Analysis of the innovative development of circumpolar countries in the context of the fourth industrial revolution

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Abstract. Industry 4.0 is a new paradigm in the manufacturing world. It has radically changed the way people and machines interact. Main features of Fourth Industrial Revolution are the following: technological transformation, artificial intelligence and digitalization. The variability in innovation performance in circumpolar countries has led to the development of many theoretical concepts. These concepts include the role of public policy, research and development, foreign direct investment, human capital and financial development in the Fourth Industrial Revolution. This study examines the macroeconomic performance of circumpolar countries in terms of technological innovation from 2012 to 2017. The results show that globalization, R&D, GDP, financial development and human capital are important factors behind technological innovation. The article provides a detailed analysis of Industry 4.0 technologies in circumpolar countries. The authors believe that it is important to compare the statistics in circumpolar countries with the general statistics of the countries – members of the Organization for Economic Cooperation and Development (OECD), in the framework of the Fourth Industrial Revolution.

Keywords: circumpolar countries, Arctic, R&D, patenting, Fourth Industrial Revolution

1. Introduction
The term "Industry 4.0" was first introduced in 2011, and it describes the fourth industrial revolution taking place nowadays. This revolution evolved from three other industrial revolutions as shown in Figure 1. The first industrial revolution took place in the second half of the 18th century, giving rise to new mechanical production facilities using water or steam power. The second industrial revolution began in the 1870s due to the introduction of electrification, division of labor and use of conveyor belts. Finally, the third industrial revolution caused by the automation of production processes took place in the 1970s.
Industry 4.0 is a new production concept that involves industrial automation and the integration of new production technologies, which improves working conditions, productivity and quality of work. The fourth industrial revolution is one of the most pressing topics both in the professional and academic fields. This concept also includes intelligent manufacturing [1]. Intelligent manufacturing is a new form of manufacturing that integrates manufacturing assets with computing platforms, communications technology, data intensive modeling, and predictive engineering.

Industry 4.0 is a new industrial phase in which several new technologies are combined to provide digital solutions [2]. The new paradigm of Industry 4.0 is a revolution that allows communication between people and machines in the entire highly networked environment [3] using automation technologies such as Cyber Physical Systems (CPS), Internet of Things (IoT) and cloud computing [4]. Embedded computers and networks control physical processes using feedback loops [5]. The wide spread of these devices in the communication-executive network creates the Internet of Things (IoT), in which sensors and actuators merge with the environment, and information is distributed between the platforms [6].

The purpose of this article is to study the development of Industry 4.0 and compare the innovative development indicators of circumpolar countries with the general statistics of the countries – members of the Organization for Economic Cooperation and Development (OECD).

2. Literature review on the research topic: the Fourth Industrial Revolution and the Arctic

This revolution prompted the industry to distribute its production processes across multiple sites, or decentralize them more effectively. This organizational structure gave birth to virtualization of reality: performance monitoring and automated control. Thus, decentralization and virtualization are paradigms related to the Fourth Industrial Revolution [7].

Industry 4.0 has developed in a new market where competition demands new production facilities based on continuous flexibility and reconfigurability. It includes five layers: connectivity, transformation, cyber, cognition and configuration. The main characteristic of this new type of structure is the transition from centrally controlled processes to decentralized ones. Industry 4.0 has evolved from the concept of smart products. One of the main pillars of the Fourth Industrial Revolution as considered by DrathR., & HorchA [8] is the concept of the Internet of Things.

The fourth industrial revolution is based on the concept of cognitive automation as a step between the industrial model, in which robots replace people, and another model, in which information flows quickly and everything is perfectly synchronized [9]. Klochkov Y, Didenko N., Skripnuk D. considered Industry 4.0 as a major innovation that resulted in big changes in the organization of the workplace and organizational commitment [10].
The interaction of man and machine has changed profoundly over the years and Industry 4.0 has introduced great innovations, which can be explained by the main features of the Fourth Industrial Revolution:

- Big data and analytics;

  The introduction of Industry 4.0 into production requires involving specialists capable of dealing with communication devices and data analysis [11].

