Renewable Energy in the Global Energy Transformation: Global Perspectives

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Abstract. This paper explores the technical and economic characteristics of an accelerated energy transition to 2050, using new datasets for renewable energy. The analysis indicates that energy efficiency and renewable energy technologies are the core elements of that transition, and their synergies are likewise important. Favourable economics, ubiquitous resources, scalable technology, and significant socio-economic benefits underpin such a transition. Renewable energy can supply two-thirds of the total global energy demand, and contribute to the bulk of the greenhouse gas emissions reduction that is needed between now and 2050 for limiting average global surface temperature increase below 2°C. Enabling policy and regulatory frameworks will need to be adjusted to mobilise the six-fold acceleration of renewables growth that is needed, with the highest growth estimated for wind and solar PV technologies, complemented by a high level of energy efficiency. Still, to ensure the eventual elimination of carbon dioxide emissions will require new technology and innovation, notably for the transport and manufacturing sectors, which remain largely ignored in the international debate. More attention is needed for emerging infrastructure issues such as charging infrastructure and other sector coupling implications.

Keywords: Energy Transition · Sustainable Energy · Energy Policy

1 Introduction

The Sustainable Development Goals (SDGs), adopted by the United Nations General Assembly (UNGA) in 2015, provide a powerful framework for international cooperation to achieve a sustainable future for the planet. The 17 SDGs and their 169 targets, at the heart of "Agenda 2030", define a path to end extreme poverty, fight inequality and injustice, and protect the planets environment. Sustainable energy is central to the success of Agenda 2030 (Phung, 1985, pp. 920-921). The global goal on energy – SDG 7 – encompasses three key targets: ensure affordable, reliable and universal access to modern energy services; increase substantially the share of renewable energy in the global energy mix; and double the global rate of improvement in energy efficiency. The different targets of the

SDG 7 contribute to the achievement of other SDG goals and recently this has been the focus of an increasing number of studies.

According to Jamasb (2007), earlier analysis of future energy pathways shows that it is technically possible to achieve improved energy access, air quality, and energy security simultaneously while avoiding dangerous climate change (p. 65). In fact, a number of alternative combinations of resources, technologies, and policies are found capable of attaining these objectives. Although a successful transformation is found to be technically possible, it will require the rapid introduction of policies and fundamental political changes toward concerted and coordinated efforts to integrate global concerns, such as climate change, into local and national policy priorities (such as health and pollution, energy access, and energy security). An integrated policy design will thus be necessary in order to identify cost-effective “win-win” solutions that can deliver on multiple objectives simultaneously (Table 1).

Table 1. Reserves of network capacity in consumers, 2016.

	Subject of the Russian Federation	Number of consumers	Electricity, thousand kWh	P Fact. mW	Pmax. mW	Share of provision, %
1	Tyumen region	80	36,226,163	4,389.3	6,406.7	31
2	Belgorod region	61	7,627,078	990.5	1,485.6	33
3	Kaluga region	62	982,772	229.9	440.7	48
4	Vladimir region	70	1,940,008	297.0	571.7	48
5	Omsk region	68	3,238,991	616.9	1,256.9	51
6	Moscow region	396	3,143,956	2,035.4	4,228.4	52
7	Perm region	61	8,003,835	1,635.5	3,489.1	53
8	Moscow	258	3,819,295	848.9	1,834.8	54
9	Samara region	80	6,424,396	876.3	1,942.9	55
10	Sverdlovsk region	181	12,282,534	2,026.0	4,550.3	55

Source: (Bergmann, Hanley & Wright, 2006).

Predicting the timing and the extent of energy transitions is not straightforward. The age of nuclear and the age of hydrogen were “announced” but have not yet come to pass. Recent examples of other projections that have not proven accurate include inflated natural gas projections and structural underestimations of renewables growth. Experience has shown that an energy transition takes time, typically half a century from first market uptake to majority market share for energy transition. Previous energy transitions were driven by technological change, economics, access to resources, or superior energy service for consumers (Kahouli, 2011). Therefore, business opportunities, energy transition benefits or self-determination of individuals were at the heart of the change.

