority to achieve its 2030 GHG emission reduction goal. The country aims at installing 650 MW of power generation capacity through micro, mini, small, and medium scale hydro power plants, 8 to 10 sites with a budget of $1/W for power plants plus $1.35/W for electricity distribution grids.

Recognising this potential, the government requested the Global Environment Facility (GEF) to finance a project to promote investment in MHP-based mini-grids for rural electrification in the country. The project entitled "Promotion of mini- and micro-hydro power plants in the Democratic Republic of the Congo" is implemented within the framework of the "Sustainable Energy for All" initiative (SE4ALL) launched by the Secretary General of the United Nations (UN). The country joined in December 2012 at the SE4ALL Initiative with a national agenda and a strategy.

The GEF contributed a total $3,187,669 grant for the project and leveraged $14,150,000 of co-financing. The project covers four areas: (1) policies and a regulatory and institutional framework for private and community-based investments supplied by small scale hydropower; (2) reinforcement of the technical capacities in the technological supply chain; (3) pilot investments in selected mini-and micro-hydropower stations in rural areas; and (4) communication, management, public relations and promotion of investment.

The project is expected to lead the development and construction of 39 microgrids using hydro power technologies with a total installed capacity of 10MW. It will provide electricity for over 200,000 homes in the poor communities of the Democratic Republic of the Congo. The project will likely avoid nearly of two million tonnes of $CO2$ equivalent.

Sources: GEF (2012 and 2018).

Box 9: Pico hydro plant in at the Rwenzori Mountaineering Services in Uganda

The Rwenzori Mountaineering Services (RMS) is a community based nongovernmental organization owned by 1500 members of indigenous Bakonzo people. Among its activities, RMS operates a mountain camp at the foothills of Rwenzori Mountain in Western Uganda. Previously, the mountain camp used a diesel generator which was very expensive to operate and maintain, was noisy and provided electricity for 3 hours per day only.

The Private Sector Foundation Uganda (PSFU) in partnership with RMS developed a pico hydro power plant of up to 5 KW. The project was implemented by the Centre for Research in Energy and Energy Conservation (CREEC). RMS contributed up to 40% co-financing so there was ownership, with additional funding from the World Bank's Energy for Rural Transformation Project, which aims to improve the productivity of rural enterprises as well as the quality of life of households in Uganda.

Implementation included civil works and installation of a cross flow turbine and an induction motor. Two features of the pico-hydropower scheme are the use of equipment sourced from within the East-African region and the local capacity building component. The turbine was manufactured at the University of Dar es Salaam (Tanzania) and other materials were locally sourced. The plant is locally managed and operated by RMS staff trained specifically for this project. In addition to that, the technical skills of five university students, one graduate student and two local companies were developed.

The pico hydro scheme commenced operations in August 2013. The project has attracted considerable number of visitors from other communities, schools, and researchers in the Rwenzori Mountains to learn more and appreciate this decentralized electricity generating plant. The plant put renewable energy into productive use and replaced the expensive diesel generator previously used. It increased access to electricity for the tourists to power their gadgets. Savings from the replacement of diesel with a renewable energy source led to the diversification of services through charging services.

Source: Contribution from the Government of Uganda.

Whether grid-based or off-grid, affordability is a major challenge to increasing access to electricity. Even if grid access is available, high connection charges can limit the ability of poor rural communities to connect to the grid.[14] Although the development benefits are appreciable, and in some cases urgently needed, many rural communities 'live below the poverty line and lack access to other basic services, such as roads, safe water and telecommunications that might act to spur their development. This means that electrification strategies there cannot rely on market solutions.' (Banal-Estañol et al., 2017).

There is contrasting evidence as to whether grid or off-grid solutions are preferable. A grid based approach would typically involve strong government involvement either via a state owned utility, or as public-private partnership delivered in the public interest. However, this kind of top-down approach can take time to reach the whole of society. In such situations, it is possible that off-grid renewables may be able to provide access to electricity to communities faster than grid electrification can manage. In some cases grid access may be available, but the power quality remains intermittent or unreliable. In such cases off-grid options may offer an improved service.

[14] Contribution from the Government of Kenya.

Nonetheless, Bhattacharyya and Palit (Bhattacharyya and Palit, 2016) observe that off-grid projects can suffer from negative perceptions from consumers. In many cases off-grid electrification continues to be seen as a temporary stage until grid electrification can be achieved. With limited capacity and hours of use, the demands met by such projects are often limited to some lighting and use for entertainment from TV and radio – productive income generating activities are often not encouraged or achievable through such projects. Such projects can thus be perceived as 'inferior' and 'temporary', creating perceptions of 'isolation' and 'discrimination' for users (Bhattacharyya and Palit, 2016).

There is mixed evidence as to the relative cost-effectiveness of off-grid compared to grid based solutions. Some have argued that off-grid solutions can be a more cost-effective way of increasing energy access in remote rural areas, because they would avoid the additional costs of extended electricity distribution infrastructure. However, in a review of off-grid solar PV in sub-Saharan Africa (SSA), Baurzhan and Jenkins (2016) find that the costs of PV are significantly higher in SSA than the global average, due to 'political, financial and technological risks'. On the basis of this conclusion, they suggest that grid expansion is preferable to off-grid solar in sub-Saharan Africa. In contrast, in bottom-up case studies of four communities in Togo, Practical Action (2016) find that 'in all cases decentralized systems are cheaper than grid extension'. Further, in analysis of its Energy for All scenario, IEA finds that three quarters of the additional investment required above current policies to achieve universal electrification in sub-Saharan Africa would be most cost effectively achieved by off-grid solutions. On the basis of this contrasting evidence it would be safest to say that the relative cost effectiveness of grid compared to off-grid solutions can vary and must be considered in context. However, it might also be observed that the risks factors that Baurzhan and Jenkins (2016) cite as contributing to increased costs of PV in SSA, might all be amenable to reductions through strong and stable policy frameworks.