  Kumar R., Haleem A., Garg S. K., & Singh R. K focus on the fact that companies will use algorithms for real-time data analysis. The use of big data will entail staff redundancies, therefore an industrial data specialist with skills in the use of statistical programming languages will be in demand [12].

  The difference between a traditional worker and an Industry 4.0 worker implies a huge gap in competence and knowledge.

- Robotic production;

  Robots will replace humans in many fields, and they will reduce manual labor in many production processes [13, 14]. The use of robots will lead to a revolution in the workplace, as robots will ensure ergonomic improvements. Machines will perform manual work, while humans will oversee the production processes.

  Francisco Almada-Lobo argues that robots will have a fundamental role in the dynamic environment of the manufacturing process due to their cognitive skills and ability to re-adapt their status in accordance with the new situation and new inputs [15]. There will be a robot coordinator to supervise the robots in the workshop and respond to faults or error signals.

  The coordinator robot will perform both routine and emergency maintenance tasks, and, if necessary, involve other specialists. In case there is a need to replace a robot, this responsibility will be taken by the coordinator. Using automation to assist human workers will be especially relevant in many developed countries. The robotic device allows the worker to do their job in an easier and more ergonomic way, avoiding mistakes and accidents. Manufacturing processes will become more flexible in Industry 4.0. Robots, smart machines, and smart products that communicate with each other and make autonomous decisions will provide this flexibility.

- Automated Guided Vehicles;

  In modern industrial conditions, automated guided vehicles systems are becoming an integral part of overall production systems. AGVS (Automated Guided Vehicles System) contains one or more automated guided vehicles, which are unmanned vehicles used to transport materials. AGVS are widely used in manufacturing plants, distribution centers, warehouses and transit points [16].

  AVGS is wireless, and communication between machine and workers is provided by simple interfaces. Information can circulate throughout the system so that each vehicle knows its own status and that of the others, so that the order is given to a vehicle that can fulfill it in a more efficient way. The smart vehicle allows for easy collaboration between human workers and robots, increasing production efficiency.

- Virtual reality and additive manufacturing

  In Industry 4.0, the workers can rely on augmented reality, which allows them to monitor the logistics, including the exact location of the goods on the shelf, and automatically scan the barcode. The system also provides remote assistance for basic maintenance [17]. Ferdows and DeMeyer prove the importance of understanding how augmented reality will change the way a factory works: workers will receive repair instructions on how to replace a particular part and this information will be sent through various devices such as tablets, etc. [18]. With the development of digital technology, it will be possible to create complex products in small batches, because manufacturing in decentralized factories, as well as transportation, will no longer be a problem. This new scenario is characterized by highly customizable production processes as greater communication between machines and people reduces work-in-progress.

3. Research methodology and initial data
The term Industry 4.0 was first used at the 2011 Hannover Fair and it implies the application of the general concept of cyber physical systems (CPSs) to cyberphysical production systems. In North America, General Electric put forward similar ideas under the name of Industrial Internet. The technical framework is very similar to Industry 4.0, but the scope is broader than industrial production and includes smart grids. In this connection, the researchers take into account the indicators of innovative activity of circumpolar countries since 2012 using the comparison method. Silvestri (Silvestri L. et al, 2020) note [19] that the academic debate on the topic of maintenance management under the influence of Industry 4.0 began in 2015. These researchers presented a literature review on the subject. According to them, most researchers deal with case studies and conceptual applications, and to a lesser extent – with theoretical simulations, experimentation and prototype. At the same time, case studies contain the results of testing theoretical concepts through empirical applications.

There are practically no publications of the empirical studies results regarding the impact of Industry 4.0 on various areas of human activity. We explain it by the fact that this term and the concept itself are quite new, and therefore it is difficult to obtain reliable conclusions from databases using econometric and statistical approaches.

In this regard, the main tool for assessing the dynamics of various indicators characterizing changes in various spheres of human activity and sectors of the economy is a visual analysis of rather short time series. The limited data available is explained, among other things, by the fact that within the framework of the Industry 4.0 concept, only innovative areas are considered that have arisen relatively recently and have not yet become widespread.

Research areas and development vectors within Industry 4.0:
- Industrial Internet of Things (IIoT);
- Big Data and Analytics;
- Horizontal and vertical system integration;
- Simulation;
- Cloud computing;
- Augmented Reality (AR);
- Autonomous Robots;
- Additive manufacturing;
- Cyber Security.