National energy transition narratives include learnings from both successes and failures. Success stories show that energy transitions that build on enabling energy policy frameworks designed by governments that can accelerate energy transitions and determine their direction. Well-designed transition policies consider energy systems characteristics and encompass energy supply and demand. Lessons from several countries and regions are examples to this. In Brazil, the Proalcool programme was started in 1975 and a mix of policy instruments that evolve over time were used to address the needs of both supply and demand sides. It remains the case that government blending mandates are driving biomass-based ethanol demand, but the sector's long-term success continuous to be impacted by economic cycles and changing government priorities. In Germany, the *Energiewende* is the result of a national consensus to abandon nuclear and reduce greenhouse gas (GHG) emissions by 80% by 2050 through an accelerated uptake of renewables (Dincer & Rosen, 2011, pp. 22-37, 34). However, the *Energiewende* still remains as a power sector transition policy with small impact on coal-fired generation and for accelerating transition in heating and transport sectors. In Denmark, there also is a consensus on climate objectives in combination with tacit renewable supply industry support policy.

2 Materials and Methods

REmap is based on a unique technology and project cost dataset. Technology costs and cost projections were derived from a comprehensive and publicly accessible database of renewable energy technology cost. Also a number of IRENA datasets have been developed in recent years at different levels of spatial resolution that detail the economic and technical potentials of various renewable resource types and strategies how to enhance and deploy these potentials in the future in a cost-effective manner (Fig. 1).

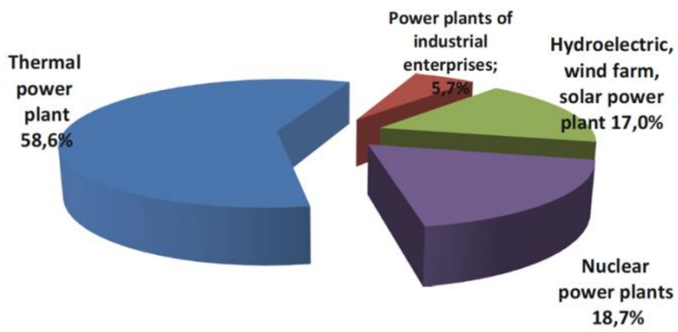

Fig. 1. Structure of power generation by types of power plants EES of Russia. *Source:* (Federal Statistical Office, 2018).

Regarding the technology deployment potentials in the 2030 and 2050 timeframe, extensive consultations took place with country experts and this information was combined with model analysis for power sector transformation. It includes potentials and market information from 150 countries as well as the most recent national energy plans of 70 countries collected directly from governments provide additional insights into the methodology, strengths and limitations of the REmap global energy modelling framework by comparing its application with the findings of national IEA-ETSAP models as well as other scenarios acknowledged by the global energy and climate community (Puka & Szulecki, 2014).

Annex 1 provides further methodological details of REmap. In recent years, IRENA has worked together with the governments and their national experts to contribute to the renewable energy planning and target setting of 70 countries through implementation of the REmap approach. It has been deployed for the Group of Twenty (G20) countries and for various regional settings such as Association of Southeast Asian Nations (ASEAN), the Africa Renewable Energy Initiative (AREI), the European Union (EU) and the United Arab Emirates (Federal Statistical Office, 2018).

Numerous global, regional and national tools and models exist to assess low-carbon and energy transition pathways. REmap findings for the year 2030 are found to be comparable with other scenario analyses that use different techniques but similar assumptions on technologies, costs etc. The strength of the REmap approach is to allow IRENA national experts to develop their own scenarios and review data and assumptions of the analyses. By using a simpler accounting framework than complex integrated assessment models, REmap creates country engagement and dialogue, and is able to provide direct feedback to countries about technology pathways, investments and policy making. The idea is not to be prescriptive of a technology mix but communicate results with a diverse group of audience. These are important assets REmap brings to the energy scenario debate while generally the support of sophisticated models dedicated certain tasks are required to enhance Remap's technical capabilities, such as the analyses of grids, infrastructure and biomass supply (Knapp & Ladenburg, 2015). Earlier examples of such soft-linking of REmap with other models have yield successful results, for instance in the analyses of the European Union's power system.