Grid based solutions would typically involve the upfront investments in infrastructure being paid for by the government or utility and spread through customer bills. As such, the upfront cost to any individual customer willing and able to connect would be relatively low – a small connection charge followed by running costs. For off-grid projects, the upfront cost may be a more significant issue, as there is no wider customer base over which to spread it. Low-income communities may be unable to pay upfront for the investments required, and investors may be equally unwilling to invest in low demand communities where the return on investment is uncertain. A range of business models may be available to try and bridge the gap between investor and customer. Banal-Estanol et al identify three business models for attempting to increase electrification: the dealer model, the concessionary model and the community-led model (Banal-Estañol et al., 2017). Each requires different combinations of financing and capacity building to be successful, and each is dependent on the energy intervention being sufficiently beneficial to the community, including in terms of income generation, to be perceived as sufficiently valuable and thus financially self-sustaining. Micro-financing and pay-as-you-go models are also approaches that would enable users to spread out upfront costs. In all cases, Bhattacharyya and Palit argue that mobilisation of funds and identification of appropriate financing instruments are key (Bhattacharyya and Palit, 2016).

From the investor perspective, a challenge can be the low expected returns on low density, low demand users. For this reason private sector investors are not always interested in remote off-grid applications (Bhattacharyya and Palit, 2016). One approach to address this issue could be clustering and bundling of projects may help to achieve scale up – however this requires organisational capacity (Bhattacharyya and Palit, 2016).

Local support, training and capacity building are key – a local 'eco-system' has to be developed for supporting the off-grid system (Bhattacharyya and Palit, 2016). Mandelli et al (2016) suggest that while the cost of off-grid solutions may not always be competitive with grid extension, the potential benefits to local development can be greater. One example of this is the Southern Africa Solar Thermal Training and Demonstration Initiative (SOLTRAIN), started in 2009 with funding from the Austrian Development Agency and the OPEC Fund for International Development. This initiative aims to increase the deployment of solar thermal technologies, but also to build capacity and training to support these systems. Since 2009 it has raised awareness and built competencies in Lesotho, Namibia, Mozambique, South Africa and Zimbabwe. During its first two phases (2009-2016) 187 small to large scale solar heating systems were installed, and 2,150 people trained. In the third phase a particular emphasis will be placed on demonstration projects in organisations that support women and other marginalised groups (REEESAP p. 39).[15]

In rural energy applications, the effectiveness of training and capacity building can be enhanced by taking into account the socio-economic context, including gender issues. One possible outcome of training engineers in rural areas in the maintenance of renewable energy systems, is that with the new skills they have acquired they will be tempted to migrate to the cities in search of more lucrative work. This may of course constitute a success story from the perspective of the individual concerned, however it can result in the rural energy system falling into disrepair and disuse. Even in 'dealer' or 'concessionary' models, there are also issues with maintenance, as the companies or dealers that install the technologies do not always provide maintenance or offer training in maintenance to communities (Banal-Estañol et al., 2017). Partly in response to this, the Barefoot College's International Solar Training Program takes an imaginative approach to capacity building in rural areas. Its trainees are often the grandmothers of the village, who 'maintain strong roots in their rural villages and play a major role in community development', and are thus often the most effective people to train from the point of view of the sustainability of the project. Banal-Estañol et al (2017) emphasise that implementation of training alongside renewable energy installations requires good social and political understanding of how the community works (Banal-Estañol et al., 2017).

Opportunities for linking with rural development and livelihood activities should also be carefully considered (Bhattacharyya and Palit, 2016). Some have suggested that communities can become dissatisfied with small scale renewable energy interventions if they do not have sufficient output or reliability to power machinery that can provide economic activities and income generation (Banal-Estañol et al., 2017).

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[15] Contribution by the Government of Austria,

A robust governance structure, clear regulatory environment and enabling policy environment are crucial. Measures to overcome barriers to private sector led investment in small scale renewable energy projects may include standardising the licensing procedure, and providing an off-grid tariff; providing risk guarantees for commercial banks; improving technical training (Kakooza et al., 2014). REEESAP (p. 37) report that Tanzania has been successful in promoting off-grid solutions, using innovative power purchase agreements (PPAs). Bhattacharyya and Palit emphasise the importance of a stable regulatory environment and agreeing tariffs which are acceptable both to users and investors (Bhattacharyya and Palit, 2016). Khodayar (2017) adds that microgrids would require 'a concrete business model to engage the communities, set appropriate tariffs that are comparable with utility tariffs, and provide incentives and subsidies to ensure that affordable energy is supplied to customers' (Khodayar, 2017). Social tariffs are a way of increasing access to energy amongst the poor. Some countries achieve these through cross-subsidisation, others from public funds. A challenge is that lower energy prices can disincentivise energy efficiency, and it is difficult to restrict social tariffs only to the poorest. Inefficient subsidies can also disincentivise utilities from investing in infrastructure required to improve supply (Banal-Estañol et al., 2017).

This suggests that electrification of low-income communities may not be successful if it is seen as an isolated intervention. It must be supported by a manageable business model that provides for the customer the ability to defray the upfront investment costs, at the same time as giving the investor an investment in which there is a prospect of some return. Governments can support these arrangements by providing regulatory frameworks and tariffs that are acceptable to both parties, by providing low cost finance for social enterprises, and backing investments in supporting infrastructure. Furthermore, it should be seen as part of a strategy that is not only providing basic quality of life, but also driving broader development including income generation, and supported by other measures that support that income generation, such as infrastructure, roads and telecommunications. For off-grid systems it is particularly important to establish a supportive 'eco-system' around the project. This requires both careful design of systems that are sufficiently robust for field conditions, as well as business models that include maintenance strategies. In many cases the training and involvement of the local communities themselves, including women and the elderly who may have the strongest personal investment in their community, may be the ideal way to achieve this.

In summary electrification projects 'need to be adapted to the socio-economic and geographic conditions of the area. These projects also need to promote the coordination of all the institutions and local communities involved in the electrification process' (Banal-Estañol et al., 2017).

The interactions between grid, micro-grid and off-grid solutions also need to be considered. Regulatory frameworks need to account for the possibility of off-grid or micro-grid projects eventually joining up to an expanded grid.

4.4 Use of renewable energy in the household sector

Energy use in the household sector in developing countries is a major development issue. About 2.8 billion people worldwide currently do not have access to clean forms of cooking, a number which has not reduced since 2000. Of these, about 2.5 billion people – approximately a third of the world's population – are reliant on the traditional use of solid biomass, with 170 million cooking with kerosene and 170 million with coal. 1.9 billion of those without access to clean cooking are in developing Asia, with 850 million in sub-Saharan Africa (IEA, 2017).

