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Current State and Costs of Low-Carbon Generation

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ABSTRACT

Transition to renewable energy (RE) is in large part motivated by the global concern about the climate change, which is related to the enormous amounts of carbon dioxide generated by fossil fuels. This study considers the current state and costs of low-carbon generation. In Chapters II and III, we provide an overview of targets and current state of low-carbon generation in different countries, with focus on wind, solar, and nuclear. In Chapter IV, we report historical trends, current and projected costs of RE. In Chapter V, we summarize major economic and technical barriers hindering the expansion of RE. Finally, we recap the main points in the Conclusion.

1. Introduction

The major factor to consider in policies aimed at mitigating greenhouse gases is electricity generation. Although, since 1990, there has been a continuous improvement in the share of emissions from the electricity sector, it still accounts for about 40% of the total global emissions [1]. However, the electricity sector has been anticipated to reduce emissions – in fact, faster than any other sector – through the use of low-carbon sources such as solar, wind, biomass, nuclear, storage, and hydro [2]. This paper provides an overview of the current state of low carbon generation with focus on solar, wind, nuclear, and battery storage. For that purpose, we consider the targets and the penetration level of low-carbon sources in different parts of the world. We also review historical trends, current and future costs of renewable energy (RE). We analyze costs mainly in terms of LCOE. The LCOE approach gained popularity due to its simplicity [3] [4]. Despite some criticism [5] [6], LCOE remains a popular and convenient way to compare the costs of generating technologies on a common basis of $/kW

II. Overview of the targets for low-carbon generation in different regions of the world

The Paris Accord has defined greenhouse gas ”pathways” for countries to follow, with a target to limit the global warming to 1.5-2˚C through the reduction of carbon dioxide and other greenhouse gases through the year 2050. Consequently, different countries set up targets for their carbon dioxide emissions. The US President, Joe Biden aims to obtain a carbon-free power sector by 2035 and net zero emissions economy by no later than 2050 [7]. Germany has designed a four-component energy transition target: 40-45% share of renewables by 2025; all nuclear power plants shut down in 2022; greenhouse gas emissions reduced by 55% from 1990 levels by 2030; and a 50% reduction in the primary energy consumption by 2050 as compared to 2008 [8]. In India, renewables have a 23% share of the total installed capacity. The overall non-fossil installed capacity (which includes large hydro, nuclear, and renewables) is 38% — two percent short of the target 40% by 2030 [9]. The president of the People’s Republic of China declared a course towards carbon neutrality by 2060 [10]. In line with the national commitment to transition to a low-carbon economy in South Africa, the Integrated Resource Plan (IRP 2010), promulgated in May 2011, set a more ambitious target of 17,800 MW of renewable capacity to be achieved by 2030. Within this 20 year pipeline, 5000 MW were planned to become operational by 2019, with another 2000 MW to come online by 2020. Already in 2017, 6,422 MW of electricity were procured from 112 renewable energy Independent Power Producers using a competitive bidding process known as bidding windows [11]. In December 2019, the President of the European Commission presented the European Green Deal for 2050. This is a growth strategy to transform the EU in a climate neutral and circular economy, while preserving Europe’s competitiveness [12]. The South Australian government is aiming to reduce South Australia’s greenhouse gas emissions by more than 50% from 2005 levels by 2030, and to achieve net zero emissions by 2050 [13].

III. Survey of penetration of wind, solar, and nuclear generation in different regions

since 2015, global electricity demand rose 11% but the increase in renewable generation was insufficient. That resulted in fossil generation uplift. For example, gas-based generation rose 10% since 2015, half of that being in the US. At the same time, moved by the global transition towards clean energy, coal fell a record 4% in 2020 – almost everywhere, with large drops in the US (-20%), the EU (-20%), and even India (-5%). Wind and solar produced 9.4% of the world’s electricity in 2020, doubling from 4.6% in 2015. A lot of G20 members now cover around a tenth of their demand from wind and solar: the US (12%), Turkey (12%), Brazil (11%), Japan (10%), China (9.5%), India (9%) (see Fig. 1). Europe is the leader, with Germany at 33% and the UK at 29%. Russia, Indonesia, and Saudi Arabia still have negligible amounts of wind and solar. Fossil fuels still provided for 61% of the total electricity in 2020. With the world’s priority of reducing coal-based generation, gas and oil-based production also needs to decline rapidly. In 2020, 23% of the overall electricity still was from gas and 4% – from other fossil fuels [14].