3 Results

This section provides an overview of the latest trends for the key renewable energy and energy efficiency technologies that are needed for the global energy transition. Progress in reducing the energy intensity of the global economy continued to accelerate, improving by a 2.1% compound average annual growth rate between 2010 and 2016. In 2015, the share of renewable energy in total final energy consumption climbed to reach nearly 19%, continuing the slight acceleration of trends evident since 2010.

In terms of power generation, renewables have accounted for more than half of all global capacity additions since 2012. In 2017, newly installed renewable power capacity in the world achieved a new record of 167 GW (Sharma & Kar, 2015, pp. 234-236). This was another record year where more than 60% of all new electricity capacity was from renewables. Solar PV capacity has experienced a growth more than any other source of electricity generation. Grubler (2010) states that global new investment in renewables amounted to USD 241.6 billion in 2016; more than that, 2017 was the fifth consecutive year that new investment in renewable power generating capacity was roughly double the one in fossil power generation capacity (pp. 5179). At the root of this acceleration are substantial reductions in renewable technology costs.

The levelized cost of electricity from solar photovoltaics has fallen by an astounding 73% between 2010 and 2017, and for electricity from onshore wind cost have fallen by 23%. IRENA analysis estimates that by 2020, all renewables technologies currently in commercial use will be cost-competitive with fossil-fuels in many parts of the world, and even undercut them significantly in many cases. Policy mechanisms such as auctions have contributed to lowering prices. World-wide recent tenders have resulted in record-breaking prices: in recent years utility scale solar PV and onshore wind projects are offered at US cents 2–3 per kWh under the best conditions. These prices are below this of conventional fossil and nuclear generation, in some cases even below the operating cost of existing conventional plant.

According to the REmap analysis, share of renewables in power generation would need to increase from around one-quarter in 2015 to around 60% by 2030 and 85% by 2050 for energy sector decarbonisation. The substantial annual growth rate of 0.7% of renewables in total generation over the past five years needs to more than double to realise these.

Countries around the world are in the midst of an energy transition that appears to favour electricity as the preferred final energy carrier. This is favourable from the perspective of both renewables and energy efficiency. Electricity is an efficient energy carrier and it becomes a clean source of energy when it is sourced from renewables. Electricity' share in total global final energy consumption (TFEC) is around one-fifth, but it is much higher in high-income countries and it is rising fast in developing countries.

Especially in the residential sector, a conversion to all-electric solutions is conceivable. Electricity for cooking, water and space heating, and cooling is available today. Light industry and the service sectors are areas where electricity can make similar significant inroads. However, in heavy industry, electricity use is limited to specific processes, such as smelting or electrolysis. Generally, new electric solutions are technically feasible but often not economic.

4 Discussion

Technology breakthroughs can be reflected in patent filings, so IRENA has developed a database of International Standards and Patents In Renewable Energy (INSPIRE) to track them. The patterns of patent filing over time offer interesting insights into where renewable energy technologies are headed. The data show for example a gradual shift in patenting activity over recent years, away from supply side to sector coupling.

The sectors with the most significant challenges are energy-intensive industry sectors such as iron and steel making, chemical and petrochemical, and cement making. It also includes road freight transport, shipping and aviation. These are all end-use sectors where addressing the innovation challenge to improve existing technologies, develop breakthroughs and major shifts is most urgent. There is an urgent need to act today to change this situation for these sectors, as a full-scale energy transition takes decades due to the different technology development steps and the long lifespans of the existing capital stock. In these sectors, biomass could play a role as the only renewable energy carrier with carbon content (for hydrocarbon products and chemical reactions) that can be stored with a high energy density (for transport). But this is not an obvious transition: the economics are not attractive today and sustainable, affordable and reliable feedstock supply is a major issue. According to a recent study, supplying the volume of biomass like estimates here for the iron and steel, cement and chemical and petrochemical sectors alone would require the mobilisation of around 1000 million tonnes of feedstock. This compares with today's feedstock demand for all types of modern heating, transport and electricity applications from biomass worldwide. For the United States alone, the biomass feedstock potential is a one billion tons global potentials are at least four times higher (Harris, Heptonstall, Gross & Handley, 2013, pp. 435-440).