4. Research results

The analysis shows that modern technologies can make the Arctic region more comfortable and safe. In the modern economy, innovation and the development of new technologies is a key driver of economic and social development of both individual regions in particular, and the world as a whole. The period since the beginning of the 21st century has seen an explosive growth in the number and scale of technical developments and improvements in almost all sectors of the economy.

One of the most significant indicators of innovation activity in a country or region is patenting. As part of the fourth industrial revolution, the authors consider it important to analyze the relevant statistics in this area in circumpolar countries in comparison with the general statistics of countries belonging to the Organization for Economic Cooperation and Development (OECD). This organization pays particular attention to the specific areas in the field of patenting, such as biotechnology, nanotechnology and the environment. These areas, as well as developments in the field of artificial intelligence, are among the main ones in the implementation of the Industry 4.0 concept.

It should be noted that in the countries of the Arctic region, the statistics varies on the above indicators (Figure 2-4).

1 http://www.oecd.org/sti/intellectual-property-statistics-and-analysis.htm
Figure 2. Patent applications filed under the Patent Co-operation Treaty in Biotechnology (Priority date, Inventor(s)'s country(ies) of residence) (Source https://stats.oecd.org/).

Figure 3. Patent applications filed under the Patent Co-operation Treaty in Nanotechnology (Priority date, Inventor(s)'s country(ies) of residence) (Source https://stats.oecd.org/).
Figure 4. Patent applications filed under the Patent Co-operation Treaty in environment-related technologies (Priority date, Inventor(s)'s country(ies) of residence). (Source: https://stats.oecd.org/).

Below is the statistics for these areas in Iceland (Table 1)

| Table 1. Iceland Patent applications filed under the Patent Co-operation Treaty (Priority date, Inventor(s)'s country(ies) of residence) |
| --- |
|  | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
| Environment-related technologies | 1 | 1 | 3,5 | 3 | 3,333 | 2 |
| Nanotechnology | 0 | 0 | 0 | 0 | 0 | 0 |
| Biotechnology | 2,2 | 0,85 | 2,167 | 2 | 0 | 2 |

Statistics related to patenting in areas related to artificial intelligence is shown in Table 2.

| Table 2. Patent applications filed under the Patent Co-operation Treaty in Technologies related to artificial intelligence (Priority date, Inventor(s)'s country(ies) of residence) |
| --- |
|  | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
| Canada | 1,25 | 4,4 | 4,625 | 13,758 | 24,567 | 4 |
| Denmark | 0 | 0 | 0 | 0 | 1,5 | 0 |
| Finland | 0 | 0 | 1 | 1 | 2,5 | 1 |
| Iceland | 0 | 0 | 0 | 0 | 0 | 0 |
| Norway | 0 | 1 | 1 | 0 | 0 | 0,75 |
| Sweden | 2,333 | 1,333 | 0 | 0 | 2 | 0,857 |
| United States | 59,083 | 75,429 | 100,567 | 131,444 | 212,187 | 87,888 |
| Russia | 1 | 2 | 1,625 | 5 | 1,2 | 1 |
The analysis of the above data has shown that there are significant differences in patenting in circumpolar countries in the key areas of the fourth industrial revolution. However, countries' efforts to stimulate research and development in these areas do not differ significantly. The statistics on the total expenditures on R&D carried out in the territory of the countries of the Arctic region during a certain reporting period is quite similar (Figure 5). A competent state policy and international scientific and educational cooperation are considered by the circumpolar countries as the key tools for ensuring sustainable development of the Arctic and solving national problems in the region.

Figure 5. Gross domestic expenditure on R&D (GERD) is total intramural expenditure on R&D performed in the national territory during a specific reference period (Source https://stats.oecd.org/).

The most important conditions for the technological revolution in the Arctic region are the following: reliable, affordable communications and wider Internet access. This allows us to validate the equipment and industry, monitor online environment, and conduct additional research and development [20]. Indigenous people in the North can use remote services, such as health care and education, to develop their businesses.