The use of such fuels for cooking presents a serious health risk – the burning of solid biomass, kerosene or coal in indoor traditional stoves creates very high levels of indoor particulate pollution, which when inhaled can cause serious respiratory problems. Kerosene is also a common source of domestic fires and of child injuries due to accidental ingestion (IEA, 2017). At present there are an estimated 2.8 million premature deaths per year attributable to household air pollution caused by the burning of solid biomass in inefficient stoves, or from the burning of coal or kerosene. Women and children are typically more exposed to these risks (IEA, 2017).

The extensive use of collected woodfuel as a household cooking fuel has environmental impacts in areas where the rate of collection exceeds the natural renewal rate of the biomass. Woodfuel is collected for direct use in rural areas, however many countries also have significant charcoal production sectors, with charcoal being transported predominantly to urban areas – in sub-Saharan Africa nearly 60% of urban dwellers rely on charcoal for cooking (IEA 2010, in Lambe/SEI). Charcoal production also exerts pressure on forest resources (SEI). Unsustainable woodfuel collection occurs throughout South America, Africa and Asia, with particular 'hotspots' in regions of East Africa extending from Eritrea through western Ethiopia, Kenya, Uganda, Rwanda and Burundi, and in parts of West Africa (Bailis et al, 2015). The collection of woodfuel also has socioeconomic impacts as it is often a highly time consuming activity. Again, it is predominantly women that are exposed to these impacts, as cultural factors mean they are typically tasked with this activity (Practical Action, 2016). According to the IEA, in woodfuel-using households, women spend on average 1.4 hours each day collecting fuel wood, although in some countries the average is as much as 4 or 5 hours (IEA, 2017), as well as several hours each day cooking, with increased times in part due to inefficient stoves (IEA, 2017). If this time was made available for other activities it could contribute women's empowerment, through enabling more time for education or income generating activities. Education has a significant impact on poverty reduction, income generation and improving gender equality (ECREEE, 2015).

Access to clean cooking is therefore an important development priority. It is also potentially one of the most cost effective, the IEA for example finding that the investment that would be required to deliver clean cooking for all is one tenth of that required to deliver universal electricity access (IEA, 2017).

There are a number of possible alternatives for providing access to clean cooking. According to the IEA '*access to clean cooking facilities* means access to (and primary use of) modern fuels and technologies, including natural gas, liquefied petroleum gas (LPG), electricity and biogas, or improved biomass cookstoves' (IEA, 2017).

Improved biomass cookstoves implement some improvements, such as a chimney or closed combustion chamber, that reduce pollution and increase efficiency compared to a traditional three-stone stove. Although these improvements do reduce health impacts, the extent to which they can be said to deliver truly clean cooking is not entirely clear, and subject to context. It has been suggested that laboratory tests tend to overestimate emissions reductions compared to real-life performance, because they rely on a fixed combination of technology, fuel, pot and burn sequence. In reality, these elements and their sequence are subject to contextual variability, and other factors such as the room size, shape and ventilation can also have a significant impact. Results from randomised control trials suggest that in practice 'virtually no biomass cookstove currently on the market meets World Health Organisation (WHO) standards for exposure to household air pollution' (IEA, 2017).

Advanced biomass cookstoves are equipped with further technical improvements to improve the efficiency of biomass combustion, such as micro-gasifiers and forced-draft. These designs can substantially reduce particulate pollution compared to improved cookstoves, however even the improvements offered by forced-draft micro-gasifiers are insufficient to meet WHO targets (IEA, 2017). The Global Alliance for Clean Cookstoves has been working in partnership with the International Organization for Standardization (ISO) to develop international standards for cookstoves, in line with WHO guidance (SEI, Lambe et al, p. 11).

Box 10: EcoZoom wood and charcoal stoves in Kenya

EcoZoom is a company that produces and sells efficient charcoal-burning and wood-burning stoves that substantially reduce fuel costs due to their more efficient performance. EcoZoom founded in 2011 and established in Kenya in 2013. A key feature of EcoZoom's approach is its range of financing options. Rather than providing end user subsidies, it provides credit terms to distributors who then pass them on to customers, or works with micro-finance providers to provide loans attached to products. The company is also piloting direct loans to customers repaid via mobile money. The company also undertakes a 'human centred' design process to ensure the stoves meet the needs of customers, provides training on use and maintenance of the product, undertakes monitoring and evaluation, provides product warranty, offers maintenance and repair, and interest free loans via Kiva microfinance. One barrier to the further dissemination of stoves is the added cost of taxes, including an import tax, on the stoves.

Other types of modern stoves run on LPG, ethanol, biogas, electricity or natural gas. Such stoves have much higher efficiencies and low levels of pollution (IEA, 2017), and in general succeed in meeting WHO exposure standards (Pilishvili et al, 2016; Quansah et al, 2017). However use of such stoves is dependent on the availability of the available fuel. Furthermore, some of these fuels are not renewable.

Shifting cooking onto LPG fuel and cookstoves is an alternative pursued in a number of countries, including India. Despite significant progress on electricity access, as discussed in Section 4.4, India still has significant numbers of people without access to clean cooking. Over the last 15 years the number of people without access to clean cooking has increased in India by 80 million, however the total number has not increased since 2010, suggesting that policies have begun to take effect. The proportion of people primarily using biomass for cooking fell from 66% in 2011 to 59% in 2015.

The IEA reports, 'this seems to have been driven by an increase in domestic LPG consumption, and in 2016, India became the third-largest LPG importer in the world, behind China and Japan.' The Indian government aims to provide clean cooking access through LPG to 50 million households below the poverty line, by 2019 (IEA, 2017). A number of other countries are also promoting LPG. Cameroon has set a target for to increase current levels of LPG use from 17% of the population currently to 58%. Senegal also provides incentives to encourage switching to LPG particularly in urban areas (IEA, 2017).

Small scale biodigesters can be used to produce biogas from organic matter including crop wastes, kitchen scraps, manure and sewage. In contexts where such residues would otherwise be wasted, the fuel might be considered free. The biogas produced is a methane-rich fuel that burns relatively cleanly. There are also potential for synergies with waste water treatment. A study of anaerobic digester systems installed to treat toilet wastewater in Haiti found that the system reduced coliforms and E. coli by 99.1% and 98.5% respectively, with chemical oxygen demand reduced by 93.6%. The system produced an effective organic fertiliser, as well as biogas with an average 65% methane content (Lansing et al., 2017). Abarghaz et al (2013) report on an anaerobic digester pilot project in the village of Dayet Ifrah in Morocco, using input material of manure and toilet wastewater, for which the system provided effective sanitation. The system also provided biogas used for heating and cooking, sufficient for a farming family of 17 people (Abarghaz et al., 2013).

