Renewable Energy in Russia: A Forthcoming Transformation Driven by Economic and Industrial Factors

Mario Pagliaro[a]

Abstract: With a relatively small population, Russia accesses huge oil, natural gas, coal and uranium resources, and hosts advanced nuclear energy, oil and natural gas industries. However, the combined effect of today's low cost electricity generation via photovoltaic modules, water and wind turbines and similarly low cost storage in Li-ion battery and solar hydrogen obtained via water electrolysis will have a profound impact on Russia's energy and automotive industries.

Keywords: Russia; solar power; hydrogen energy; electric vehicle; lithium battery

1. Introduction

Tsarist Russia hosted an advanced oil industry with several oil refineries (export of crude oil was forbidden), but it lagged behind in electrification [1]. By 1913 Russia hosted 327 MW of installed power, 177 MW of which were located in just three cities: the capital St. Petersburg, Moscow and Baku [2]. World War I and the subsequent civil war worsened matters. In the early 1920s the overall power from all the Russian power stations had decreased to about 70 MW, producing about 500 million kWh of electrical energy [3].

On February 7, 1920, the State electrification commission (GOELRO) was formed and tasked to devise a plan for electrifying the country. By December 2020, the commission presented the delegates of the 8th All-Russia Congress of Soviets held in Moscow a document of more than five hundred pages urging the construction in 10 years of a network of huge ("regional" in a country whose regions are as large as entire countries) thermal, hydropower power, and combined heat and power stations [1,2].

By 1935 the output of electricity in Russia had reached 13.5 billion kWh from 2 billion kWh in 1913 [4]. After World War II, Russia pioneered the use of nuclear power with the world's first nuclear power plant (a 5 MW reactor) located in Obninsk, about 100 km southwest of Moscow, connected to the power grid in June 1954 [5].

Today Russia hosts 700 electric power stations with a total installed capacity of 243 GW (comprised of 165 GW thermoelectric power plants mostly burning natural gas and coal; 29.13 GW nuclear power reactors, and 48.5 GW hydroelectric plants). All combined, the aforementioned power plants in 2018 produced 1091.7 TWh of electricity dispatched in the form of alternating current with a single 50 Hz current frequency across the world's longest (3.018 million km) electric power lines [6].

[a] Dr M. Pagliaro
Istituto per lo Studio dei Materiali Nanostrutturati, CNR
via U. La Malfa 153
90146 Palermo (Italy)
E-mail: mario.pagliaro@cnr.it
Web: www.qualitas1998.net

In accordance with the 2003 law "On electric power industry", the electricity market in Russia is open (since 2011) to full competition in generation by ensuring third party access to the grid. The energy market regulator is the "NP Market Council" whose main task is to ensure the correct functioning of the national wholesale electricity and power capacity market. All companies in the wholesale electricity market must become member of the NP Market Council, which by mid May 2018 had 415 members [7].

In 2018 Russia's thermal power plants including those of large industrial firms produced 693 TWh, hydroelectric dams gave a 194 TWh output, and nuclear reactors afforded over 204 TWh, with two new nuclear reactors entering service in Leningrad region nuclear power station and in Rostov [6].

Russia is the world's 2nd natural gas [7], the 3rd largest oil [8] and the 6th largest uranium [9] and coal [10] producer. The nation globally ranks second in oil, first in natural gas exports and third in coal exports.

Though being the world's largest country, Russia hosts only 143.2 million inhabitants, less than Nigeria. Its natural gas, oil, coal and uranium reserves are immense. Why then should Russia be willing to develop electricity production from intermittent wind and solar energy, or start manufacturing electric vehicles?

The reasons, I argue in this study, are of economic and industrial nature. Putting arguments in the rapidly evolving international energy context, this study provides arguments justifying this forecast.

2. Renewables in Russia

Since mid 2013 the development of renewable energy in Russia, is regulated by a decree entitled "On Procedure for Incitement of Use of Renewable Energy Sources at Wholesale Power Market" [11].

The law establishes a system for which renewable energy developers of projects with an output between (at least) 5 MW and 25 MW can bid in annual tenders for capacity supply contracts with Russia's Administrator of the Trading System.

