Renewable Energy Sources and Technologies for the Transition to a Climate Neutral Economy

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Abstract: The paper focuses on the feasibility of the transition to a climate neutral economy from the point of view of existing technologies, the surface occupied by renewable energy power plants, the materials needed and the cost of energy production. Based on the existing situation and using rather conservative estimates regarding the energy supply from renewable sources as compared to the energy demand of the global economy, the conclusion is that this transition is fully feasible and that already some renewable sources of energy are cost-effective compared to the use of classical fuels, such as coal. The paper also highlights the importance of consistent political decisions in favour of this decade-long transition and the leading role of the European Union in this respect.

Key words: renewable energy sources, climate neutral economy, feasible technologies
JEL Classification: O33, O44, Q42, Q56

1. Overview

The transition to a climate neutral economy has become an increasingly acute priority during the past decade, as result of the clear manifestations of the impact of human activities on the environment. This impact is so significant that there is almost universal agreement among scientists that humankind has entered a new geological era, named the Anthropocene (Stromberg, 2013). The name of this era suggests that the characteristics of the environment on planet Earth have changed significantly due to human activity, this modification including the pollution of the soil, water, and air with plastic materials and other substances, even in the most remote corners of the world, including at the two poles. At the same time, climate change is distinctly visible and undeniable, even if it is difficult to assess the exact contribution of human activity to this change.

In this context, the majority of large (and even some smaller) economies have already presented plans and strategies in an attempt to became climate neutral until 2050 (2060 in case of China), with a progress of evaluation in 2030. The European Union is one of the most ambitious actors in this process, having already defined detailed strategies for energy system integration, the use of hydrogen to support decarbonisation, circular economy, just transition and others (European Commission, 2020).

The awareness of the impact and implications of human activities on the environment at a global scale started in the early 1970s but concrete actions appeared in the late 1980s, with the adoption of the Montreal Protocol in 1987 regarding the banning of substances that negatively affect the Earth's ozone layer (chlorofluorocarbons - CFCs) and thus expose people to harmful UV radiations. The implementation of this protocol has been a success, as almost 99% of these substances used as aerosols and refrigeration agents have been eliminated. In 2016, the Kigali Amendment to the Montreal Protocol added a new category of substances with similar utilizations and effects to this interdiction (hydrochlorofluorocarbons – HCFC). The success of these first attempts to globally regulate the use of substances harmful for the environment can be explained first of all by the fact that alternatives were available without modifying the technologies and therefore without involving huge costs and the harmful effect for people was clearly understood (UNEP, 2021).

The much larger and complex issue of climate change has been gradually recognized during the 1980s and led to the adoption of an international treaty on climate change under the aegis of the United Nations Organization: The United Nations Framework Convention on Climate Change (UNFCCC). This treaty was signed in 1992 and entered into force in 1994. The signatory countries meet annually during the Conference of Parties (COP) to evaluate progress and adopt further protocols reflecting the new developments in the climate change domain.

Key moments of the UNFCCC have been the signature of the Kyoto Protocol (which established emission reduction obligations only for developed countries) in 1997 and of the Paris Agreement (which established

emission reduction obligations for all countries) in 2015 (UNCC, 2020). These two international agreements are important steps in controlling the negative impact of human activities on the environment, but they are far from being fully adopted by all signatory states. An example of this long and difficult process of adoption and entering into force, not to mention implementation, is the position of the United States who signed the Paris Agreement, then withdrew from it in November 2020 and re-joined in February 2021 (UNCC, 2021).
While at present there is a broad consensus that all countries have to make efforts to maintain the increase of global temperature below 2 degrees Celsius compared to the pre-industrial era (1850 – 1900) the adoption of concrete steps in this respect is much more difficult. The difficulties arise from the following characteristics:
- the large-scale change of technologies in almost all domains of activity is objectively a long-term process, requiring huge funds, qualified people and logistic support;
- the economic, social and political implications of such changes are enormous, even difficult to quantify. There are significant risks that technological changes may lead to unemployment or increased inequality within countries and among countries (OECD, 2019);
- in order to be successful and fair, such a transition has to be implemented simultaneously at a global level, a fact that raises numerous challenges (as not all countries have the technologies and resources to undertake the transition, not all countries can cope with the economic and social implications, strict measures have to be implemented in order to avoid unfair competition from the part of those who will not observe the emission reduction obligations and will have lower production costs, etc.).