However biogas digesters require upfront investment and space for the equipment to be housed, which can be limiting factors. Their construction can create local employment, however the construction requires supervision by skilled masons and plumbers as poorly constructed structures can be leaky with poor resulting performance, and ongoing maintenance is also required (Khan and Martin, 2016). Factors that have caused biogas digesters to fail or be abandoned include: structural failures or lack of maintenance leading to leakage of the gas from the system; lack of or disruption to supply of feedstock; problems caused by blockages in or flooding of the effluent storage tank or blocking of pipes; the supply of biogas found to be insufficient to meet expected needs (Ahiataku-Togobo and Owusu-Obeng, n.d., Bensah and Brew-Hammond, 2010).

There are also questions of how to store and transport the gas in order to supply users. One social enterprise operating in Africa, Asia and Latin America offers a solution in which biogas is filled directly into portable back packs which users can then carry home to connect to their appliances ((B)energy, 2017).

Biogas digesters have been rolled out extensively in a number of countries. In China in 2013 around 100 million people in rural areas were using biogas digesters. The Indian National Project on Biogas Development has to date installed almost 5 million biogas plants, and in Bangladesh, the National Domestic Biogas and Manure Programme installed an estimated 80,000 small-scale biogas systems using animal waste, in rural areas (IEA, 2017) (Box 11).

Box 11: Using biogas plants for cooking in Bangladesh

To increase the access to clean cooking, the Infrastructure Development Company Ltd. (IDCOL) in Bangladesh has been implementing a domestic biogas program. IDCOL is a government-owned financial institution established to catalyze and mobilize private sector participation in the development and financing of infrastructure, renewable energy and energy efficient projects.

IDCOL has been implementing the National Domestic Biogas and Manure Programme since 2006 with support from SNV Netherlands Development Organization and KfW. The program has been supporting the expansion of biogas technology in rural areas, with the ultimate goal of establishing a sustainable and commercial biogas sector in Bangladesh. Until June 2017, IDCOL has financed the construction of over 46,200 biogas plants all over Bangladesh.

The program promotes a fixed dome design biogas plant, with two types: a design for cattle dung and human excreta, and a design for poultry droppings. Each design has six sizes of plants of different capacities between 1.2 and 4.8 m3 gas production capacity. The gas produces from the two largest types of plants are used for multiple houses whereas other sizes are used for single households. The biogas produced through these plants is used for cooking and lighting of rural households, but the slurry, by-product of biogas plants, can be also used as an organic fertilizer.

The program is being implemented through a network of 45 partner organizations including private companies, NGOs and micro finance institutes. According to IDCOL, the program saves 44,300 tons of firewood every year, and reduces the use of 1,400 tons of kerosene every year. IDCOL has a plan to install 60,000 biogas plants in Bangladesh by 2018.

Source: Infrastructure Development Company Ltd. (2017).

Another option available to certain kinds of agricultural systems producing starchy or sugary crops is fermentation to produce bioethanol – see Box 12.

Box 12: Bioethanol in Ethiopia

Ethiopian NGO Gaia Association has been developing an alternative cooking fuel by producing bio-ethanol from molasses, a by-product of large state-owned sugar factories. Gaia Association has also produced an ethanol stove which reduces carbon monoxide levels below the WHO threshold, and $PM_{2.5}$ levels close to the WHO threshold. The NGO has commissioned a demonstration micro-scale ethanol plant, which will use surplus molasses from the sugar industry to produce bio-ethanol for households in peri-urban Addis Ababa. One significant barrier to bio-ethanol in Ethiopia is that it cannot compete on price with kerosene, as the latter is subsidised by the government.

Source: Stockholm Environment Institute (2011).

Electricity and natural gas are widely used cooking fuels in developed countries, though less so in general in developing countries. South Africa is a notable case of high usage of electricity for cooking. In 2000 50% of people used electricity for cooking, and this share has now risen to more than 80%, with only 8% relying on wood for cooking. In China around 12% of the population, or 160 million people, use electricity for cooking, and it is reported that this share is growing rapidly (IEA, 2017). However electric cooking requires a relatively large electrical load, and it is relatively expensive, which makes it unlikely to be suitable as an off-grid application (IEA, 2017). The availability of natural gas for domestic use is dependent on infrastructure, which is more likely to be cost effective to install in areas of high population density, or in the presence of industry (IEA, 2017).

An important observation in relation to the various cookstoves and fuels described in this section, is that whilst increasing access to clean cooking facilities has some potential overlaps with increasing the deployment of renewable energy, the two objectives are not necessarily entirely aligned in all cases. The transfer of households from traditional biomass use to LPG or natural gas fuelled cooking devices would have significant health benefits to those households, but would entail an increase in fossil fuel consumption. Similarly, to the extent that clean cooking can be provided by electricity, whether this is aligned with the increased deployment of renewables depends on whether or not the additional electricity generation capacity built to meet this demand is itself using renewable sources.

Conversely, some options would be consistent with increased deployment of renewable energy. As noted above, in many regions the rate of woodfuel collection exceeds the natural renewal rate of the biomass (Bailis et al, 2015), meaning that under this rate of usage biomass is a non-renewable resource. If improved efficiency cookstoves were able to contribute to the reduction of the rate of woodfuel collection to below its natural renewal rate, this would mean that the resource itself could now be considered renewable, and as such an increase in use of renewable energy would have effectively occurred. The use of biological processes to produce biogas or biofuels from crops, bio-wastes or agricultural residues would meet ambitions to deploy renewable energy at the same time as providing a fairly clean burning cooking fuel, however as discussed these options have other constraints which may mean they are not the first to be chosen.

