IMPLICATIONS OF DIGITALISATION ON ENVIRONMENTAL SUSTAINABILITY

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Abstract
In this paper we aim to analyze through the literature, the implications of digitalization on environmental sustainability in the field of production (product design, production, transport and customer service). The analysis of specialized works highlights the following aspects: 1. Digitization in production contributes positively to environmental sustainability by increasing resources and information efficiency as a result of the application of Industry 4.0 technologies throughout the product life cycle; 2. The negative side of digitalisation on the environment is primarily due to increased use of resources and energy, as well as increased waste and emissions from the manufacture, use and disposal of the hardware component (product life cycle).
Based on these findings, a product life cycle perspective is proposed, taking into account the environmental impact of both the product life cycle and the technology. Through this study, we identified the key implications of digitizing production on environmental sustainability, raising awareness of both positive and negative impact of digitization, and the need to invest in new digital technologies.

Keywords: digitization, digital technologies, resource efficiency, resource productivity, artificial intelligence.

J.E.L. classification: F63, F64, O44, Q50.

I. METHODOLOGY

This study uses the method of qualitative research. The methodology is based on the analysis of the specialized literature and the identification of the implications of the digitalization of the production on the environment. The study considers the selection of documents available on this topic, which contain information, ideas, data and written evidence to achieve a particular goal. Therefore, the ideas and work of other authors / researchers make it possible to understand the interrelationships between the subject studied and other fields of activity. In other words, our study includes procedures for search, classification, reading, analysis, organization and expression. In this context, we specify that the steps taken in conducting this study are: selection and evaluation of literature, content analysis and description of results.

II. INTRODUCTION

We define digitization as "the technical process of converting analog signals into a digital form and eventually into binary numbers, and is the basic idea presented by scientists in the field of early computer science", based on the work of Tilson (2010) and Hess (2016) (Legner C et al., 2017, pp.301-308). In other words, digitization involves the technical potential of separating information from physical data carriers and storing it. In other words, digitalization is described as “multiple socio-technical phenomena and processes of adoption and use of these (digital) technologies in a wider individual, organizational and societal context” (Legner C et. Al, 2017, pp.301-308) . This definition aligns with the statement of Yoo et al. (2010) [15]: digitization consists of both social and technical dimensions (Yoo, Y et al, 2010, pp.1-41). Therefore, "Industry 4.0" is based on digital technologies that allow its digitization.

In this context, we specify that digitalization allows innovations that are both sustainable and economically viable. Innovations must be closely linked to the use and reuse of existing raw materials and materials for as long as possible, as well as to preventing the occurrence of waste wherever and whenever we can. We want this because our planet is short of resources and it is necessary to preserve non-renewable raw materials for as long as possible. In this sense, we take into account the fact that natural resources fuel production and consumption, create wealth and jobs, contribute to increasing the quality of life and the well-being of the population.

To achieve this, strategic objectives and concrete action programs must be proposed, which aim at smart, sustainable and inclusive social growth. We are talking about "resource efficiency" about the creation of production systems that generate smaller and smaller amounts of waste or that produce more with a lower consumption of raw materials.

It is important to take into account the resources that are essential for human activities. For example, the energy system includes the types of energy we use (coal, wind energy, solar energy, oil, natural gas, etc.), how we extract or generate this energy (wind farms, oil wells, shale gas, etc.). .), the purpose for which we use it (industry, transport, home heating, etc.) and how we distribute it. Other issues, such as land and water resources affected by energy use and production, would also be addressed in this way.

To produce a good or a service, we need a supply of raw materials. For example, in order to get crops, in addition to their labor force, farmers need land, seeds, water, sun (energy), tools and, in modern agriculture, more complex fertilizers and pesticides and machinery. The same is more or less true for the modern manufacturing industry. To produce electronic devices, we also need labor, as well as energy, water, land, minerals, metals, glass, plastics, rare ores, research and so on.