A. China

Fast-growing electricity demand (7% per year since 2015) was the driver for China’s scale-up of both renewable and nonrenewable generation in recent years. Renewables have seen an exceptional increase in China in 2015-2020, in particular, wind and solar (see Fig. 2). Wind and solar accounted for

9.5% of total China’s generation in 2020. In absolute terms for wind and solar, China is leading among G20 countries. In the same period, the share of coal-fired generation dropped by 7%.

However, in absolute figures, all production has been increasing, although the expansion rate of wind and solar
(45% per year) has far exceeded that for coal (4% per year).
China is the world-leading manufacturer of wind turbines and solar panels, electric cars, and buses. China is working on new projects of nuclear power plants, and many could run by 2060 — enough to substitute coal, in combination with wind and solar. Renewable energy has been subsidized by the government since 2011, but those subsidies are to be withdrawn by 2022 [15].

B. Brazil

Brazil is one of the largest world's energy producers. Over 80% of its electricity comes from renewables, primarily hydro. Hydro is accounting for over 60% of the country's electricity mix (see Fig. 2). Brazil's hydroelectric potential has not yet been fully realized – there is enough capacity to build several more hydropower plants. However, further development may be restricted because of environmental concerns regarding the remaining hydro resource in the Amazon basin. This was the motivation for the expansion of wind and solar in recent years. In Brazil, wind and solar accounted for 11% of total generation in 2020, slightly above the global average of 9.4% [17]. The expansion of wind and solar is too low in Brazil provided that the country has high incidences of direct sunlight in most of its territory and its onshore wind potential is about 522 GW; this is three times the country's current demand [16]. The main limitation for further expansion of wind and solar is the prohibitively high cost of power plants. The majority of power consumption centers are a long way from the generation, resulting in pricey transmission and distribution. Besides, 66% of distribution and 28% of generation is owned by private companies. This makes it harder for the officials to make changes and develop new policies in the power sector [16].

C. Germany

In Germany, wind and solar accounted for 33% of electricity in 2020 vs. 18% in 2015 (Fig. 2). This gives Germany the lead in G20. Hydro remained stable, with 6 GW of installed capacity. Overall, renewable production has doubled since 2015 and now delivers 45% of electricity. The year 2020 was pivotal as renewables first-ever surpassed fossil fuels. Nuclear production dropped by 30% over the five years. Nuclear is currently delivering 11% of Germany's electricity but all the plants are to be closed in 2022. Germany's coal production has decreased by 43% since 2015. Still, Germany is to totally phase out coal only by 2038, which is inconsistent with the EU's low-carbon policies and targets. To catch up, Germany will need to stop all of its coal-based power plants by 2030. Despite the progress in coal, Germany still relies on fossil fuels. The gas-fired generation has increased by 67% since 2015 and now provides 16% of the country's electricity [18].

D. Australia

Australia has recently had wind and solar boom – rising from 7% in 2015, they now provide 17% of the country's electricity (see Fig. 2). This is the third result in G20. However, there is a concern about the retardation of wind and solar scale-up, as the national Renewable Energy Target has been met in 2019. State governments have taken the initiative and announced their own renewable targets, but it is unclear whether these targets will help meet the global climate change mitigation goals. The penetration of renewables is still hampered by numerous techno-economic issues (e.g., system security, grid integration). In 2015-2020, coal-fired generation in Australia dropped by 10%. Nonetheless, coal is still dominant in the electricity mix, with over 50% of the electricity supply in 2020. There is still no policy or targets for nation-wide coal reduction, and coal is expected to provide above 30% of electricity in 2030. In 2020, fossil fuels provided 75% of the total country's electricity [19].

E. The United Kingdom

The UK is the G20 leader in coal phase-out by renewables. 2020 marked the first year that renewables surpassed fossil fuels in generated electricity – 42% vs. 41%, respectively. The installed capacity for wind and solar increased by 67% and 75% in 2015-2020. In 2015, the UK government announced the intention to phase out coal-based generation by 2025. In 2020, coal provided 1.7% of the UK's electricity as compared to 23% in 2015. This 1.7% seems negligible against the world's average of 33.8%. Inspired by this progress, the government has shifted the coal phase-out deadline to October 1, 2024. Fossil gas has dropped since 2015 and dramatically declined in 2020 – by 15%. The UK's officials recommend a 2035 fossil gas phase-out [20].

