THE IMPACT OF THE INDUSTRIAL REVOLUTIONS IN THE TRANSITION FROM LINEAR TO CIRCULAR ECONOMY

Vessela Petrova

University of Mining and Geology “St. Ivan Rilski”, 1700 Sofia; E-mail: vessela.petrova@mgu.bg

ABSTRACT. The Industrial Revolution marked a major turning point in history as it deeply influenced society, culture, and economy and significantly affected global economy and the way we produce, use, and dispose of the goods. One of the main consequences is linear economy based on the model “take, make, dispose”, and this paper discusses in brief the need of transition to circular economy aiming for resources to be used as long as possible and waste to be as less as possible. The present paper briefly considers the five individual phases of the industrial revolution, each marked by significant technological progress and changes in society. Historical levels of carbon emissions are discussed and compared to energy consumption. The analysis has confirmed the need of transition to a model of production and consumption that minimise the negative impact on the environment. The emergence of clean and green technologies is regarded as the next industrial revolution.

Key words: industrial revolutions, linear economy, circular economy.

ВЛИЯНИЕ НА ИНДУСТРИАЛНИТЕ РЕВОЛЮЦИИ В ПРЕХОДА ОТ ЛИНЕЙНА КЪМ КРЪГОВА ИКОНОМИКА

Весела Петрова

Минно-геоложки университет „Св. Иван Рилски“, 1700 София

РЕЗЮМЕ. Индустриалната революция е повратна точка в човешката история, тъй като има дълбоко въздействие върху обществото, културата и икономиката и оказва значително влияние върху глобалната икономика и начина, по който произвеждаме, потребяваме и разполагаме със стоки. Една от основните последици е линейната икономика, основана на модела „вземи, направи, изхвърли”, като публикацията разглежда накратко необходимостта от преход към кръгова икономика, имаща за цел ресурсите да бъдат използвани възможно най-дълго и да сведат до минимум отпадъците. Настоящата публикация разглежда накратко петте отделни фази на индустриалната революция, всяка от които е белязана от значителен технологичен напредък и обществени промени. Разгледани са нивата на въглеродни емисии в исторически план и са съпоставени с потреблението на енергия. Анализът потвърждава необходимостта от преход към модел на производство и потребление, ограничаващ до минимизиране вредите върху околната среда. Счита се, че следващата индустриална революция ще е на чистите и зелени технологии.

Ключови думи: индустриални революции, линейна икономика, кръгова икономика.

Revolution and industrial revolution

The term “revolution” denotes a dramatic, comprehensive change, which does not necessarily take place quickly or suddenly (Vries, 2008). The term “industrial revolution” is defined as a transition from pre-industrial to industrial society (Abbadi et al., 2020). That period has transformed human life by the introduction of technological innovations in industries - going from hand production methods to power driven machines and rise of large factory systems. The industrial revolution needs natural resources, infrastructure, and financial resources for investments.

The past 250 years were marked by five industrial revolutions that occurred at uneven intervals of time (Fig. 1).

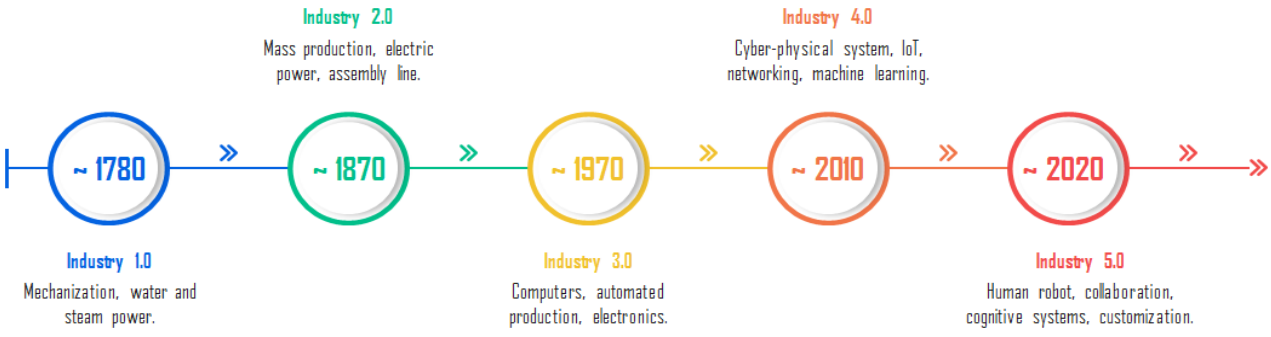

Fig. 1. Timeline of the industrial revolutions

The first three revolutions occurred at long intervals of time, while each revolution that followed came faster than the previous one due to introduction of technologies and digitalisation; what is more – there has been an overlapping between Industrial Revolutions 4.0 and 5.0.