Statistics show that most materials used in production in the European Union are also extracted in the European Union and up to 4% of materials used in production are imported. Material consumption varies considerably from country to country. Over the last decade, the EU economy has created greater "added value" in terms of gross domestic product per unit of material (minerals, metals, etc.) consumed. For example, using the same amount of metals, the industry has produced mobile phones or more "valuable" (higher value) laptops than their predecessors. This means resource productivity. Since the beginning of the millennium, resource productivity in the EU has increased by about 35%, despite a slight decline in 2020 (Eurostat Statistics Explained, Glossary: Resource productivity, [online]. Available at: www.ec.europa.eu /eurostat/statistics-explained/index.php?title=Glossary:Resource_productivity,[Accessed on 25.06.2021]. (chart no.1)

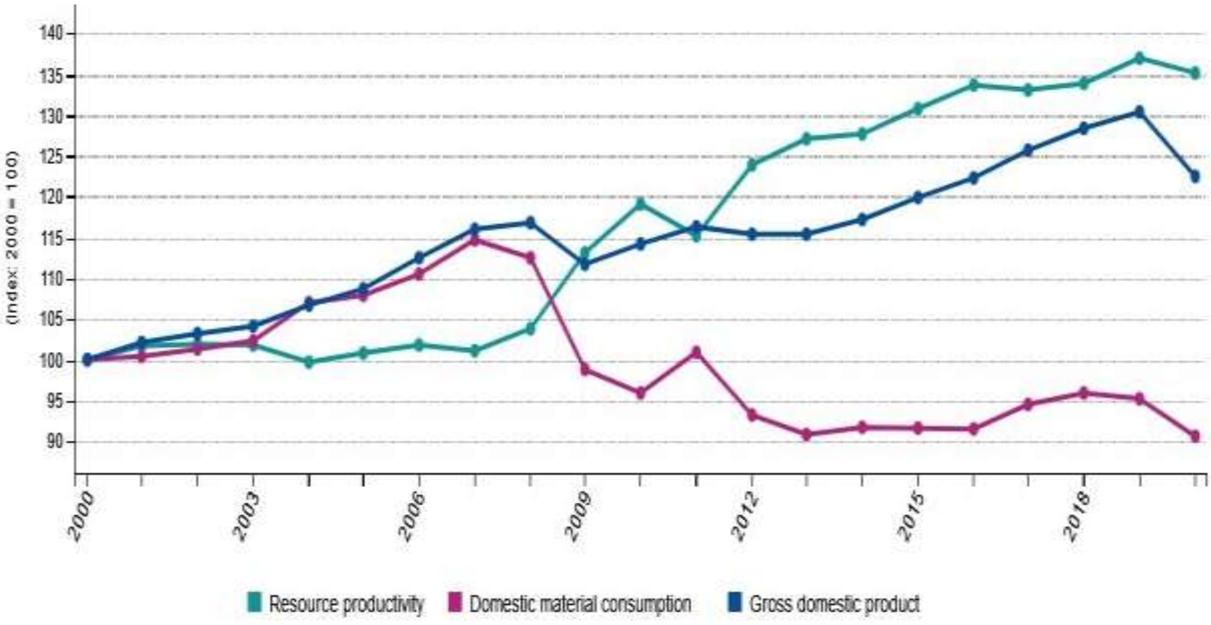


Figure no.1 Resource productivity in comparison to GDP and DMC, EU, 2000 – 2020
Source: www.ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210713-1

Resource productivity quantifies the relationship between the size of the economy and the use of natural resources. The value of resource productivity increases when the economy, as measured by GDP, grows at a faster rate than the consumption of raw materials, as measured by domestic consumption of materials (DMC). After a period of moderate growth in the early 2000s, resource productivity rose sharply during the 2008-2009 financial and economic crisis, as a result of sharp declines in domestic consumption of materials. The crisis has affected the production and construction industries with intensive consumption of materials more than the rest of the economy. Then, after several years of steady growth, resource productivity declined slightly in 2020. This was largely due to a significant decline in GDP due to the COVID pandemic, while domestic material consumption declined moderately as what consumption of building materials and biomass remained stable.

An analysis of resource productivity shows that it is the highest in the Netherlands and the lowest in Romania and Bulgaria. The level of resource productivity varies greatly between EU Member States: from less than 0.4 EUR / kg in Romania and Bulgaria to 5.4 EUR / kg in the Netherlands in 2020. After taking into account price differences, The Netherlands remains the EU Member State with the highest resource productivity (4.7 purchasing power standards (PPS) per kg), followed by Luxembourg (3.9) and Italy (3.7). At the opposite end of the scale, three EU Member States recorded a resource productivity below 1.00: Romania (0.7 PPS/kg), Bulgaria (0.8) and Estonia (0.9) (Eurostat Statistics Explained, Glossary: Resource productivity, [online] Available at: www.ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Resource_productivity ,[Accessed on 25.06.2021] (Table no. 1)