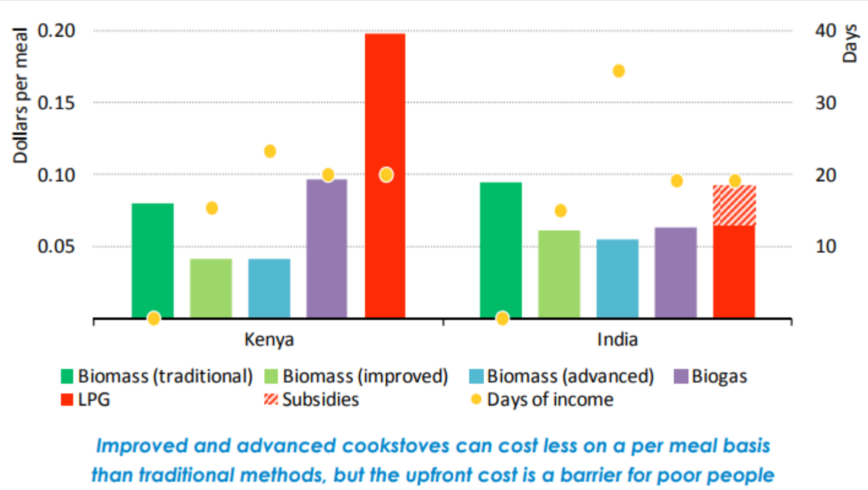
The IEA's Energy for All scenario, which achieves universal access to clean cooking by 2030, involves supplying 800 million people in urban areas with LPG, natural gas and electricity. In rural areas the scenario projects a mixture of approaches depending on available resources, but projects around 1 billion people in rural areas gaining access to improved biomass cookstoves, with LPG and biogas providing for a further 1 billion people (IEA, 2017). Evidently this scenario involves a range of cooking fuels and technologies, not all of them renewable.

Whilst the potential synergies between the Sustainable Development Goals are often emphasised, it is also important to acknowledge that sometimes there can be tensions between them. In this case, some of the nearest to hand solutions for achieving the overall aim of Goal 7 to ensure universal access to affordable, reliable and modern energy services by 2030, may not be the same solutions that would promote one of Goal 7's targets, to 'increase substantially the share of renewable energy in the global energy mix' by 2030.

There are numerous barriers to promoting access to clean cooking. Affordability is a key constraint. Despite its drawbacks, the use of biomass in traditional stoves may appear low cost to households, because the fuel is considered free – households may not factor in the opportunity cost of the time spent collecting fuel wood. However, even if such opportunity costs are considered, the affordability of clean cooking may still not be clear cut. Figure 9 shows the costs per meal of certain clean cooking options in Kenya and India, in comparison to the traditional use of biomass. The costs include the investment cost of the stove, the cost of the fuel and the opportunity cost of collecting fuelwood, averaged out on a per-meal basis. The Figure shows that even with the inclusion of opportunity costs, the cost per meal of cooking with biogas and LPG in Kenya is greater than traditional biomass use, LPG substantially so. In India the costs of all alternatives on a per-meal basis are below the traditional use of biomass. However the real cost of LPG is only marginally below it, with subsidies required to bring its costs down to the level of the other options.

Another important factor is the relation of upfront costs to running costs. Figure 9 also represents the upfront costs required to invest in the equipment required by the alternative cooking methods in terms of days of income needed. The typical investment costs of around 15-20 days of income are substantial, and represent a very significant barrier to low income households. Advanced biomass stoves in India appear to have a particularly high investment barrier, equivalent to more than 30 days of income. Improved biomass stoves often have the lowest upfront cost and are therefore often the most accessible option.

Figure 9: Cost of cooking a meal in Kenya and India



Notes: Poor in this figure is defined as a person living at the poverty line ($1.9 per day). Cost includes the stove, fuel and the opportunity cost of collecting fuelwood. Fuelwood is assumed to be collected, and the opportunity cost is calculated assuming that gathering fuelwood takes 1.1 and 1 hours per day for India and Kenya respectively (Figure 1.4), which could be redirected towards income generation, which, with the number of days' income to purchase the stove, is valued at the poverty line. A "standard" meal is defined as cooked for 45 minutes on an improved cookstove, requiring approximately 3.64 megajoules of final energy per meal. Note that the cost of attaining an LPG cylinder, typically a deposit, is not included, but can contribute to the financial barrier.

Sources: IEA analysis; Fuso Nerini et al., 2017; Politecnico di Milano; KTH-dESA.

Source: IEA (2017).

Further economic factors that could inhibit the uptake of alternative fuels are that some households engage in woodfuel collection in order to sell it as well as it uses, hence it is a source of income generation (IEA, 2017). Similarly, charcoal production is a significant activity in many rural economies in African countries. In 2007 the charcoal industry in sub-Saharan Africa was estimated to be worth more than $8 billion and to employ more than 7 million people (Lambe / SEI).

LPG has to be bought in relatively large amounts which can also be an upfront cost constraint. Pay-as-you-go business models can start to address these barriers, as can subsidies (IEA, 2017). However, there is also a question as to whether subsidising fossil fuels (in this case LPG) is a sustainable long-term and scalable strategy.

Social, cultural factors and issues of awareness and trust in alternative cooking fuels and technologies. Alternative cooking fuels and technologies will not be accepted in practice if they do not deliver an appropriate quality of service and performance that reflects the customs and practices of the user. Such qualities could include the speed of boiling, and the physical robustness of the stove itself to certain preparation techniques. In some cases the smoke created by a traditional biomass stove confers a flavour upon the food which has become an essential part of it – as a result of which smokeless alternative technologies may be considered for the preparation of that particular food. These kinds of cultural factors can inhibit take up of alternative cooking technologies, or can result in 'fuel stacking' – the use of different stoves, including traditional and modern, for different purposes. More general awareness of the risks if smoke may be low. Practical Action (2016) report from a case study in rural Bangladesh, that women did not perceive significant health risks associated with the smoke coming from their stoves, and indeed both men and women valued the smoke as a means of deterring insects.

The viability of alternative cooking technologies also depends strongly on the availability of the relevant fuel and an associated distribution infrastructure. Biogas and biofuel options can be limited by environmental and geographical conditions (Practical Action, 2016). LPG requires a distribution infrastructure, including reliable roads. In some remote rural areas the lack of availability of alternative fuels and the limited investment potential in new technolgoies, due to low overall demand, makes improved biomass cookstoves the only option (IEA, 2017).