The time before the first industrial revolution was marked by small, poor societies, high level of child mortality, and low life duration. During that period, nearly 60% of global wealth and power were concentrated in two Asiatic countries: China (33%) and India (25%). Great Britain and the United States compounded nearly 2% of the global wealth (Mohajan, 2021).

Brief analysis of industrial revolutions

At the end of the 18th and beginning of the 19th century (~ 1780-1840), significant socio-economic changes occurred, in Great Britain first, denoted in scientific references as the First Industrial Revolution. In its nature, that period was defined by immense progress of humankind, characterised by transition from human-driven power to technologies, growth of industrial processes, improvement of waterpower efficiency, use of steam power, development of machine instruments. Iron and textile occupied the decisive role in that process. The period was characterised by the improvement of steam engine, which was made of iron and fueled with coal. The growth of coal production had a decisive role in the First Industrial Revolution and consequently that resource was established as a reliable basic power source. The global energy consumption of coal during the First Industrial Revolution is presented in Fig. 2. The drastic increase of coal consumption at the end of the period was remarkable.

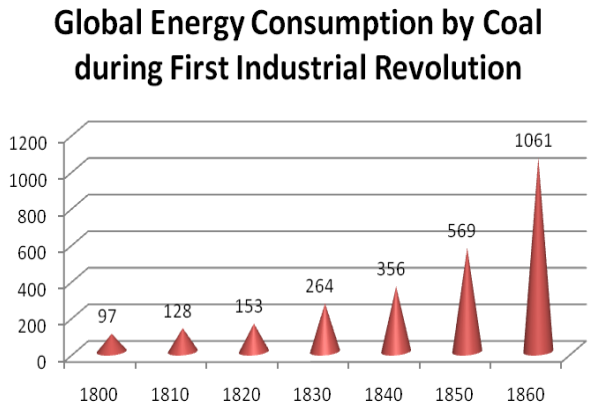

Fig. 2 Global energy consumption of coal during the First Industrial Revolution, in terawatt hour (TWh)

The Second Industrial Revolution (~ 1870-1900) was characterised by a large number of new technologies, the focus being on the introduction and development of electricity. That period had set the beginning of a continuous fast growing technological change, driven mainly by the development of new electricity-based production technologies. That revolution established a new economy with a higher growth of both rate of production and effectiveness.

The Third Industrial Revolution is considered to have begun around ~ 1970, to have reached its peak at the end of the 1990s, and to have continued in the years afterwards. At those times, mechanical and analogous technologies transited to digital electronics. Green buildings, electrical vehicles, and distributed production were introduced. It was based on energy transition, digital technologies and the Internet, and it was often referred to as “The Digital Revolution”.

Industrial Revolution 4.0 commenced around 2010; however, the term became widely popular during the World Economic Forum in Davos in 2016. Industrial Revolution 4.0 is an approach to describe a number of current and forthcoming transformations in the systems that surround us. Its nature is a new phase of human development, like the three previous industrial revolutions; however, it is mainly focused on extending interaction among innovative technologies. The locomotive of the Forth Industrial Revolution are the knowledge-based systems, established during the previous industrial revolutions, in particular the use of digital options, inherited by the Third Industrial Revolution (Schwab and Davis, 2018).

Nowadays, society is on the threshold of Industrial revolution 5.0. Industrial Revolution 5.0 is considered to allow end-users to receive products and services complying with their specific needs, improving human approach to production by a new technological progress (Özdemir and Hekim, 2018). That phase applies virtual technologies like the virtual and extended reality. It is focused on improving efficiency and productiveness and the main industrial component is the human brain. Human brain has automated the entire production process and it has allowed a new production approach. Collaboration between men and machines has been applied in order to meet the requirements of the end-user.

Rise of a linear economy

The industrial revolution defines times when machines have determined significant rise of production growth rate and relevant goods have become more plentiful, cheaper, and accessible compared to goods produced by hand tools.