Winning suppliers are paid both for the capacity they add to the energy system, and for the energy they supply, based on long-term 15-year contracts with fixed tariffs [11], provided that wind, solar and hydro projects source 55%, 50% and

20% of production equipment from within Russia (in 2016, these figures were increased to 65%, 70% and 45%).

To avoid a rise on electricity prices, yearly limits control the increase of newly added renewable generation capacity. According to a government's resolution of May 2013 auctioned power between 2014 and 2020 cannot surpass the 5871 MW threshold (3600 MW wind, 1520 PV and 751 MW small hydro).

Figure 1. The Yelshanskaya 25 MW photovoltaic park in the Orenburg region supplies power to the grid since July 1, 2019. Using only components made in Russia, the plant is expected to produce 30.5 million kWh annually. [Image courtesy of Hevel Energy Group, Reproduced from hevelsolar.com].

Between 2013 and 2016, slightly more than 2 GW of renewable capacity was awarded in the annual tenders. The 2017 auction saw a total of 2.2 GW across wind, solar and small hydro awarded in a single tender. The 2018 auction had 1.08 GW of capacity distributed across 39 projects [12]. Finally, in 2019 the competitive tender for new renewable energy capacity from 2019 to 2024 was set at slightly more than 313 MW, most of which comprised of new hydro power capacity (about 230 MW), followed by wind (78 MW) and only 5.6 MW new photovoltaic power (Figure 1, to be connected to the grid in 2022) [12].

The effects of the newly installed wind, solar and hydroelectric power capacity on power generation became noticeable in 2018 when production of wind energy in Russia rose by 69.2%, and that from PV by 35.7%. Combined, wind and solar PV output crossed the 1 TWh threshold [6]. Even more importantly, the amount of time during which wind and solar PV parks in Russia in 2018 supplied energy at their nameplate capacity was, respectively, 1602 and 1283 hours.

Russia's almost unlimited land available for development, the latter long functioning times, and the low and decreasing cost of both PV and wind power generation systems create the conditions for significant penetration of wind and solar PV in Russia's energy mix via utility-scale PV and wind parks coupled to storage in large Li-ion battery and solar hydrogen systems.

In other words, the combined effect of today's low-cost power generation and storage via, respectively, photovoltaic, wind turbine, Li-ion battery and solar hydrogen technologies will shortly have a profound impact on Russia's energy and mobility industries.

3 Electric Vehicles

"New energy vehicle" (NEV) is the name aptly given by China's government to vehicles including battery electric vehicles, plug-in hybrids and hydrogen fuel cell vehicles. The use of the "new energy" term to indicate electric vehicles (EVs) is revealing as it points to their forthcoming impact on the global energy system, in which Russia, supplying natural gas and oil to numerous countries, plays a crucially important role.

Generous and prolonged subsidies to support NEV sales (over $30 billion between 2009, year of subsidy introduction, and 2018 [13]) drove in China mass production of both Li-ion batteries and battery electric vehicles. By the end of 2018 China's cities hosted 380,000 electric buses (or 56% of the country's public bus fleet [14].

Only in the first nine months of 2019, 880,000 NEVs were sold in China (+35% year on year), 90% of which were passenger cars, 5% buses, and 5% special purpose vehicles such as trucks and vans [15].

Since July 2019 subsidies to EV sales in China were cut by up to 60%, and it is expected they will be fully cancelled in 2020 [16]. In other words, in China EVs are ready to compete with internal combustion engine (ICE) vehicles without subsidies.

Today's EVs are competitive because the cost of Li-ion batteries manufactured and marketed in China was below $100/kWh already by late 2018 [17].

As put it by the managing director of a reputed lithium battery consultancy based in Britain during a US Senate hearing on the supply chain for EV batteries and energy storage held on early 2019:

> «We are in the midst of a global battery arms race, in which so far the US is a bystander. The advent of electric vehicles and energy storage has sparked a wave of battery megafactories that are being built around the world.
>
> «Since my last testimony only 14 months ago we have gone from 17 lithium ion battery megafactories to 70. In gigawatt hour-terms we have gone from 289 GWh to 1,549 GWh, that's the equivalent of 22 million pure electric vehicles worth of battery capacity in the pipeline.
>
> «The scale and speed of this growth is unprecedented and it will have a profound impact on the raw materials that fuel these battery plants. The scale of investment will also drive the cost of lithium ion battery production down below $100 kWh this year [18]».