Tabel no.1 – Resource productivity, GDP and DMC, by country, 2020

	GDP_{PPS} per capita (PPS per capita)	**DMC per capita (tones per capita) (tonnes per capita)**	**Resource productivity (PPS per kg)**	**(GDP_{PPS} DMC) (Index EU-27 = 100)**
EU	29727	13.4	2.2	100.0
Belgium	34783	11.8	2.9	132.1
Bulgaria	16258	19.8	0.8	36.7
Czechia	27884	14.3	2.0	87.5
Denmark	40361	24.9	1.6	72.9
Germany	35951	1.4	2.7	120.1
Estonia	25691	27.7	0.9	41.7
Ireland	62722	22.3	2.8	125.5
Greece	19031	8.9	2.1	96.1
Spain	25611	8.1	3.1	141.3
France	31091	10.3	3.0	135.7
Croatia	19103	11.2	1.7	76.5
Italy	28002	7.4	3.7	168.3
Cyprus	25790	17.8	1.5	65.1
Latvia	21398	13.3	1.6	71.9
Lithuania	25878	18.6	1.4	62.6
Luxembourg	79223	20.6	3.9	173.9
Hungary	22103	14.4	1.5	68.7
Malta	28746	11.7	2.5	110.1
Netherlands	39541	8.5	4.7	209.1
Austria	36972	18.8	2.0	88.3
Poland	22717	17.5	1.3	58.8
Portugal	23062	16.4	1.4	63.2
Romania	21296	29.1	0.7	32.8
Slovenia	26414	13.3	2.0	89.5
Slovakia	21260	11.6	1.8	82.0
Finland	34136	31.3	1.1	48.9
Sweden	36643	25.0	1.5	66.0
Iceland (*)	40354.9	30.2	1.3	59.9
Norway (*)	45905.2	30.8	1.5	66.9
Switzerland (*)	49109	11.0	4.5	200.0
North Macedonia (*)	11849	9.3	1.3	57.0
Albania (**)	9190	8.0	1.1	51.5
Serbia (*)	12715	18.2	0.7	313
Turkey	19163	12.1	1.6	70.9
Bosnia and Herzegovina (***)	9031	10.3	0.9	39.2

GDP in current price, Purchasing Power Standards
(*) 2019 instead of 2020
(**) 2018 instead of 2020
(***) 2017 instead of 2020
Source Eurostat (online data codes env_ac_mfa.nama_10_gdp.demo_gind)
www.ec.europa.eu/eurostat/statistics-explained/images/b/b7/Resource_productivity%2C_GDP_and_DMC%2C_by_country%2C_2020.png

These differences can be explained by a country's natural resources, the diversity of its industrial activities, the role played by its service sector and its construction activities, its scale and consumption patterns, and its various energy sources.

Figure no. 2 is a dispersion graph showing the DMC relative to GDP levels. There is no clear linear relationship between GDP and DMC. There are countries with low GDP and high DMC (for example, Romania and Bulgaria), but also countries with high GDP and low DMC (for example, the Netherlands). In addition, there are countries with low DMC and low GDP (for example, Greece), as well as with high DMC and high GDP (for example, Denmark).