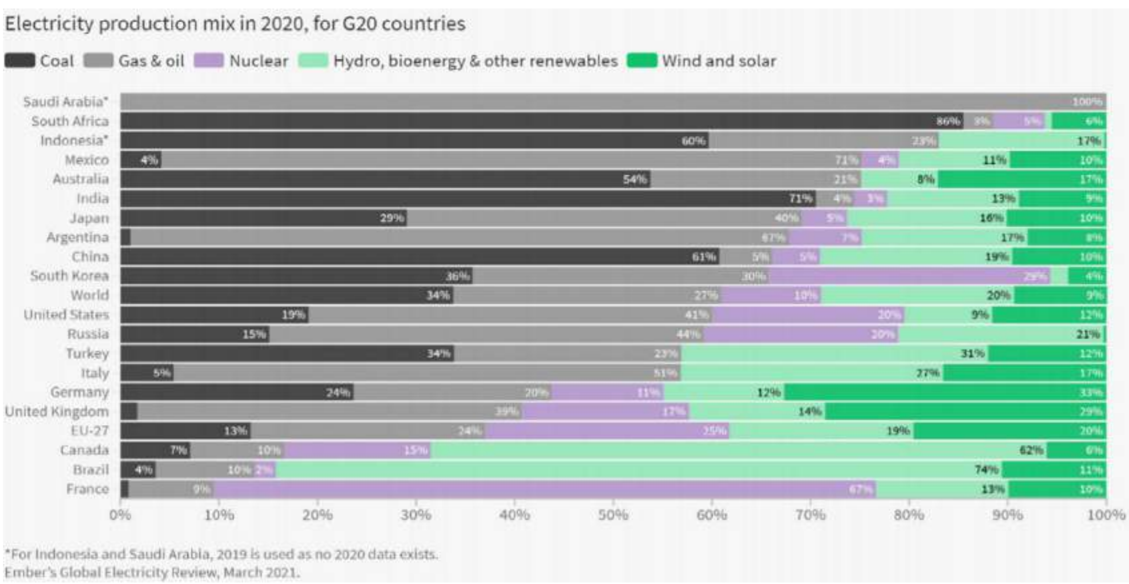

Fig. 1. Electricity mix in G20 countries, 2020 [14]

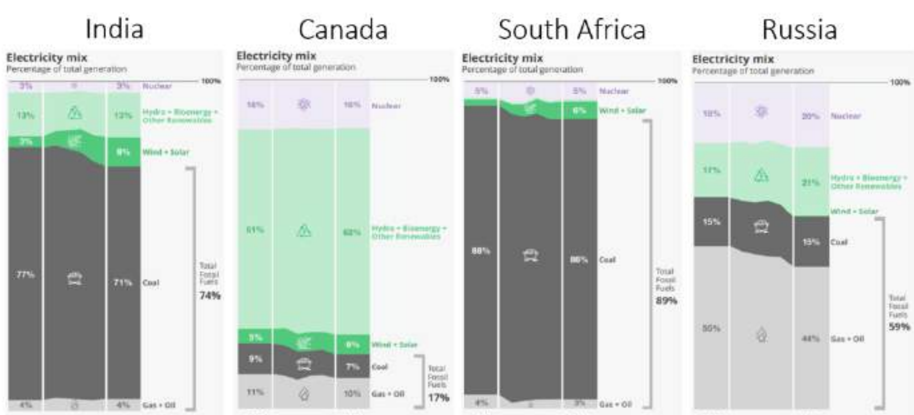

Fig. 2. Electricity mix in several countries, 2015 – 2020, [17]-[19]