The consultant provided also figures for the US import dependency for the main minerals used to manufacture Li-ion batteries in 2018: 59% for nickel, 92% for lithium, and 100% for cobalt and graphite [18].

In Russia, the price of electricity is extremely low, and the grid is ubiquitous. Shifting mobility from internal combustion engine to electric vehicles therefore is an economically convenient opportunity starting from companies and cities operating large vehicle fleets.

The State owned company managing the 6,500 Moscow's bus fleet has already ordered 300 electric buses. All bids required as mandatory contract condition the localization of the manufacture process within Russia. Indeed, the first 300 electric buses were commissioned to two Russia's automotive manufacturers (Kama and Gorky automobile plants: KamAZ and GAZ): 200 in Spring 2018 and 100 in April 2019.

The first electric buses started to circulate in Moscow streets on September 2018. Less than one year later, there were over 180 of them deployed on 13 e-bus routes, carrying more than 80,000 passengers every day [19].

Moscow's public transport company since 2021 will only purchase electric buses, completely discontinuing the purchase of diesel buses [19].

The electric bus supplied by Kamaz, which won the bid to supply 200 electric buses, makes use of lithium batteries using the lithium titanium oxide (LTO, lithium titanate)) cathode technology. The LTO cathode ensures high frost resistance (a key requirement in cold regions), extended service life, and fast charging, which eliminates the need for high storage capacity, lightens the bus and increases the passenger capacity.

Perhaps not surprisingly, Kamaz is currently building in Moscow a 500 vehicle/year production plant and a R&D innovation centre for electric buses [20].

Every 1000 battery electric buses, about 500 barrels of diesel are displaced every day [21], making the e-bus powered by electricity stored in Li-ion batteries (and shortly in solar hydrogen fueling hydrogen fuel cells) the first electric vehicle to become ubiquitous across the world, entirely replacing buses and coaches powered by diesel or natural gas fuels burned in internal combustion engines [22].

4. Electric mobility, stationary storage

With 1.8 million passenger cars sold in 2018 and more than three million vehicles produced yearly, Russia is one of the 12 largest automobile markets worldwide [23]. Around 400,000 workers are employed in automotive manufacturing facilities and special economic zones, where tax and customs benefits are granted to manufacturers and public financing of infrastructure construction is provided [23].

As shown by the case of electric buses ongoing mass scale delivery in Moscow, Russia's automotive industry has in "new energy" vehicles powered by electricity stored in Li-ion batteries the first real opportunity to emerge as a leading automotive manufacturer refocusing production from ICE to battery electric vehicles so far mostly produced in China.

Along with lithium, nickel, iron, cobalt and graphite are the main minerals used to produce Li-ion batteries. Russia in the world's largest nickel manufacturer and 7th largest graphite manufacturer [24]. Significant increase in graphite production is expected during the next several years due to two ongoing investment projects (Dalgrafit and Uralgraphite).

When it opened in in Novosibirsk, Siberia, in 2011 as a joint venture between a Chinese lithium battery manufacturer and state-owned Rusnano technology group, the lithium-ion battery plant using the safe and reliable lithium-iron phosphate (LFP) cathode technology was "the world's largest" [25].

The plant was expected to produce "up to 500,000 lithium batteries per year, to supply electric vehicles and larger bus batteries, in addition to a variety of energy storage applications, and emergency power supplies" [25].

According to market analysts based in Britain the company "saw downtimes between 2014 and 2016" due to "continuous ruble devaluations that pushed up the cost of imports" [26], namely the import of battery-grade lithium carbonate from abroad needed to manufacture the battery cathodes.