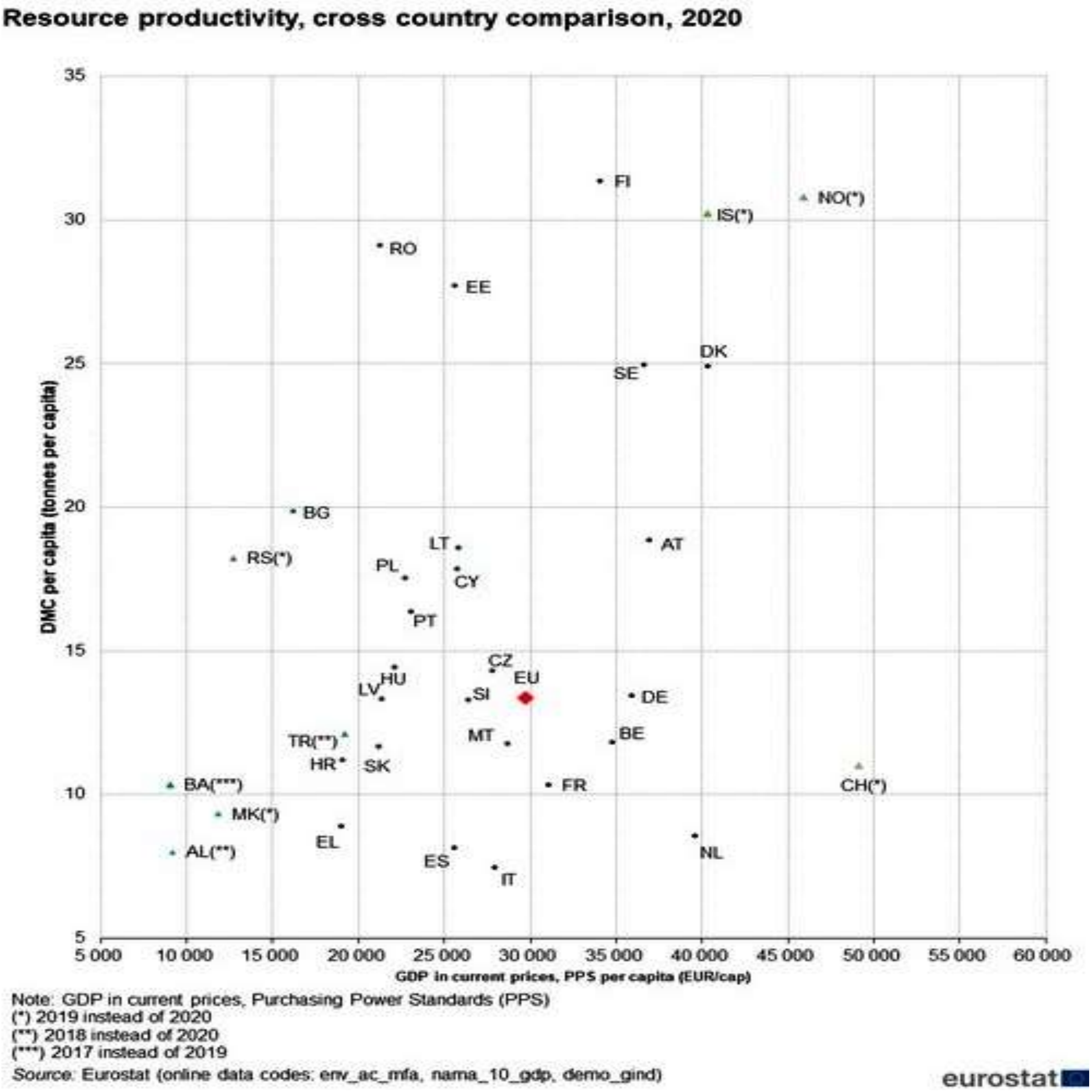


Figure no.2 – GDP in current prices, PPS per capita (EUR/cap)

Eurostat's environmental accounts and statistics inform policy making under the European Environment Pact. The European Green Deal is the first of the six priorities of the European Commission for the period 2019-2024. It is a growth strategy that will transform the Union into a modern, resource-efficient and competitive economy, where there are no net greenhouse gas emissions until 2050, economic growth is decoupled from resource use and no person and no place is left behind. The European Green Agreement stimulates the efficient use of resources by moving to a clean, circular economy, restoring biodiversity and reducing pollution. The European Green Deal is the plan to make the EU economy sustainable.

III. DIGITIZED AND INTELLIGENT PRODUCTION (INDUSTRY 4.0)

This type of production requires fewer resources and lower costs that lead to increased productivity. At the same time, “Industry 4.0” is based on the progress of information and communication technologies (ICT) and data storage (Nascimento D.L.M. et al, 2019, pp. 607–627). In other words, Industry 4.0 is made using eight key technologies: physical cybernetic systems (CPS), Internet of Things (IoT), cloud computing, big data analysis, virtual reality (VR) / augmented reality (AR), intelligent robotics , Industrial Artificial Intelligence (IAI) and Additive Manufacturing (AM) (Oláh, J. et al, 2020, p.4674).

This concept of "Industry 4.0" was introduced in 2011 at a Fair in Hannover and highlighted its ability to improve the way it operates by integrating production and business processes. Also, “Industry 4.0” offers economic benefits and opportunities for environmental sustainability (by Sousa Jabbour, A.B.L et.al, 2018, pp 18-25). The technologies used in "Industry 4.0" have the ability to optimize and save energy used in production through real-time monitoring of energy consumption in production (IoT); reduce resource and waste consumption through custom production design (MA) (Mehrpouya, M. et. al., 2019, p.3865); reduce emissions from transport due to efficient and transparent communication (SPC) (Ford, S. et al., 2016, pp. 1573–1587).