Overcoming such barriers requires a range of approaches. Access to clean cooking has tended to lag access to electricity in terms of policy targets and actions, but there is no reason it should not be given equal priority given the serious health impacts that can arise from traditional biomass cooking.

Household energy use is embedded in cultural practices and it is vital that any intervention to improve access to clean cooking is firmly embedded in and informed by the social and cultural context. This must include an awareness of the full of range of values attributed to traditional cooking methods, potentially including attributes which might not externally be understood as positive, such as the smoke itself. Suggested alternative solutions will only succeed if these are established collaboratively with local users, among whom it is particularly important to engage with women. Thus, to improve chances of success, the social and cultural fabric of the particular setting must be considered. As the IEA note, 'providing funds is not enough on its own. Experience shows that past programmes can fall short if they don't take account of social and cultural factors and do not involve women from the outset' (IEA, 2017). The IEA reports that 'several initiatives now bring together energy, gender, health and climate with women's empowerment, employment and representation in the energy sector, including the Global Alliance for Clean Cookstoves, SEforALL, ECOWAS Energy-Gender Policy and Regulation, ENERGIA and the Clean Energy Ministerial' (IEA, 2017).

In some cases available interventions may be limited to improved biomass cookstoves, however evidence suggests that real-world performance of these stoves may still not meet WHO standards. Further research and innovation is needed to develop stoves which can meet WHO standards in real-world conditions, and to establish international standards for these stoves.

Research and innovation is also needed to improve small scale renewable options for producing clean cooking fuel, including anaerobic digestion and fermentation. Need place-based research to produce appropriate workable technologies.

LPG is a near-at-hand alternative which can substantially improve health outcomes compared to cooking with traditional biomass. However some reflection is needed as to the potential conflict in such a strategy with ambitions to reduce use of fossil fuels and increase deployment of renewables. Where LPG needs to be imported, and is supported by national governments through end-use subsidies, it is worth reflecting whether this is a sustainable long term economic strategy. Long-term outcomes are important to consider given the power of the 'lock-in' effect in energy systems.

Education and communication about the relative advantages and disadvantages of traditional compared to modern cooking options, must also be central. Many user may be unaware of health impacts of smoke from stoves. There also may be distrust and unfamiliarity with alternative stoves, which would need to demonstrated as having a comparable or better functionality if they are to be adopted.

The means to pay for alternative cooking fuels and technologies is a major barrier which needs to be addressed through a number of means. First of all the upfront cost which is an inevitable part of investing in a new stove must be managed, for users who very often will not have sufficient capital. Microfinance schemes such as those offered by (B)energy ((B)energy, 2017), and pay-as-you-go business models are useful ways of defraying upfront costs. Business models must also include a strategy for ongoing maintenance of household devices and any shared infrastructure. But this must also be seen in terms of a sustainable long-term income generation strategy for people that means they are able to repay such costs over time, and to continue to rise out of poverty. It must be acknowledged that the health-value of reduced indoor pollution is not necessarily well perceived, and that for some people a reduction in overall consumption of woodfuel or charcoal would actually translate into reduced income, as they earn a living from producing or selling these products. As such household energy interventions also need to be situated within a clear understanding of the economic development strategy for the communities concerned.

5. Strategies and policies

This section offers some general reflections on strategies and policies, before summarising our more specific policy recommendations in section 6.

The discussion in this section is grouped within two general themes. The first is on the importance of mixes of policies in order to achieve the aims of increasing deployment of renewables most effectively and efficiently, across the range of situations discussed in the preceding sections. The second theme concerns the potential for and importance of international and inter-regional collaboration.

5.1 The importance of policy mixes

Section 3 of this paper has already emphasised the importance of policy mixes rather than individual policies acting in isolation (Rogge and Reichardt, 2016). When considering the prospects for transforming well-established electricity systems, dominated by fossil fuel generators for decades, into systems with a much greater contribution from renewables, policies that create strong and stable market incentives for renewables are necessary. However, these new systems must be supported by policies that consider the structure of power markets themselves in relation to more variable generation sources, as well as address issues of infrastructure and market integration with neighbouring systems.

Strengthening innovation systems for renewable energy can involve coordinating actions by government including international collaborations and supply-chains. There is potential for synergistic benefits from considering renewables policy within broader industrial and economic policy. The latter should be based on understanding where national comparative advantage lies, and acting strategically to maximise this to generate macroeconomic benefit whilst meeting renewables deployment objectives. This joined up approach to energy and economic policy is more likely to generate legitimacy and public support for the energy transition.

In a comparable way a policy mix approach is crucial for increasing energy access in developing countries and LDCs. The potential benefits of increasing access to electricity and to clean cooking are manifold, however the barriers to low income communities are substantial. As much for grid or off-grid approaches, affordability is a major issue. This challenge needs to be addressed through addressing upfront costs through low interest credit and microfinancing.

However, to make a project sustainable, a supportive 'ecosystem' needs to be established around it. This should include attention to productive and income generating activities that will generate the income to make the increased energy access a financially sustainable option; it should include a maintenance plan, preferably involving members of the community; and it should be responsive to the needs of the community itself.

It is also important to build capabilities: to increase awareness of renewable energy technologies, as well as developing skills to installing and maintaining them. Some capacity building initiatives that are inclusive regarding women and the youth include, for example, the Clean Energy Education and Empowerment (C3E) program that aims to encourage women's participation in clean energy careers worldwide, or the STEM, Energy, Economic Development (SEED) in the United States of America, which aims to create economic opportunity and energy-literate communities, including energy literacy, STEM education, and job-driven skills training.[16]

The overall balance between grid extension and off-grid solutions is another important policy question, and the issue of subsidies for fuels such as kerosene and LPG requires careful consideration. All of these issues need to be considered in an integrated way.

5.2 The role of international and inter-regional collaboration

Technological innovation can be accelerated both by competition and cooperation. An important aspect of policy making is to recognise the value of both, and the benefits of encouraging them as appropriate in different circumstances. The competitive international dynamics shown by the case studies examined in Section 4.2 highlight the question of to what extent countries can be in competition, or in collaboration with each other. The example of solar PV shows that innovation dynamics are highly international in nature, with drivers in one country having the potential to impact significantly upon others. Within these international dynamics, competition is a significant factor and it can produce the positive effect of driving down costs, which from a global perspective is beneficial. However, the industrial sectors of individual countries can lose out within these competitive dynamics. The challenge for individual countries is to identify appropriate areas of specialisation due to comparative advantage, within this international dynamic. One way of approaching this is, rather than only promoting renewables through market-based instruments, to consider policy measures that can support supply chain related domestic industries as appropriate according to potential areas of national comparative advantage. There is a benefit of embedding renewables policy within broader industrial policy.