It is instructive thus to learn that Russia's state nuclear company "pursuing its goal of applying lithium ion battery technology in the Russian economy" lately signed an agreement outlining the acquisition of up to a 51% ownership in a Atacama lithium project in northern Chile… after sealing a non-binding agreement in July with Bolivia's energy ministry to cooperate in developing lithium deposits and making lithium products" [26].

Russia, in other words, is trying to secure supply of strategically important lithium to manufacture batteries on the multi gigawatthour scale required for mass producing electric vehicles (a 1 GWh storage capacity is enough to equip 40,000 electric cars with a 50 kWh battery pack each).

As shown by the first 100-500 MWh ESS deployed in Australia, California, Hawaii and numerous regions of China, coupled to energy storage systems (ESS) based on containairized Li-ion batteries, intermittent renewable power produced at low cost by utility-scale PV and wind parks becomes of higher quality (precise frequency of alternate current, reliability and immediate availability) than power produced by state of the art gas-fired thermoelectric power plants [27].

In brief, as the ongoing solar energy PV revolution unfolds [28], the potential of PV in Russia will be fully realized when the country will access energy storage systems based on Li-ion battery at the low cost and on mass scale.

By then, Russia will use renewable power plus ESS in place of the diesel-fired thermoelectric power units currently used to supply Russian citizens in sparsely populating areas of the country connected to local grids powered by said thermoelectric stations.

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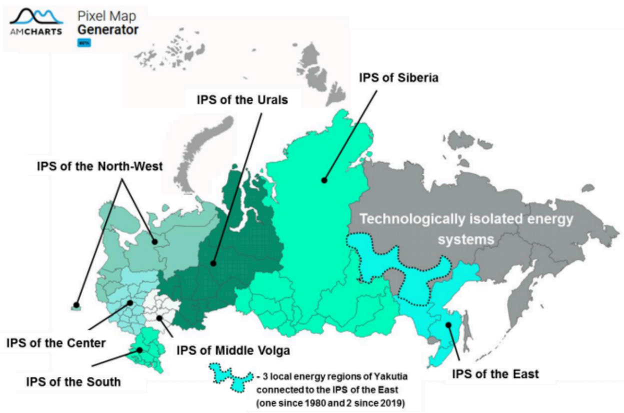

Figure 2. The seven integrated power systems of Russia's unified power system. The geographically isolated energy systems are Chukotka Autonomous Okrug, Kamchatka Territory, Sakhalin and Magadan Oblast, Norilsk energy Districts of Taimyr and Nikolaev, western energy systems of Sakha (Yakutia) [Image courtesy of eclareon, Reproduced from Ref.29].

We briefly remind that the unified energy system of Russia (UES) is divided into seven integrated energy (or power) systems (IES or IPS of the South, Center, Middle Volga, North-West, Urals, East and Siberia) and a huge area of geographically isolated energy systems (Figure 2), representing a total of 71 regional power systems and different owner structures [29].

With an excellent performance of 1283 hours in terms of kWh/kW$_p$ in 2018 for the first 834 MW of PV power installed in Russia [6], generating power at overly low generation cost of today's photovoltaic technology is now an achieved outcome also for Russia.

The results of a recent study aimed at identifying which renewable energy source and where in Russia has the highest potential revealed that even in Krasnoyarsk Region which "seems to be a territory with a northern climate, the actual potential of solar power in the region, which combined with other renewable sources of energy relevant to each municipal entity, outlines a solution for thinly populated, agricultural and remote areas" [30].

For example, large manufacturers of solar modules in China already commercialize bifacial PV modules of 460 W nominal power at less than $0.3/W. Supplied with a linear performance warranty guaranteeing peak performance for 25 years, such modules are made of half-cut cell in monocrystalline silicon using the PERC (passivated emitter and rear cell) technology and 9 busbars to ease the electricity flow [31].

5. Solar hydrogen: Heavy duty transport and low temperature heat

Solar hydrogen, namely hydrogen produced via water electrolysis using overly abundant solar and wind power [32], is also in Russia the complementary, and necessary, energy storage technology that will rapidly adopted in Russia to power heavy duty electric vehicles and provide electricity *and* low temperature heat to buildings.