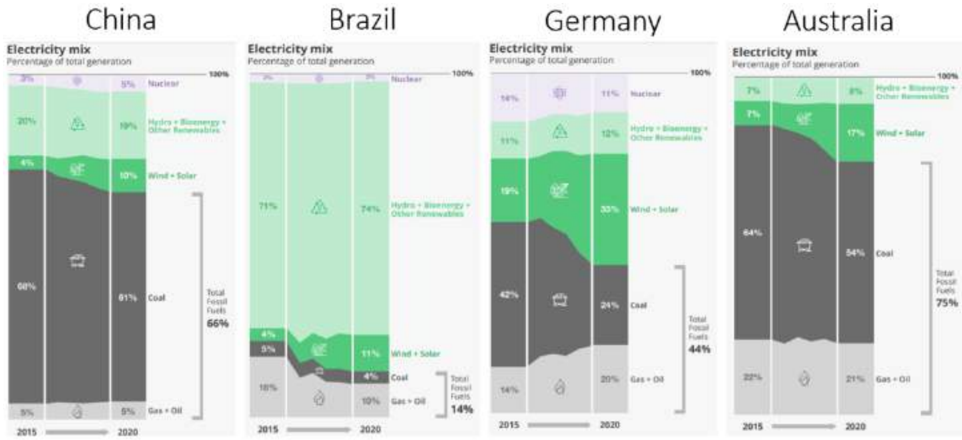

Fig. 3. Electricity mix in several countries, 2015 – 2020, [17]-[19]

F. Canada

Canada's electricity transition has decelerated in recent years. The share of wind and solar has only increased by 1% to 6% in 2015-2020 and is far below the global average of 9.4%. There has also been a slow reduction in coal-based generation – from 9% of the electricity mix in 2015 to 7%, in 2020. Despite Canada's modest progress with wind and solar in G20, it places the second after Brazil in terms of the share of renewables in the electricity mix (69% vs. 85% in Brazil) because of its abundant hydro. In 2018, Canada announced the intention to phase out coal and have a 90% low-carbon share in the electricity mix by 2030. Provided that low-carbon sources already make up 83% of the power mix, a goal of
90% in 12 years seems pretty easy to achieve. Canada is wellpositioned to set a lot more ambitious target. A net-zero goals of 2035 or even 2030 would be feasible if the shift from fossil fuels happened at a pace comparable to the US' rate of coal reduction [21]. The field of energy storage is growing rapidly:
Canada currently has a total utility-scale storage capacity of more than 130 MW/250 MWh, 10% of which came online in 2020 alone. System operators and regulators are actively working on options for integrating storage into the grid, including a review of market rules in Ontario and Alberta and pilot projects in Quebec and Saskatchewan [22].

G. South Africa

In South Africa, 89% of electricity comes from fossil fuels, with coal alone providing 86%. In 2015-2020, the share of renewables increased from 2.5% to 6.2% — as coal-fired production has dropped. The decline in the fossil-fired generation has been largely driven by unreliability of coal plants; recently, unplanned outages at coal plants have caused rolling blackouts. Wind and solar provide for almost all renewable electricity in South Africa. Although their share in the electricity mix almost tripled in 2015-2020, it is still lower than the world average. There is also a nuclear power plant, which supplies 5% of the demand and will be operable for another 20 years [23].

H. Saudi Arabia

Despite continual assurances by the government, Saudi Arabia's shift to sustainable energy is practically non-existent – in 2020, the share of wind and solar in the electricity mix was below 0.05% [24].

I. Russia

Russia's share of fossil-fired electricity is 59%, with gas providing 43%, and coal making up another 15%. It almost equals the global average of 61%, with nuclear and hydro producing the rest of electricity. Russia's share of renewables in the electricity mix is 21% – and it is almost entirely hydro (20%). In 2020, just 0.3% of electricity was produced by wind and solar. Russia's power system has seen very little structural change over the last several years. There was only minor growth in wind and solar capacity. While hydro generation has increased by 4% since 2015, this has been due to anomalous weather conditions rather than new installations [25].

J. India

The shift to renewable energy is a priority in India. India aims to introduce 175 GW of renewables by 2022, with 100 GW of PV and 60 GW of wind, as well as bioenergy and small hydro. By 2030, this objective will be adjusted to 450 GW, making system flexibility a major concern of system operators and policy makers. Achieving India's renewable targets will require enhanced planning and coordination from the government. At the same time, India's states are in different levels of system integration and some of them might face great challenges [26]. Wind and solar drove the low-carbon generation growth in 2015-2020. India's wind and solar share in the power mix (8.9%) was close to the world average in 2020. Hydro and nuclear shares remained stable at 12% and 3%, respectively [27]. Coal still supplies 71% of electricity. In 2015-2020, the coal generation increased by 9% because the growth in renewables did not keep up with the rise in the demand [26]. The development of wind and solar in India is hampered by numerous barriers related to grid integration, land acquisition, lack of investment into battery storage, poor financial state of discos, and lack of sound state-level policies. For instance, SECI, India's nodal agency, has allocated 10,330 MW of wind capacity since 2017. However, only 2,307 MW is being operated down to grid connectivity delays and land acquisition issues. Many wind projects were planned to arise in Gujarat, which has well-suited locations for wind power plants, but the state refused to lease land to the auction winners. Faced with these difficulties, some winners have even sought to abandon their power purchase agreements [28].