On the other hand areas of collaboration, of mutual benefit to all participating countries, may still emerge. Wieczorek et al (2015) give a number of arguments for cross border collaboration. The geographical distribution of renewables can be better harnessed through collaboration and closer connection between energy systems – such closer ties could allow countries to focus collectively on the regions with best resources. The greater geographical region covered by such cooperation would also have a better chance of capturing a more complementary spread of renewables, whose outputs were uncorrelated, thereby enabling a more balanced system (as discussed in Section 4.1).

Collaboration also entails greater potential to leverage investment in innovation and experimentation zones. A good example of this is demonstration of floating wind turbines off the coast of Scotland, which required the collaboration of Norwegian energy company Statoil, and the United Kingdom Crown Estate. Furthermore, homogenous regional markets may offer greater policy stability and greater investment economies of scale than national markets. International collaboration on cross-border grid and infrastructure projects may also be of mutual benefit.

Governments can also play important roles in coordinating and bringing together actors who are required to work together within a supply chain, to encourage them to jointly invest in areas of shared value (Box 13).

[16] Contribution from the Government of the United States of America.

Box 13: The United Kingdom Offshore Wind Accelerator

In the United Kingdom, the 'Offshore Wind Accelerator', organised by the Carbon Trust in the United Kingdom, brought together the major project developers with the aim of reducing the costs of offshore wind by 10%. The aim was to identify components of the supply chain which all of the project developers would need to call on, including designs of foundations and site access systems, to clarify the performance needs in each case and jointly commission these from potential providers. By pooling their interests with others, each participant leveraging their own investment by many times due to the contributions of the other participants, the group as a whole was able to establish a clear market demand for the products required, at a desired cost (Grubb et al., 2014). Thus, there can be occasions when cooperation increases efficiency more directly than competition. There is a clear role for governments to spot these opportunities and to take coordinating measures as necessary.

Source: Grubb et al. (2014).

Collaboration also underlies the concept of technology transfer, which has been discussed within the context of international environmental agreements for over four decades. Whilst technology transfer is often discussed as if developed country governments can and should transfer technologies to developing countries, this is far from straightforward. Cleaner technologies are often owned by firms rather than governments (Ockwell et al, 2008). Therefore the main challenge is to design policies and co-operation mechanisms that facilitate technology transfer by those firms to firms in countries with emerging renewables sectors.

China is starting to facilitate foreign wind farm development e.g. in Pakistan and Argentina (Gosens and Lu, 2013). A solar panel factory has been set up in Mozambique with joint investment by the Governments of Mozambique and India. The factory produces four types of panel, but is focussed on off-grid applications. Mozambican technicians are being trained, including in India. The factory currently employs 33 people. Though currently small scale, this factor is an interesting example of how technology and skills transfer can benefit countries by producing and deploying renewables quickly, despite lack of R&D background in the country, but also develop new skills and employment in the manufacturing stage of the supply chain (REEESAP p. 42). Mission Innovation and the Global Alliance for Clean Cookstoves are two important examples of international collaboration initiatives to promote innovation in clean and renewable energy (Box 14).

In summary, competition can be healthy. It can drive specialisation and cost reduction. However, there are areas where cooperation is needed, for example bringing different actors together along a value chain, or to benefit from shared natural resources and shared infrastructure. Therefore as well as forming markets to which private actors can respond in a normal competitive environment, governments need to be aware of where their role as a broker can improve the functioning of value chains or enable an efficient accessing of naturally shared assets – be they natural, infrastructure, or knowledge.

Box 14: International initiatives to promote innovation in clean energy

Mission Innovation is a global initiative of 22 countries and the European Union that aims to accelerate global clean energy innovation with the objective to make clean energy widely affordable. Member countries pledged to double their public investment in energy R,D&D between 2016 and 2021 – though it remains to be seen whether their actual spending matches their pledges. They have also identified seven priority 'innovation challenges' to focus their collaborative R,D&D. Several of these challenges focus on renewable energy or related innovations, including: smart grids, off-grid electricity access, sustainable biofuels, new technologies to convert sunlight into energy and clean energy materials.

The Global Alliance for Clean Cookstoves is a public-private partnership hosted by the United Nations Foundation. Acknowledging that the use of traditional fuels and inefficient technologies is one of the most pressing health and environmental issues in developing countries, the alliance's aim is to save lives, improve livelihoods, empower women and protect the environment by creating a thriving global market for clean and efficient household cooking solutions. The focus countries are Bangladesh, China, Ghana, Guatemala, India, Kenya, Nigeria, and Uganda. The alliance's "100 by '20" goal calls for 100 million households to adopt clean and efficient cookstoves and fuels by 2020. The alliance has an instrumental role in supporting the research, design and rolling out of programmes for improved cookstoves, including cookstoves using biofuel and solar energy. In particular, an emphasis is given to develop markets, by raising consumer awareness and ensuring availability and affordability. The organization is bringing together more than 1600 partners worldwide, representing the private sector, governments, NGOs, philanthropists and donors, and academia.

Sources: Contribution from the Government of Canada; Global Alliance for Clean Cookstoves (2016).

6. Key findings and policy recommendations

This final section summarises some key points from the paper, and discusses implications for national government policies and for the CSTD.

6.1 Renewable energy and the Sustainable Development Goals

This paper has shown that the expansion of renewable energy can play an important role in meeting several Sustainable Development Goals, not just the goal for energy (Goal 7). Strategies to expand the use of renewable energy are therefore not only a matter for energy policy – they also link to wider economic, industrial and development policies.

The current share of global energy from renewables is a relatively modest 10% if traditional sources of bioenergy are excluded. But that is starting to change quickly, particularly due to the rapid expansion of renewables for electricity generation. If hydro power is excluded, the share of renewables in the global electricity mix grew from 2% in 1990 to 10% in 2015.

Renewable energy sources can also play a role in other parts of energy system beyond electricity, either directly or indirectly: in transport, heating and industry. The share of renewables in these other parts of the system tends to be lower, especially in transport.