Other studies show that “Industry 4.0” is rarely beneficial for environmental sustainability and that economic opportunities are a priority over environmental and social benefits (Brozzi, R. et.al., 2020, p. 3647). The negative impact of “Industry 4.0” on the environment also results from the fact that large amounts of electronic waste are produced through the widespread use of electrical and electronic equipment and devices (Berkhout, F. et.al, 2004, pp. 903-920). The production and use of ICT (information and communication technologies) consume an increasing amount of materials, which accelerates the depletion of natural resources (by Sousa Jabbour, A.B.L et.al, 2018, pp. 18-25). The growing demand for energy supply for digitization and data centers generates abundant emissions (Cosar M., 2019, p.600). Therefore, it must be taken into account that the digitalization of production has both positive and negative effects on environmental sustainability.

At the same time, we specify that digitization allows production processes to be fully integrated, automated and optimized in a production flow that benefits production companies in terms of productivity, income growth, employment and investment (Stock, T. et. al., 2016, pp.536–541.). At the same time, the evolution towards digitalization offers opportunities for a more environmentally sustainable production (Rüßmann, M. et.al, 2015, [online]). Studies over the past 20 years have shown that digitalisation and environmental sustainability remain a difficult and uncertain research topic due to the pace of technological and societal change. At the same time, digitalization could unlock the full potential of ecological production due to its ability to provide more accurate, high quality data and real-time event management (Oláh, J et.al, 2020, p.4674).

Sousa Jabbour and associates (by Sousa Jabbour, A.B.L et.al, 2018, pp. 18-25) argue in their study that “Industry 4.0” technologies have the potential to support the sustainability of the production environment by mainly applying business management. Stock and collaborators argued that the allocation of materials, energy and water can be done efficiently based on intelligent modules for creating cross-linked value (Stock, T. et.al., 2016, pp.536–541.). Statistically, as stated by the German Association of Engineers, digitalization can lead to a 25% increase in resource efficiency; this association also demonstrates that digitization has the potential to reduce carbon emissions by 20% (Kopp, T. et.al., 2019, pp. 1-11). CPS and IoT allow transparency in production by monitoring the real-time process of resource consumption, thus providing production management with a solid basis for improved responsiveness (Song, Z. et.a., 2017, 1365–1382). Intelligent robotics increases productivity and stabilizes production quality, leading to greater efficiency of resources with less waste (Ghobakhloo, M., 2020).

But, according to some researchers, the production and use of digital technologies consume more resources and energy, and produce more waste (Berkhout, F. et.al., 2004, 903-920.). In this context, we point out that the rapid growth of the exploitation of digital technology, including the "rebound effects", is accelerating the depletion of natural resources; because the number of transistors that can be packaged in an integrated circuit doubles every 18 months (Nascimento D.L.M. et al, 2019, pp. 607–627). Digitalized production is energy consuming, generating a growing demand for electricity to meet the energy demand of data centers and their support networks (Cosar M., 2019, p.600).

Given the lack of studies on the general implications of digitalisation on environmental sustainability in the context of "Industry 4.0", we are interested in the following issues: "What impact does digitalisation have on production in the environment?" and "How can digitalisation in production reduce the negative impact on the environment?"