K. Nuclear Energy

Nuclear energy is the second-largest non-fossil source of electricity after hydro. Around 10% of the world electricity is being produced by 441 nuclear reactors, 30% of which are located in the US. Most of the nuclear expansion is driven by new reactors coming into operation in Asia and the Middle East. China and India are driving the most growth. The slight sagging from 450 operating plants in 2018 to 443 in 2019 was due to shutdowns in North America and Europe. These two continents comprise the majority of the world's reactors and also have the oldest ones, with many being retired. Currently, Europe is leading the course in reducing dependency on nuclear. Germany is going to close all nuclear plants by 2022, and Italy has become the pioneer country to shut down all the plants. However, Europe is still the most nuclear-reliant territory. In 2019, nuclear accounted for 26.4% of the total electricity produced in the EU-27. Nuclear power production in the EU-27 decreased by 16.3% in 2006-2019, mostly because of the shutdown of reactors in Germany [29].

L. Storage

Battery storage is crucial for expansion of renewables because it offers the required flexibility to support the integration of variable low-carbon generation to the grid. Decreasing costs and improving performance are promoting the market for storage. Combined solar and storage will constitute most of new deployments in 2021. Asia-Pacific (APAC) was the largest market for battery storage systems in 2020, having 49.9% of the global installed capacity. Europe, Middle East and Africa (EMEA) was the second largest market, with 30% of the global installed capacity in 2020. The Americas had around 21.1% of the global installed capacity by 2020 and the US was the largest market across the globe. Policy support is one of the top drivers for battery storage technologies in the US. APAC is expected to retain its leadership until 2025, with a market share of 53.5%, followed by EMEA and the Americas. China will likely surpass the US as the major market, with an expected 12 GW of the installed storage capacity in 2025. The UK and Germany are expected to be the top European storage markets. The Middle East and Africa are not expected to become notable in the global market until 2025; however, they are projected to succeed in the long run [30].

M. Electric Vehicles

2020 was a great year for plug-in vehicles: global sales increased by 44% from 2.26 mln. in 2019 (see Fig. 3). The boost was caused by the development of new attractive models, the 95g CO2 standard, incentives by green recovery funds, improved availability, and marketing of EVs. Europe accounted

for 43% of global EV sales in 2020 vs 26% in 2019 and overtook China as the driver of EV growth. Germany became the 2nd largest EV market after China. Outside Europe, the EVs growth was slower but still substantial. In the US, EV sales increased by a modest 4%, despite the start of the sales of Tesla Model-Y. Markets in Japan, Canada, and Australia saw declines, although increases in South Korea, India, Taiwan, Israel, Hong Kong, and UAE compensated for these drops. In 2021, 4.6 mln. sales are expected with higher growth in China and North America. Europe will hardly repeat the 137% boost of 2020, but 2 mln. sales are feasible [31].

N. Hydropower

The global hydropower installed capacity was 1308 GW in 2019, with a projected increase of 14.5% by 2026. Hydropower is the leading renewable source in terms of installed capacity (46% of total renewable capacity). Large hydropower (over 100 MW) is the most prominent segment due to increasing investment and global efforts to shift towards sustainable energy. The top 20 countries by new planned hydropower capacity are in Asia, Africa, and South America. China is the leader with 93 GW in the development pipeline. South Asia has the largest hydropower development pipeline (118 GW, see Fig. 4). However, East Asia has the largest capacity “under construction”. South Asia, Southeast Asia, and Oceania have the largest number of projects—more than 600 each—but their average capacity is significantly lower than in East Asia. Around the globe, the public domain status of waterways and the multiple uses of water reservoirs cause administrative intricacies. The need for coordination from agencies at various government levels, along with extensive study requirements and stakeholder consultations, result in multiyear hydropower authorization processes. Another factor is the negative environmental consequences, which may hinder hydropower growth in different regions [32].