Internet access directly depends on the population and economic importance of the region. For example, in Alaska, many service providers immediately offer telecommunications services as well as satellites connection in remote areas. The urban areas of northern Scandinavia are fully covered by cellular networks (Figures 6, 7). The Russian Federation is slightly behind the general trend, so it is necessary to develop rapidly the information and communication infrastructure. Satellite communication technologies are most important in remote and sparsely populated parts of the Arctic zone.
Fixed broadband access refers to fixed subscriptions for high speed access to the public Internet (TCP/IP connection) with a downstream rate of 256 kbps or more. This includes cable modem, DSL, fiber to home/building, other fixed (wired) broadband subscriptions, satellite broadband, and terrestrial fixed wireless broadband. This amount does not depend on the ways of payment. This excludes subscriptions that have access to data transmission (including the Internet) over mobile cellular networks. It should include fixed WiMAX and any other fixed wireless technologies. It includes both consumer and business subscriptions.

Internet access is open to the shift workers' settlement in the Russian Arctic. Due to the small population, building a base station and laying optical cables is unprofitable, and satellite communications are very expensive. Unmanned technology has the tremendous potential in the areas of logistics, exploration and extraction of natural resources, science and tourism. Companies and
locals can quickly get their goods, and scientists will study climate change and animals' migration. Drones can provide emergency assistance.

Building roads and railways in the north is difficult and expensive due to the problems with delivery of goods and technology. Moreover, road construction destroys the environment and ruins the way of life of the indigenous people. Biodiversity is declining and traditional methods of nomadic life are being shattered. Cargo drones can help to reduce the cost and time of delivering parcels from the mainland.

Unmanned technologies can be used for aerial photography and aerial surveillance, and they will help the mining companies to monitor the development of the site and the integrity of the pipeline. Environmental organizations can quickly receive information about fires, and drones can assess the state of the iceberg and update the weather forecast.

In the Arctic region, there are difficult living conditions: low temperatures, pressure drops, polar day and night, increased geomagnetic activity, lack of sun light and vitamin, which leads to a shorter life expectancy in the region. It takes at least a year to get accustomed to Arctic conditions, and human health is at risk.

Natural resources such as oil and gas deposits, gold and diamond deposits, as well as numerous fishing grounds have always been important for the development of the Arctic. With global warming, sea ice is shrinking, and sea travel in the Arctic Ocean is increasing. The Northern Sea Route is becoming more and more attractive for logistics companies, and mining costs are decreasing [21].

The Arctic is changing at an unprecedented pace. Recent shifts have occurred in the components of the Arctic cryosphere, and further extremes are expected. Regardless of the fact which emission scenario will be developing over the next several decades, in the middle of the century the Arctic will have a significantly different environment from what it has today (less snow and sea ice, melted permafrost, different ecosystems). Ice caps delay the rise in atmospheric temperature [22]. The melting of Arctic glaciers, ice sheets and ice caps will continue even under reduced emission scenarios. The predicted increase in air temperature in the summer in the Arctic significantly brings the Greenland ice into a state of irreversible loss. The Arctic is part of the global climate system and plays a regulatory role as the main reservoir of cold for the global climate. Innovative technologies, monitoring, forecasting should help avoid a crisis.

The economic development of the Arctic territory reveals a serious imbalance. Raw materials are exported from the region, and inexpensive finished products are delivered to the residents. This makes the Arctic highly dependent on other regions and reduces employment opportunities. Companies based on innovation and respect for the environment can solve these problems [23].

5. Conclusion
The fourth industrial revolution, like the previous industrial revolutions, has the potential to raise the level of world income and improve the quality of human life. It will have a big impact on business, government and society. From an evolutionary point of view, the fourth industrial revolution evolves from the previous revolution, and it is often referred to as the digital revolution. To a certain extent, the goal of the fourth revolution is the fusion of technologies that bring the physical world closer to the biological and digital world. The Fourth Industrial Revolution involves the field of ecology, which is very important for the Arctic region. This study analyzed the existing literature and the level of Industry 4.0 technologies in circumpolar countries in order to provide insights into the subject from an academic point of view. This study revealed a high level of circumpolar countries in the field of technological innovation. As part of the future study, the authors intend to analyze the level of the Internet development, as a factor in the world economy development and in terms of each circumpolar country.

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