IV. ANALYSIS OF THE SPECIALIZED LITERATURE

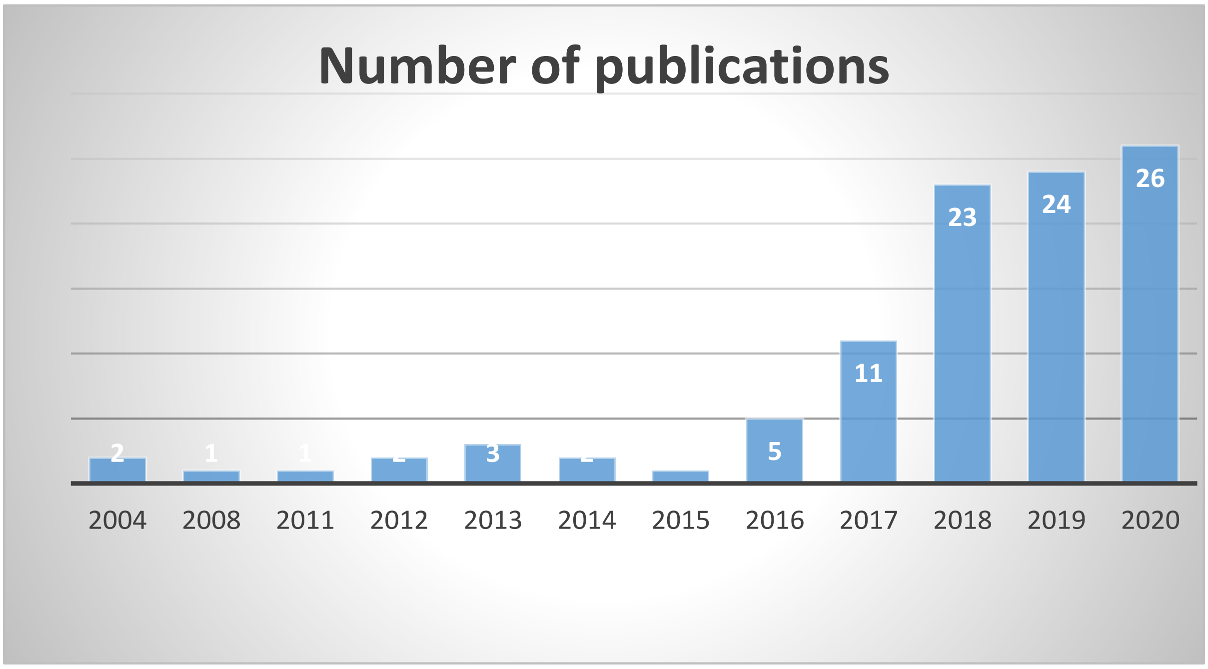
We analyzed Scopus and Web of Science scientific databases through which we identified 100 articles that answer our questions, articles that were published by 2020. We specify that the search query applied to the Scopus and Web of Science database targeted the theme of digital technologies and the sustainability of the environment in production and was based on the following selection criteria: the use of digitized technologies, the manufacturing stage in which digital technology is implemented; what kind of impact does digital technology have on the environment?

The results obtained show that the analyzed articles also addressed the economic and social aspects, aspects found in terms of economy, social, society, human, people, citizens, user, employee, worker, etc.

The analysis of the content of the selected articles showed that the impact on the environment comes from two life cycles: the product life cycle for products manufactured with the support of digital technologies and the life cycle of digital technology itself (hardware). We mention that in the search query we used keywords to obtain relevant results such as: "digitization", "environmental sustainability" and "production". Qualitative analysis was influenced by the authors' preconceived ideas, which led to a degree of subjectivity in the results presented. These issues are needed to interpret the conclusions and propose a new perspective for the adoption of digital technologies towards more sustainable production.

The steps taken have led to the expansion of scientific knowledge on the implications of digitalisation on environmental sustainability. The results obtained show that articles on this topic have been published since 2004, and the number of articles has started to increase since 2016 (figure no. 3)

Figure no. 3 - Number of studies per year from the analyzed publications



This reflects an increasing importance and the need to address environmental issues. The analysis shows that most authors are from Europe and the USA. We specify that a number of 17 works from the selected ones are by some Asian authors. Most articles deal with the technology used in "Industry 4.0" in general and focus on the life cycle of the manufactured product and / or the hardware life cycle of digital technologies, as well as the impact on the environment. An important aspect of the analyzed works highlights the fact that the product at the end of the life cycle could re-enter the cycle of value creation through reuse, remanufacturing, recycling and other circular strategies. In the life cycle of technology, incoming energy and material create value and come out as technological hardware. This hardware could also re-enter the value-creating cycle through similar circular strategies. In the product life cycle, digital technologies make it possible to reduce the impact on the environment so that digitization could be implemented at every stage of the product life cycle and technology. But on the other hand, the results show that the life cycle of technology leads to a high consumption of energy and resources and an increase in total emissions.

V. CONCLUSIONS

Digitization is playing an increasingly important role in the evolution of production and environmental sustainability. The analysis of the articles written on this topic highlighted both the positive and negative implications of digital technologies on environmental sustainability. The results confirm that digitization allows the use of innovations that require the use and reuse of raw materials and existing materials for as long as possible. Reducing the consumption of non-renewable raw materials and the resulting waste is the current needs of the planet, and achieving these requires the development and implementation of concrete action programs aimed at smart, sustainable and inclusive growth. Therefore, environmental sustainability depends on the amount of materials used in production and the productivity of resources. Currently there are national economies that have the capacity to achieve an increase in resource productivity (measured by GDP) faster than the consumption of raw materials (measured by domestic consumption of materials). These issues are also supported by European environmental policies by implementing strategies that lead to economic growth focused on resource efficiency, biodiversity restoration and pollution reduction.

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