The use of biofuels for transport has been limited in most countries due to concerns about environmental sustainability – particularly life cycle emissions and land use implications of first generation biofuels.

National pathways for renewable energy development and deployment vary markedly. Whilst renewable electricity technologies have expanded rapidly in some OECD and emerging countries, traditional biomass comprises a large share of overall primary energy in many less developed countries. However, some less developed countries such as Kenya have seen significant increases in the use of modern renewable energy technologies during the past decade.

There is significant potential for renewable energy to play a much larger role in future. Scenarios that are designed to be compatible with the Paris Agreement include a significant expansion of renewable energy by 2050. Some of the most ambitious scenarios foresee renewables supplying the majority of the world's energy by this date.

6.2 Policies and strategies to support renewable energy

An innovation systems approach is a useful way to understand renewable energy strategies in different countries and contexts, and to help explain their relative success or failure. Research using innovation systems approaches shows that whilst single policies or interventions (e.g. R&D or a feed in tariff) are important, successful strategies are often broader – and use 'policy mixes' to create the conditions for successful renewable energy innovation and deployment. To maximise the chances of success, such policy mixes should not only focus on policy instruments. They should also include policy strategies that provide long-term direction, policy processes that have a positive influence on innovation and characteristics such as policy stability.

This highlights the important role for governments in supporting innovation in renewable energy technologies. Whilst a lot of renewable energy innovation is carried out by the private sector, this does not happen in a vacuum. Governments play a crucial role in the innovation and deployment process – e.g. by funding R&D, creating demand through deployment incentives, by reforming energy markets and by other measures to strengthen investor confidence.

Important factors that explain differences between national approaches include different resource endowments and differences in technological and industrial capabilities. Related to this, there are important questions about the extent to which individual countries will wish to couple renewable energy deployment with the location of manufacturing and supply chains within their country. Such choices need to take into account the international nature of supply chains and innovation systems for renewable energy and their existing areas of scientific or industrial strength.

Renewable energy strategies are usually tailored to national circumstances, even if they include similar policies such as feed in tariffs or auctions to drive renewables deployment. Such policies are often adapted so they are compatible with existing policy frameworks and institutional arrangements. However, there have been some important general trends in renewables policy including, for example, the trend towards using auctions rather than administered tariffs to drive down the costs of deployment.

6.3 Challenges and opportunities for developing countries

Developing countries have particular challenges and opportunities with respect to renewable energy. For example, whilst some developing countries lack reliable electricity infrastructures, there is a potential opportunity to develop these infrastructures in a more sustainable way than other countries have done in the past.

Some of the most rapid progress in renewable energy deployment has occurred in middle income countries, particularly China. This has also been a major contributor to the cost reductions that have been seen in recent years. Whilst there are some positive examples of renewable energy deployment in less developed countries, these examples are often on much smaller scale.

Renewable energy sources can play an important role at a range of scales – from 'bottom up' off-grid applications (e.g. solar home systems) to larger grid-scale power plants (e.g. hydro, concentrated solar or geothermal plants). There is mixed evidence and strongly held views about the relative merits and costs of these different approaches. The most appropriate balance of the two is highly context specific. Therefore, policies for renewable energy should enable the contribution of all approaches, through creating a supporting regulatory environment and tariff structure. In addition to connecting population centres with large-scale sources of generation (including centralised renewables), plans for the development of grid infrastructure should also include strategies for how micro grids might eventually be integrated in main national networks.

Given that almost 2.8 billion people do not have access to clean cooking facilities, there is an urgent need to deploy alternatives to the traditional use of bioenergy for cooking and other energy services. This is required to tackle the negative impacts of the use of these energy sources – for example on health, gender equality and poverty. The evidence shows that policies and programmes to address this challenge must be embedded in the social and cultural contexts of the communities they involve, and take account of their current energy practices, needs and expectations, and potential for productive uses. The engagement of women in this process is particularly crucial, as they frequently have predominant responsibility for household energy related practices including fuel gathering and cooking. Women can also be effective trainers and communicators in the managing and maintaining of new local energy systems.

Affordability is a key issue to overcome in increasing energy access through the use of renewable energy. A particular obstacle may be the upfront costs of purchasing equipment and devices. New business models can make this viable and conducive to development – for example by using microfinance or pay-as-you-go arrangements to spread these costs. In some cases, payments for new renewable energy technologies can be structured so they are similar to the costs of the energy sources they are replacing (e.g. for kerosene). However, in others, the new technology will not be affordable if there is not an increase in income generations. Hence the income generation opportunities that can arise from increased energy access must also be central to national and international strategies. Attention must given not only to household uses but to other productive uses in industrial, commercial and agricultural sectors.

Another barrier to affordability is subsidies for fossil fuels such as kerosene and LPG. Whilst many of these are intended to support the poor, they can create lock-in to these fuels and prolonging the exposure to fossil fuel price risks. Subsidies also risk crowding out renewable energy technologies that could be more sustainable in the medium and longer-term. Subsidised electricity tariffs also may have the unwanted effect of discouraging energy efficiency.

Business models must also take into account a maintenance strategy for the technologies, to avoid situations where technologies break, cannot be fixed and are subsequently abandoned. Frequently the engagement of the local communities themselves, including women, in training for the maintenance of these systems, is an effective strategy.

6.4 International collaboration

International collaboration can play an important role in the expansion of renewable energy. This paper has shown that it already takes a number of distinctive forms in addition to technological collaborations such as Mission Innovation and the Alliance for Clean Cookstoves. These include collaboration for policy learning and capacity building; collaboration with respect to technology development; collaboration to improve interconnection of grid infrastructures across borders; and collaboration to develop manufacturing capacity.

International organisations and bodies such as the CSTD can play an important role in supporting these forms of collaboration. With respect to policies to support renewable energy development and deployment, they can help to share lessons between countries and regions. In doing so, it will be important to recognize that policies and policy mixes cannot be simply transplanted from one context to another. This is particularly true when learning lessons from OECD or middle-income countries for less developed countries.

They can also help to identify mechanisms for improving capabilities in developing countries for renewable energy. These include capabilities to develop and implement supportive policy mixes; the development of flexible plans and regulations for the energy sector that embed incentives for renewable energy; and measures to improve capabilities to absorb, maintain and adapt renewable energy technologies to the local context.

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