Ramping up supply to these levels is challenging and would still remain insufficient to decarbonise the industry sector, thereby requiring options like electrification, renewable hydrogen and CCS. Some efforts are also still focusing on hydrogen for the transport sector or its derivatives such as formic acidor ammonia. Electrification on the other hand is a limited option for those sectors, as technologies that use electricity coupled with renewable power may not always provide a low-carbon solution.

Based on theoretical studies and practice of development of strategies of the regional level, we would like to highlight the key points here:

- Renewable energy and energy efficiency, combined with electrification of end-uses, make up 94% of the emission reductions.
- The share of renewable energy in total primary energy supply would rise from 14% in 2015 to 63% in 2050.
- To achieve this share an average annual growth rate of 1.4ppt/yr is need – a six-fold increase from recent years rate.
- The share of renewable energy in the power sector would increase from 25% in 2015 to 85% in 2050.
- To 2050, USD 120 trillion would need to be invested in the energy-system in the REmap energy transition case.
- This represents an increase of USD 27 trillion compared to the Reference Case.

Infrastructure will be needed to integrate technologies. These will include smart charging networks for electric vehicles; new low-losses cross-border electricity interconnections; super high-voltage transmission lines – possibly underground - to dispatch massive amounts of power from areas with abundant wind or solar resources to demand centres; district heating networks; and biomass feedstock management strategies (Clarke, Weyant & Birky, 2006; Energiegesetz-Nein, 2016; Visschers & Siegrist, 2014). Without this infrastructure, the commercialisation and mass deployment of low-carbon technologies for the energy transition will not occur on time. The coupling of different energy applications also creates opportunities for the integration of clean technologies. An example is the power and transport sectors through electric vehicles.

Today, especially interesting opportunities exist at the crossroads of ICT and energy technology, as well as in the areas of new high-performance materials, new battery formulations, and other challenges of materials science. New business models are emerging, notably elated to electricity markets. This includes virtual power plants, aggregators for electricity storage services. They need to be combined with new market designs with more precise time and place of use pricing for consumers, new operational practices, and new smart grid technologies. Around thirty types of innovations have been identified, covering several hundred discrete cases. The most successful cases usually deploy several innovations at once.

5 Conclusion

An increasing number of indicators point to an accelerating energy transition that can have profound implications for energy supply and demand in the coming decades.

As the analysis shows, rapid innovation is taking place that facilitates the ongoing transition through falling costs of renewable technologies and also enabling technologies such as batteries. Along with the new policy imperatives, innovation strengthens the momentum of energy transition. As technology improvements are permanent, they reduce the risk of policy volatility. The progress for solar and wind technology is a prime example that the future can be steered in a certain direction through technology policy.

The share of renewable energy can grow from 15% in 2015 to 63% of total primary energy supply in 2050 as this paper shows. Such renewables growth in combination with higher energy efficiency can provide 94% of the emissions reduction that is needed to stay within the limits of the Paris Climate Agreement. While absolute numbers vary there is consensus across recent scenario studies that renewable energy and energy efficiency is the most feasible direction to meet climate objectives.

The policy decisions to accelerate energy transition will need to be aligned with the development of enabling infrastructure. Infrastructure planning early on will be of paramount importance because of its carbon lock-in effect due to long life span and inertia. More attention is needed for emerging infrastructure issues such as smart charging of EVs, distribution grid reinforcements and the role of shifting demand and smart grids. Financing for both energy generation capacity and infrastructure will also be crucial through carefully drafted policies that create a credible, predictable and transparent investment environment. There is a need to mobilise public and private sector resources and develop innovative financing models that can mitigate investment risks.

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