2. The technical dimensions of the transition to a climate neutral economy. Is this transition feasible?

While a lot of attention has been directed towards the international agreements related to limiting climate change, the technical dimensions of this transition's feasibility have been less present in the public eye. The transition to a climate neutral economy refers to a lot of aspects but, in our view, first and foremost, this transition refers to energy because energy is involved in all human activities, be they professional or personal.
From the perspective of energy generation and utilization, as well as from the perspective of the impact on the environment, energy sources can be classified into:

- Clean and renewable sources of energy (solar, wind, hydro, geo-thermal, tidal energy, etc.). Status: Available;
- Sources with low or moderate impact on environment (nuclear energy). Status: Available and improving;
- Sources with moderate impact on environment (carbon capture technologies using coal, methane, natural gas, oil). Status: Available and improving;
- Sources with high levels of impact on environment (coal). Status: Available;
- Clean and practically infinite source of energy (nuclear fusion). Status: Unavailable yet but under development based on numerous international and national projects (World Nuclear Association, 2021).

The technical dimensions of the transition to a climate neutral economy relate to how much clean energy we need to generate at present and in the future in order to satisfy human needs and to what extend we can generate this amount of energy using available technologies. From a practical point of view, these aspects refer to:

- How much energy in all forms is consumed at a global level at present and will be at given time horizons such as 2030 or 2050?
- What is the estimated potential of renewable sources of energy at global level and how much of this potential can be used with existing technologies?
- Would it be possible to satisfy 100% of the global energy requirements using only renewable energy sources and existing technologies?

As mentioned above, a global solution for lowering climate change and the soil, water, and air pollution requires the participation of all countries because such a solution must include all human activities. Also, due to the characteristics of globalization, including a high mobility of production factors, if the emission reduction requirements are not implemented by all countries, then the economic activities will simply migrate from the countries where the requirements are strictly implemented (such as the European Union) towards developing countries where the implementation may be less strict. This is not a hypothesis; it is a phenomenon that has already taken place for decades.

Given these considerations, one question may refer to the capability of large economies and of the world economy as a whole to support such a large-scale transition in a relatively limited time frame. The change of technologies to obtain a climate neutral economy is so huge that it can be compared to the first industrial revolution. In any case, this comparison may lead to both similarities and differences.
Similarities concern changes related to the sources of energy used, the management of human activities, values and social implications; differences relate to the scale of processes and the time frame. The first industrial revolution started at the end of the 18th century and the beginning of the 19th century in England and gradually included several other countries (France, Germany, and the United States). It was a long-term process and it developed at a time when human activities were too limited in scale to pose a threat to the global environment. Nowadays, the transition has to encompass the whole world economy and it is expected or, at least, desired to be completed until 2050, meaning in about 30 years from now as compared to about 200 years for the first 3 stages of the industrial revolution (if we begin counting from around 1760 when the first industrial revolution started, and end around the early 1970s (Kellogg., 1987) when the scientific community and public opinion became more aware of the environmental impact of human activity).
On a positive note, and based on the review of international literature on the subject, one can say that answers already exist for all these questions and they offer reasons for optimism. A study carried out in 2009 by Scientific American provided some figures in support of the idea that all human energy needs for the present and for the future can be met using renewable sources and existing technologies. That approach took into consideration as clean and renewable the primary sources of energy such as water, sun and wind while electricity and hydrogen were the main presumed energy carriers (Jacobson and Delucchi., 2009). Further studies have confirmed and updated in a favourable sense the findings of the 2009 research.

2.1. Feasibility of the supply of clean sources of energy

In order to provide a clear picture of the feasibility of a transition to a climate neutral economy, the following data can be used to compare the global consumption of energy and the global potential of renewable energies:

- The global consumption of energy in 2009 was of 12.5 TW (terawatts or trillion watts). In 2021 it is estimated at 17.7 TW (The World Counts, 2021). The energy represented by 1 TW is enough to light 10 billion 100 W electric bulbs simultaneously.
- According to International Atomic Energy Agency (IAEA, 2020) by 2030 the global consumption of energy will be of about 20.35 TW (an increase of 15% compared to 2019) and by 2050 it will be of about 24.6 TW (an increase of 39% compared to 2019).
- The global potential of the wind energy is of 1700 TW, of which 40 – 85 TW in easily accessible areas.
- The global potential of solar energy is of 6500 TW, of which 580 TW in easily accessible areas (Jacobson and , 2009).