A linear model of production and consumption has been dominating for at least the past 150 years, i.e. goods have been produced by resources, marketed, used, and got rid of by deposition or burning as waste. Industrial growth and technological progress supported industrial revolutions to increase productiveness of economy and contributed to an unprecedented prosperity of the entire humankind.

The linear economic model is built on two assumptions which are denied in the recent global context, namely the limitless availability of resources – energy and raw materials, and the limitless regenerative capacity of the Earth. Following the above logic means that the faster economic growth, the higher the need of raw materials for the production of goods; and on the other hand that will result in the generation of more waste.

Nowadays, the linear economic model has endangered the sustainable development of society, creating a need of an alternative economic model. Furthermore, by 2050, the population of the Earth is forecast to reach nine (9) milliard people, with expectations of prosperity and wealth. In order to comply with the above expectations, the economy will need three times higher quantity of raw materials than the raw materials that we use nowadays, or finding another model of economic growth. The above tendency is the reason for the fast increase of carbon dioxide emissions and greenhouse gases in the atmosphere, the so-called carbon footprint, which negatively affects the environment by changing the climate. Carbon dioxide emissions released from industrial processes

are illustrated in Fig. 3. The diagram treats the period from the First Industrial Revolution until now, while the dramatic increase after the Second Industrial Revolution is remarkable, and the increase after the Third Industrial Revolution is even more obvious.

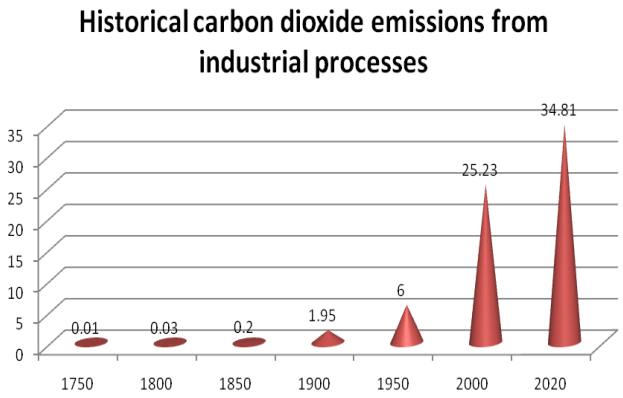

Fig. 3 Levels of carbon dioxide emissions released from industrial processes – since the First Industrial Revolution until now, in billion metric tons.

The topic of sources of carbon dioxide emissions is widely discussed in scientific references. (Hristova et al., 2023)

Kuznets (1955), Grossman and Krueger (1991) have analysed the relationship between air quality and economic growth in many cities around the world. In their publication, Grossman and Krueger (1991) have proved that beyond a certain level of development, the economic growth may reduce environmental degradation by transiting from an industrialised polluting economy to a cleaner economy, especially with regard to investments in cleaner technologies and enhancing the environmental consciousness, resulting from lifestyle improvement. The above principle is known in scientific references as “the environmental Kuznets curve”. That hypothesis was subjected to a number of investigations. Relationships between inequality of income and the environment have been compared during the years and outcomes have been rather contradictive. According to Berthe and Elie (2015), the variety of outcomes is mostly based on the endogenous variables used and an evident tendency of the impact on the environment has not been identified: emissions of CO_2, air pollution, and water pollution. Many authors, who carried out empirical investigations, have united around the theoretical analyses of Boyce (1994), Magnani (2000), Wilkinson and Pickett (2010), who are in the opinion that inequality of income effects negatively on the environment.

Consumption of different power sources for the past 20 years has been discussed in order to monitor the effect of renewable and non-renewable power sources on the CO_2, emissions.

Primary energy consumption by power source for the period 2000 – 2021 is indicated in Fig. 4. The differences in consumption of the most widely used power sources are shown. It is evident that consumption of coal, oil, and nuclear power has been reduced within the past 21 years. This is ~~a~~ the result of a wider use of renewable power sources ~~as~~ like wind, solar, modern biofuels and others – against the background of a continuous increase of power consumption.