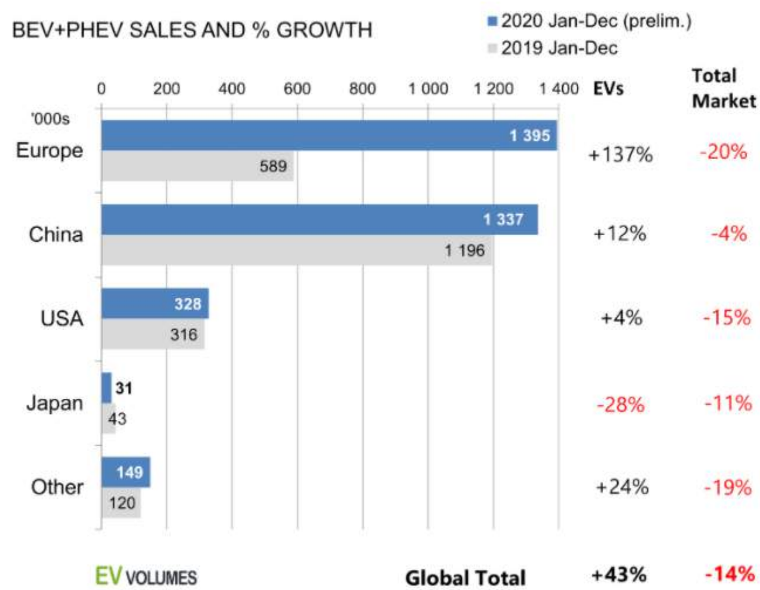

Fig. 3. EV and % growth in 2019 and 2020 [31]

IV. Historical trends, current and projected costs of low-carbon generation

Renewable generation costs have declined sharply over the past decade, owing to economies of scale, competitive supply chains, and improving technologies. They are now competitive, in LCOE terms (LCOE – the average cost of electricity production over the plant lifetime), with dispatchable fossil fired generation in many countries [36]. Solar PV and onshore wind are now the cheapest options for new-build generation facilities for at least 65% of the world's population. Those people live in territories that account for 71% of GDP and 85% of power generation. Battery storage is currently the cheapest new-build option for peaking applications (up to 2 hours-long discharge) in gas-importing areas, such as Europe, Japan, or China [33]. In 2010-2020, costs for electricity from utility-scale PV fell by over 80%, while that of onshore wind fell 60% (see Fig. 5). In 2020, the global LCOE for utility-scale PV and onshore wind were \$50/MWh and \$44/MWh, respectively. Today, the best PV projects in the Middle-East, China, and Chile, or wind projects in Brazil, India, and the US, can be even less than \$30/MWh [33].

The LCOE decline for solar was due to over 90% reduction in module prices in 2010-2020, and over 80% reduction in balance-of-system costs over the same period [36]. The drop in costs for onshore wind is largely due to a scale-up in turbine size, now 4.1 MW on average, and a reduction in installed costs. The LCOE of solar and wind are anticipated to drop further: LCOE of the best wind and solar projects will be below \$20/MWh before 2030 [33]. Over the last decade, the global LCOE of offshore wind had fallen by 60% to about \$80/MWh. The major reasons are similar to those for onshore wind: installed costs fell 18% over the decade and capacity factor improved from

37% to 44% due to a scale-up in turbine size. Operation and maintenance costs similarly dropped with larger turbine sizes and enhanced service capacities. Results of recent auctions project a strong change in competitiveness for offshore wind in the 2020s, with electricity prices in a range of $50 and $100/MWh [36]. The global LCOE of new hydropower projects saw falls and rises, with the overall 27% increase to $47/MWh, in 2010-2019. Such increase has been mostly driven by rising installed costs, particularly in Asia. Asia had an increased number of projects with more expensive development compared to earlier projects – primarily due to locations with challenging site conditions. Despite this volatility in costs, hydropower is still very competitive: 90% of all capacity commissioned in 2019 produced cheaper electricity than the cheapest new fossil-fired plant [36]. The LCOE for battery storage has fallen to $150/MWh in 2020, about half of what it was in 2018, due to a rapidly expanding manufacturing base, increasing project sizes, and more energy-dense technologies. Li-I battery pack prices have fallen 89% from $1,1/MWh – in 2010 – to $0,137/MWh – in 2020. By 2023, average prices will be close to $0,1/MWh. At this price, auto producers will be able to produce and sell mass-market EVs at the same price (and with the same margin) as comparable traditional vehicles. Battery pack prices are expected to further drop to $58/kWh by 2030. One possible pathway to such a price is the use of solid-state batteries. The cost of producing these cells at scale could be just 40% of the cost of current Li-I batteries [34]. Fig. 6 shows projected LCOE for both renewable and nonrenewable technologies in 2025 (from IEA latest report [35]).