It is obvious that such estimates are not very accurate and that they imply a number of hypotheses (like the number of days and hours of solar exposure or the wind intensity based on previous meteorological records, or the efficiency of conversion of solar panels and wind turbines at a given time) and different calculation methods. Nevertheless, however approximate such calculations may be, the order of magnitude between the needs and the potential demonstrates that renewable sources are more than enough for covering the existing and future energy needs. In this respect, it suffices to mention that the sun transmits more energy to the Earth in an hour than the global population consumes in one year (Center for Climate and Energy Solutions, 2021). At the same time, the sun is expected to exist for at least another 5 billion years.

A recent study from April 2021 pointed out that if applied on large scale solar and wind energy may supply, using the existing technologies and the most accessible places, about 765 TW per year, a figure that is about 100 times higher than the global consumption of electricity and about 43 times higher than the global consumption of energy in all forms which is estimated at 17.7 TW for 2021 (Carbon Tracker, 2021).
At this point certain comments are particularly important:

- The energy consumption at a global level will increase only moderately or even decrease with the larger adoption on a large scale of renewable sources of energy. This will happen because the energy efficiency is higher or much higher in case of a large-scale adoption of these technologies. For instance, cars with internal combustion engines transform only 17 – 20% of energy into motion, while the electric cars transform about 75 – 86% of energy into motion.

- The existing energy generation units have a limited and planned life cycle and some of them need to be replaced anyway in the coming decades. Therefore, significant costs (that can be estimated) are needed anyway, even without a transition to new technologies for energy generation.

2.2. A possible mix of clean sources of energy for satisfying global demand

Limiting the primary energy sources to solar, wind and hydro the global energy needs for 2030 (estimated above at 20.35 TW) could be satisfied by the following possible mix:

- *About 50%* of the global energy needs could be satisfied by wind energy (a hypothetical case may be represented by 2 million turbines of 5 MW each, representing 10 TW. In 2020 the total installed wind power capacity was of about 743 GW (Statista, 2021). The number of wind turbines necessary to obtain the 10 TW capacity presumed above can vary substantially if the power of wind farms increases substantially. For instance, in 2021 the largest wind farm in the world had a capacity of 20 GW resulting from 7000 wind turbines (Construction Review Online, 2021). If we extrapolate only for a reference purpose the capacity of this largest wind farm existing today, we can conclude that only 500 wind farms of the same capacity could generate the 10 TW mentioned above.
- *40 %* of the global energy needs could be satisfied by solar energy (a hypothetical case may be represented by 80000 solar power stations of 1000 MW each, representing 8 TW. For reference, in 2020 there were 5 solar power stations with over 1GW each, the largest having 1.54 GW (Power Technology, 2020).
- *10%* of the global energy needs could be satisfied by hydro energy generated by 900 hydro power stations, representing 2 TW. It is important to note that by 2021 the installed hydro power was of 1.307 TW which means that about 65% of the projected capacity is already installed (Power Technology, 2021).

2.3. The feasibility of the transition to a climate neutral economy from the point of view of inputs (land, materials, costs)

The feasibility of using 100% renewable sources of energy for the global energy demand can be determined considering elements like:

- The surface needed for solar panels, wind turbines, other energy generating installations (like tidal waves generators) compared to the surface of the Earth;
- The types and quantity of materials needed to build the above-mentioned equipment and installations;
- The cost of implementation.

According to some estimates the surface needed by wind turbines located on land may represent around 0.48% of the surface of the Earth while other wind turbines will be located on water surfaces as more and more large wind farms are located in the coastal areas (Jacobsen et al., 2019). For the solar energy the surface covered will represent between 0.166-0.33% of the surface of the Earth and a part of this surface will be represented by the roofs and facades of buildings that already exist. At the same time, important solar farms can be located in deserts where the sun is abundant and the surface of land has no other uses. In a hypothetical example, if all the surface of Sahara Desert were covered with solar panels the energy received from the Sun would be of 2511.4 TW, that is more than 7,000 times than the electricity consumption of the entire Europe (Al-Habaibeh, 2019).

The construction of energy generating equipment based on solar, wind and hydro sources implies some common materials such as cement and steel for turbines, elements or compounds of silicon, cadmium and others for solar panels and certain rare metals for generators in wind turbines. Some categories of materials are abundant. And even if other chemical elements are in relative short supply or their sources are in countries that may control or limit their export (such as rare earth metals), research is well underway to discover new resources or to replace those materials with more abundant ones.

From the point of view of utilization, the energy power stations based on renewables are more efficient because they require less downtime for maintenance compared to energy power stations based on coal (2-5% of time per year as compared to 12.5% of time per year). One usual weakness that is mentioned referring to power stations based on renewables is that their functioning depends on weather conditions (presence of sun illumination or wind). But this shortcoming is being increasingly avoided by storing energy using hydrogen (that can be used in fuel cells to generate electricity again when needed), large batteries or even compressed air.