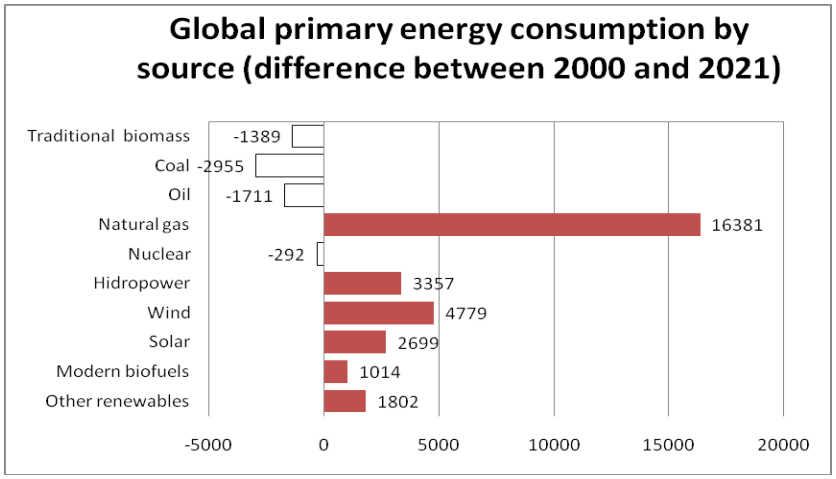

Fig. 4 Global energy consumption by power sources (difference between 2000 and 2021)

The structure of energy consumption has been investigated in detail in the scientific references with respect the engines of CO_2. Scientific investigations have proved the relationship between the consumption of renewable energy and the quantity of CO_2 emissions. Nevertheless, the present investigation may not support the above tendency. Fig. 4 marks the growth in the use of renewable power sources for the past 20 years or more and the significant reduction in coal consumption for the same period. However, Fig. 3 indicates a significant increase in carbon dioxide emissions for the same period. In that context, a higher share of renewable power sources does not result in a reduction of CO_2 emissions.

The need of transition to a new economic model

Both economic and technological processes have a key role in the fight against climate change. With regard to the above, the transition to a model limiting the waste to a minimum is required; a model beneficial for the environment, economy, and society, in general. That is the model of circular

economy and it is considered to guarantee the progress of society in a sustainable environmental-friendly approach.

Linear economy and circular economy mark two contradicting approaches which drive the industrial wheel of production. In the past years, supported by European Union legislation and a number of European Directives, the circular economy is moving forward with a significant inertia in response to the exhaustive linear system.

The objective of the transition to circular economy is the more effective use of resources. The major focus is maintaining the added value of raw materials, while completely eliminating or minimising waste. It has been confirmed that the circular economic model is concentrated on the use of products as raw materials. Thus, on the one hand, the circular model is more beneficial and less harmful to the environment, and on the other hand, the circular model has advantages related to sustainable economic growth, increased competitiveness, and new job opportunities.

Development and upgrading of industrial revolutions in time has also marked the increased emissions of carbon dioxide. Nowadays, efforts are focused on assessing the consequences of human activities and finding a solution to the above phenomenon before the occurrence of an irreversible degradation of ecosystems on our planet. The international efforts in the field of climate change are directed to the above objective. By signing the Paris Agreement on climate change in 2015, most of the countries have been bound to avoiding dangerous climate change by limiting global warming to “well below” 2°C above preindustrial levels and “pursuing efforts to limit it to 1.5°C”. In this framework, the European Union has the commitment to reduce greenhouse gas emissions by at least 40% compared to 1990 levels by 2030. The long-term strategy of the European Union is achieving a climate neutral economy by 2050 (European Commission, 2018).

This is the context of European Union legislation for promoting the renewable energy sources (wind power, solar power, waterpower, the power of the oceans, geothermal power, biomass and biofuel), which have been fast developing in the past 15 years. In that context, the European Union considers that the use of renewable energy sources will reduce greenhouse gas emissions.

The global consumption of renewable energy is shown in Fig. 5 (continuous line). It is evident that consumption has exponentially increased from 2000 to 2021.