V. Identification of technical and economic barriers for further deployment of low-carbon generation

The technical and economic barriers stated below are to a different extent faced by any country, depending on its progress in the transition towards non-fossil generation.

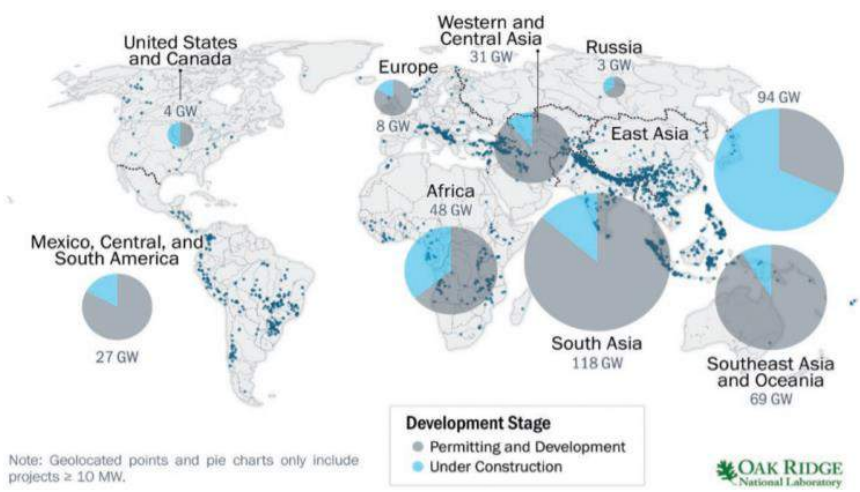

Fig. 4. Map of hydropower project development by region and development stage, end of 2019 [49]

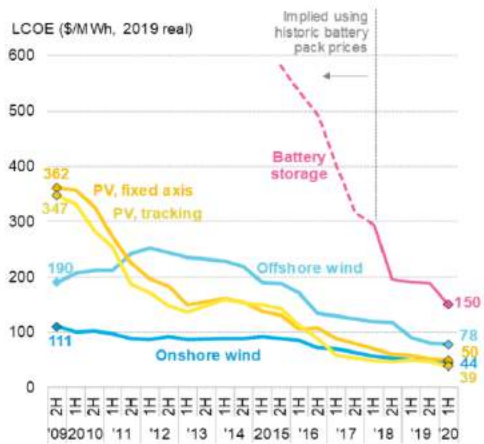

Fig. 5.Flobal LCOE, 2020 – PV, wind, and battery storage

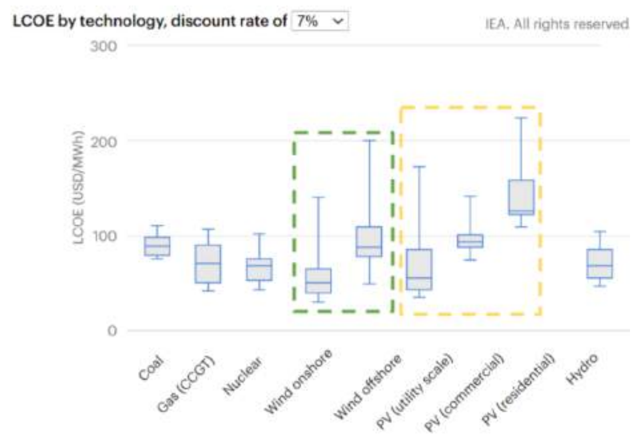

Fig. 6. Projected LCOE in 2025

A. Economic barriers for low-carbon generation

The major economic and financial factors impeding the expansion of low-carbon generation are high initial investment, lack of financial institutes and investors, competition from fossil fuels, and fewer subsidies than for fuel sources [37].