Using technology developed by a France's train manufacturer, Germany In late 2018 was the world's first country to launch on a commercial route two electric trains powered by electricity generated onboard by fuel cells converting hydrogen stored at 350 bar [33].

Derived by the analogous commercial diesel train (same train dimensions and no significant changes in weight/point of gravity), the new hydrogen train re-uses all main components (*i.e.*, bogie), and avoids adding equipment in passenger areas, with only positive impact on passenger experience and comfort. In other words, the hydrogen fuel cell technology can be scaled and used to retrofit existing fleets [33].

To date, the trains safely and reliably have been running for over one year on a non-electrified route in Lower Saxony demonstrating the full economic and technical viability of the technology. A few months after the debut, the Lower Saxony railway company ordered 14 hydrogen fuel cell trains to the French train manufacturer followed by another 27 trains order from a subsidiary of Rhine-Main Transport Authority, in each case to replace diesel trains on regional lines.

It may not come as a surprise, that in Autumn 2019 Russian Railways reached an agreement with the country's largest locomotive and train manufacturer and with the State-owned nuclear energy company for the production of the first Russia's trains using hydrogen fuel cells to be first deployed in the Sakhalin region [34].

Russia hosts several electrolyser manufacturers. The largest, PJSC Uralkhimmash, produces in Yekaterinburg electrolysers with a capacity of 4 to 300 cubic meters of hydrogen per hour [35]. Platinum in very low amount is the noble metal currently used as catalyst at both electrodes, particularly for the oxygen reduction reaction, in state of the art industrial hydrogen fuel cells. With over 25 tonnes of platinum mined annually, Russia is the world's second largest platinum manufacturer after South Africa.

The hydrogen fuel cell technology, and in particular the proton exchange membrane (PEM) technology, is now so advanced and industrially scalable with ease that China in seven months only increased the installed capacity of hydrogen fuel cells by 643% to almost 46 MW [36], with 1,176 hydrogen fuel cell electric buses manufactured and sold in China practically from zero between 2018 and 2019.

Soviet Union was leading the field of alkaline fuel cells. A large number of research institutes are engaged in Russia with research and development activities in the field of hydrogen fuel cells, and their role, including that of the OOO National Innovation Company New Power Engineering Projects (2006-2010) was recently recounted [37].

Along with electricity, H_2 fuel cells generate low temperature heat in the form of water at 70-80 °C, which is ideally suited to provide sanitary hot water to buildings.

The energy density of hydrogen is so high (120 MJ/kg for H_2 *vs.* 43 MJ/kg for diesel fuel) that it is enough to store the excess PV energy generated during Spring and Summer as electrolytic H_2 under pressure in today's safe reservoirs in composite material to provide off-grid buildings with power and hot water for the whole year even in Sweden (experiencing 220 days of rain each year) where the first off-grid homes of a public housing company powered only by solar hydrogen generated via water electrolysis driven by PV energy are currently being completed prior to customer delivery [38].

5. Outlook and Conclusions

The reason for which Russia will shortly emerge as a leading country in new energy technology based on renewable power generation and energy storage in Li-ion battery and solar hydrogen, I argue in this study, is of economic and industrial nature.

Aware that solar PV generation is the cheapest way to generate electricity, governments across the world in 2018 auctioned 81 GW of PV power out of about 100 GW installed globally.

In 2019 the amount of power contracts through a competitive procurement is expected to rise to 90 GW out of 114 GW expected [39]. In 2018, only seven countries installed between 1 and 5 GW of PV power, but by 2022 the number of such countries is expected to almost triple to 19 [39].

As countries increasingly replace thermoelectric power generation with solar and wind power, the demand of gas-fired turbines has gone from over 71.6 GW to less than 30 GW in 2018 [40].

Becoming a leading country in clean energy technology turns out to be for Russia's industry and economy an inevitable option as world's countries increasingly replace natural gas, oil and coal-fired thermoelectric plants *and* ICE vehicles with low cost renewable energy generation coupled to energy storage systems and EVs.