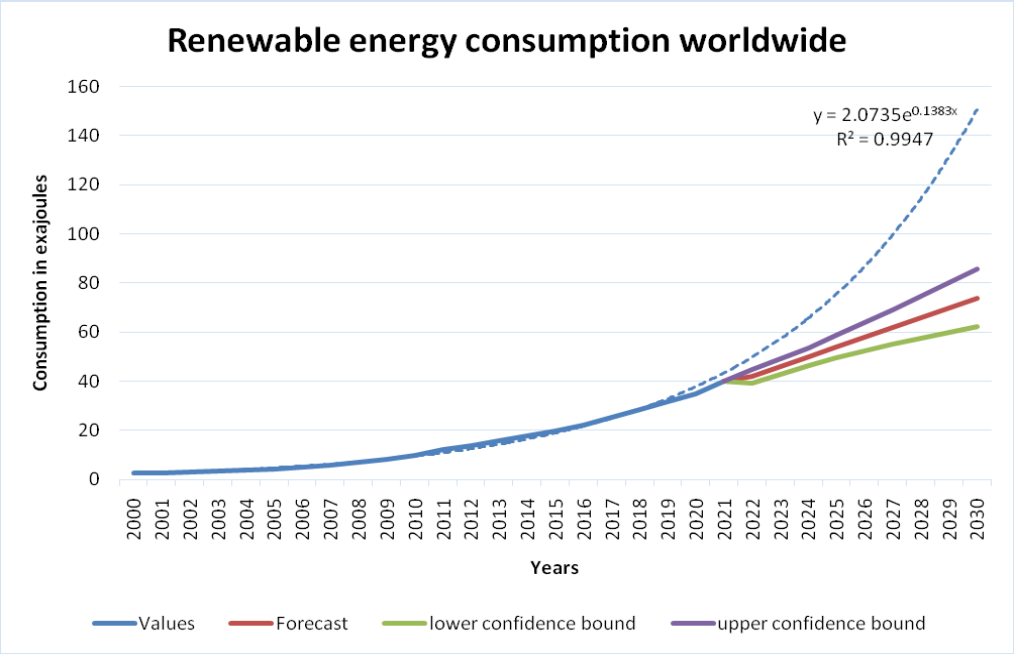

Fig. 5 Global renewable energy consumption for the period 2000 – 2030

The model describing the above dependence (dotted line) is also shown in the figure, as well as the coefficient of determination R^2=0.9947, which is the main indication of model precision. It is evident that the difference between actual consumption and model-read consumption is negligible. The model may be used as a means for prediction that if the rate of increase continues to be the same, renewable energy consumption will increase to nearly 85 (84,812) exajoules in 2025, and to 169,345 exajoules in 2030.

The present paper confirms the need and importance of the transition from the traditional logic of linear economic growth, comprising the principle “take, make, dispose” towards an economic growth, tending to limit the wasting of raw materials and the impact on the environment, and in the meantime increasing the effectiveness of all the stages of product economy. That is the principle of circular economy – a system of production and consumption based on recycling, re-use, repair, secondary production, and product share, changing consumption models and new business models and systems (European Commission, 2019). During the entire lifecycle of a product, the phase of production exerts the highest impact on climate change, exhaustion of mineral raw materials, negative impacts, and emissions of inorganic contaminants. In order to reduce the impact, the circular economy has the objective to apply various cyclic processes, including maintenance processes. In addition, those various production processes require the use of technologies reducing the impact on the environment. The above suggests that environmental innovations shall be the basis of production apparatuses for the commercial companies (Bakardzhieva, 2017). The above efforts have made, more than ever, the

means for introduction and distribution of those innovations a topical matter.

Findings

- The analysis of coal power consumption has confirmed the growth of that raw material during the First Industrial Revolution and the significant increase of consumption at the end of the period;
- Levels of carbon dioxide emissions have been rising and dramatically increased after the Third Industrial Revolution;
- A comparison of data about the levels of carbon dioxide emissions and global energy resource consumption for the past 20 years has indicated an increase of the use of renewable energy sources, but reduction of the consumption of coal, oil, and nuclear fuel. In spite of the above tendency, the levels of CO_2 emissions have not been reduced during the same period.
- The statistical analysis of global renewable power consumption may be used as a basis for predicting that if the rate of increase is preserved, renewable energy consumption in 2025 will increase to nearly 85 (84,812) exajoules, and to 169,345 exajoules in 2030.

Conclusion

Despite the tendency of environment improvement in the past two decades, the environmental and social pressure will continue to increase because of population growth, globalised markets, and increased consumption of mineral raw materials. Furthermore, much of the raw materials are becoming scarcer and dependence on them is higher. All of the above aspects have proved that the recent linear economic model, established by the industrial revolutions is unsustainable because it has increased the risk of interruption of raw material supply. Scientific references have already suggested about the forthcoming Sixth Industrial Revolution and there are tendencies that it will be focused on clean technologies and green and circular economy.

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