1) Tough competition from fossil fuels: fossil fuels are expected to remain an important player providing 78% of the global energy in 2050, according to EIA's report [38]. In 2016, investment in fossil-fired generation accounted for 55% vs. 16% for renewables. Coal is still seen as a cheap and accessible fuel source in many regions due to its abundance [38].

2) High initial capital costs are typical for renewable sources because of their low efficiencies [39]. Resulting high LCOEs may discourage potential investors.

3) Compared to renewables, fossil-fired generation is more heavily subsidized by governments. For example, the Chinese government provides a considerable support to coal-fired generation every year [40]. Restricted investment in low-carbon energy may restrain its expansion.

4) The renewable industry is considered somewhat risky due to some specific financial and technical features, which may demotivate potential investors [41]. Besides, it is quite young and immature as compared to fossil based generation, so there exist fewer financial instruments and organizations for financing of renewable projects [39].

5) Lack of consideration of intangible costs: almost everywhere, total cost of electricity only includes the cost of generation (exploration), distribution, and usage. It does not include the cost of environmental and health damage. Despite the outrageous negative effects on the health and the atmosphere, such costs associated with fossil fuels are not considered in the electricity price [42].

B. Technical barriers for low-carbon generation

There are a number of legitimate technical barriers, which include: limited availability of the infrastructure, inefficient knowledge of the operation and maintenance, lack of research and development initiatives, and some technical complexities such as energy storage and lack of necessary standards [43].

1) Limited availability of the necessary infrastructure and facilities prevails in developing countries, where the major concern is a reliable power supply. That somewhat puts aside environmental concerns, which hampers policies and actions towards the expansion of renewables.

If such a technology is available, it may then be prohibitively expensive. Renewable generation units are mostly placed in remote sites of cities; they then require additional lines to connect to the main grid.

The existing grids need to be upgraded or modified because transmission lines are generally designed for conventional energy and not for renewables [44].

2) The renewable industry may be still lacking operation and maintenance awareness because it is relatively new and immature. As a result, high efficiencies cannot be always attained [45].

3) The renewable industry may also lack R&D opportunities because it is still in its development stage and somewhat risky, so that governments and energy firms may be reluctant to finance such R&D activities [46].

4) There are not enough technical standards, procedures, and guidelines in the renewable industry, which would set durability, reliability, and performance requirements. This is an obstacle for a large scale commercialization
[47]. One of the major technical issues is storage. The solar and wind supply is intermittent and electrical grids must always balance the demand and supply. Utility scale battery storage is a must to provide the required flexibility [48].

VI. Conclusion

In this study, we attempted to provide a solid overview of the current state and costs of low-carbon generation on the global scale and in different countries. We saw that the rapid expansion of renewables in recent years was largely dictated by the global appeal to cut down carbon dioxide emissions, which contribute to climate change. Though relatively immature as compared to the traditional generation, the renewable industry is actively developing due to multiple factors such as governmental policies and subsidies, improving technologies, economies of scale, market development, competitive supply chains, the activity of international organizations, and others. However, there are also factors, which may complicate the transition to low-carbon energy. We covered basic technical and economic barriers in Chapter V – keeping in mind that all these barriers are gradually vanishing as we are expanding our experience with renewables, increasing our insights, and developing more efficient policies. Along with technical and economic factors, each country may have specific features, which may affect its low-carbon progress, and face additional challenges. For example, Russian RE policies are much more passive as compared to India. At the same time, India faced public and municipal deprecations with its wind projects.

Abundant hydro resources in Russia, Canada, and Indonesia strangely enough are having an adverse effect on wind and solar development – there is basically no motivation for deploying additional RE. The electricity demand in China and India is increasing faster than wind and solar, so these countries have to increase fossil-fired generation. Ambitions are crucial – Canada has a better initial position than the US, however, its RE policies are quite humble. The trend in RE over the last decade was towards lower costs and costs are projected to be further decreasing. PV and onshore wind are now the cheapest sources of the new generation for about 65% of the global population. Battery storage is currently the cheapest new-build technology for peaking applications in gas-importing regions, such as Europe, Japan, and China. LCOEs of the best wind and solar projects are expected to be below $20/MWh before 2030 and average battery pack prices will be about $58/kWh by 2030.

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