As for the cost of implementation of such a global scale project of transition to climate neutral sources of energy until 2050, a Stanford research group estimated it at USD 73 trillion. A positive aspect resulting from the research was that the investment can be recovered in less than 7 years as result of an estimated USD 11 trillion per year in savings, while more than 28.6 million new jobs can be created (Wade., 2019). A previous study from 2009 indicated an amount of USD 100 trillion for carrying out the transition in 20 years (Jacobson and Delucchi, 2009). While such an amount may seem impressive, some aspects must be taken into account:

- The transition to clean sources of energy in order to obtain an environment neutral economy will be a gradual process that will take time, at best 20-30 years. Therefore, there is no need for a huge amount of capital from the very beginning.
- At the same time, once power stations based on renewable sources enter into operation, they already start to recover the investment through the sale of electricity.
- Large scale implementation of technologies for using renewable sources of energy determine both the improvement of the respective technologies and the discovery of new ones and, in this way, the reduction of the cost per unit of the energy produced.
- Existing power stations that use classic fuels such as coal are gradually ending their life cycle and have to be replaced. Therefore, investments in new power stations are necessary anyway.
- Putting in perspective the amount of USD 73 trillion for the complete transition to climate neutral sources of energy, it means about USD 2.43 trillion per year for the next 30 years (until 2050). This amount is already comparable to the world military spending of almost USD 2 trillion in 2020 (Stockholm International Peace Research Institute - SIPRI, 2021).

An important aspect which is, in our opinion, of enormous help in supporting the transition to the use of renewable resources for energy is that already the cost for building a solar or wind power station is lower than building a power station using fossil fuels. In March 2021 Bloomberg announced that the renewable sources of energy are the cheapest form to produce energy for 71% of the global GDP and 85% of the global energy production (Moore and Bullard, 2021). As most of the economic decisions are cost-based this fact may have a much more significant immediate impact in reorienting the construction of new power stations towards renewables than public urges for decreasing global warming and pollution of environment.

When analysing the cost of implementation of energy generating technologies based on renewables, we have to take into account not only the cost of building the energy generating equipment but also the cost of production per unit of energy. From this point of view, during the period 2010 – 2019, due to technological improvements, the costs of energy production have been reduced by (International Renewable Energy Agency - IRENA, 2020):

- 82% for photovoltaic cells;
- 47% for concentrated solar energy;
- 40% for terrestrial wind energy;
- 29% for sea-based wind energy.

As result, the costs for producing electricity from hydro, wind and geothermal sources are at present in the range of 4-7 US cents per kW/hour (5 US cents per kW/hour for terrestrial based wind turbines). These costs are already lower than the production costs for coal-based power stations. At the same time, the costs for producing electricity from solar panels are already under 7 US cents per kW/hour (IRENA, 2020). According to the estimates until 2030-2035 the costs for producing electricity from solar panels will be in the range of 1-2 cents per kW/hour.

3. Conclusions

The significant impact of climate changes has determined both political decision makers and leaders of big businesses to adopt strategies and programs to cut emissions and reach a climate neutral status. According to Credit Suisse representatives, the world economy is at the beginning of a transition period towards renewable sources of energy that will take place over the next 30 years. An argument supporting this trend towards renewable sources of energy is represented by the fact that in only one year, from March 2020 to March 2021 the commitments of states for reaching carbon neutrality until 2050 increased from 23% to 60% of the global emissions (Ng, 2021).

Although the transition towards renewables will imply numerous costs, difficulties and adaptation efforts, the good news is that the renewable energy from solar, wind, geo-thermal, tidal waves, bio-mass and other origins is more than enough for satisfying the global demand. At the same time, existing technologies are already competing from a cost point of view with the use of classical fuels, such as coal.

The seriousness of the implication of states and big economic players in the transition to climate neutral sources of energy can be demonstrated by the fact that investments in clean energy increased 10 times between 2000-2020, from about USD 33 billion per year to about USD 300 billion (Bullard, 2021).
The transition towards a climate neutral economy and climate neutral energy sources will accelerate in the coming years as result of a concerted action from the part of political decision makers, big economic players and the civil society. The European Union is one of the most active players, setting standards for the speed of the transition and very ambitious goals. Under these circumstances it is advisable that Romania adopts a pro-active attitude, based on a good knowledge of best international practices, aiming to fully participate in the European Union initiatives. The Romanian position should be based on the best capitalization of its competitive advantages represented by both natural and human resources.

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