The country currently lags behind in solar cell, Li-ion battery, wind turbine, and hydrogen fuel cells manufacturing but it excels in practically all fields of science, with numerous milestone achievements in the areas of physics, chemistry, mathematics, aerospace, medicine and engineering. As put it by Hargittai, "there is no other city in the world that has so many memorials honoring scientists as Moscow" [41].

According to Russian scholars writing about Li-ion battery manufacturing in Russia, "the current level of competences, technologies, and production volumes in the Russian Federation does not meet the needs of modern and future markets" [42].

Yet, neither "competences" nor "technologies" can be a problem to scale-up Li-ion battery manufacturing in a country excelling in all fields of today's science and advanced technology manufacturing in fields far more complex than battery technology such as avionics, aerospace and nuclear energy.

As battery electric vehicles currently replace ICE vehicle sales in the world's largest automotive market (China) at over 1 million vehicle per year rate [43], Russia simply needs to develop its own national Li-ion battery and battery electric vehicle industry.

To unleash its potential in clean energy technology manufacturing, the country's government needs to re-invest part of the huge revenues coming from oil and natural gas sales abroad into developing the national clean energy technology industry. One single example renders said potential. Russia's sole solar cell and PV module manufacturer was established in 2009 by State-owned Rusnano technology group in Novocheboksarsk.

In 2018, the company (Hevel) started shipments of its new heterojunction solar modules replacing thin film modules not only to Russia's customers, but also to customers in Sweden, Thailand, Kazakhstan and other countries [44].

By mid 2019, the company completed the expansion of its heterojunction solar module production capacity from 160 to 260 MW annually. Though minuscule in volume in comparison to the yearly output of just one of the single top ten PV manufacturers (all based in China, with the first alone having delivered only in 2018 more than 11 GW of solar modules [45]), the new production line yields also 460 W bifacial modules with 144 half-cut bifacial cells, whose 460 W nominal power is fully in line with state of the art bifacial modules manufactured in China by the same world's leading PV manufacturer [31].

On July 1, 2019, Hevel connected to the grid a 25 MW solar park in Yelshanskaya (Figure 1). Alone, the plant will produce over 30 million kWh every year, saving the equivalent of 4 million m^3 of natural gas. All components of the power plant, including the inverters and support structures, were produced in Russia.

The competing dynamics of oil price, economic growth and oil extraction costs require that by 2025, even keeping the oil fraction in the global energy mix at the 2015 low level of approximately 33%, more than 11 additional million barrels per day will have to be added to current oil production levels [46]. Furthermore, this exceptional amount of extra oil should be available at low extraction costs, which poses an unresolvable dilemma.

In brief, driven by socioeconomic and energy global factors, mankind has no alternatives to switching to producing energy from renewable energy sources. The widespread uptake of decentralized solar energy systems in the built environment on a truly global scale is now a realistic objective for all world's countries [47]. Even in Moscow's huge (962 ha) Kuzminki-Lyublino park, 228 out of 505 existing lamps are ready to be replaced by solar street LED lights equipped with Li-ion batteries [48].

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The build-up of Russia's clean energy technology industry will require proper planning, rationalization efforts and the development of creative and effective policies which will include much-in-need new educational initiatives in today's solar energy science and technology [49].

Addressing the delegates of the 1920 All-Russia Congress of Soviets Ulianov (Lenin) said: "communism is Soviet government plus the electrification of the whole country". One century later, as the world enters 2020, with Russia fully electrified since decades and no longer a socialist economy, Lenin's insight might be reformulated as follows: "As renewable solar, water and wind electricity will soon power vehicles, buildings and industries, the government invests now part of the fossil fuel sales revenue to build the clean energy industry on the scale required by being the world's largest country" [50].

List of abbreviations

ESS = Energy Storage Systems
EV = Electric Vehicle
FC = Fuel Cell
ICE = Internal Combustion Engine
IES = Integrated Energy System
IPS = Integrated Power System
LED = Light Emitting Diode
LTO = Lithium Titanium Oxide (Lithium titanate)
NEV = New Energy Vehicle
PEM = Proton Exchange Membrane
PERC = Passivated Emitter and Rear Cell
PV = Photovoltaic
UES = Unified Energy System

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