



INDUSTRIAL REVOLUTIONS 1.0 TO 4.0: A JOURNEY TO SUSTAINABLE MANUFACTURING

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Abstract

The world has seen four industrial revolutions till the modern time, starting from industry 1.0 to industry 4.0. These industrial revolutions have emerged the new dimensions of human life. It has affected socio-economic aspect of each country in very deep manner. It has developed new horizons in the manufacturing sector of leading economies of the world. But along with these industrial revolutions new challenges also have been emerged on the surface. This leads to concentrate on the concept of sustainable development during manufacturing which cares about mainly environmental issues, natural resources conservation and energy efficiency. This paper relates the concept of industrial revolutions 1.0 to 4.0, with the sustainability of manufacturing sector. In this paper an attempt has been made to find out the presence of attributes of sustainability in manufacturing sector with different industrial revolutions. And it is established that industry 4.0 gives highest level of sustainability in the manufacturing sector among all industrial revolutions.

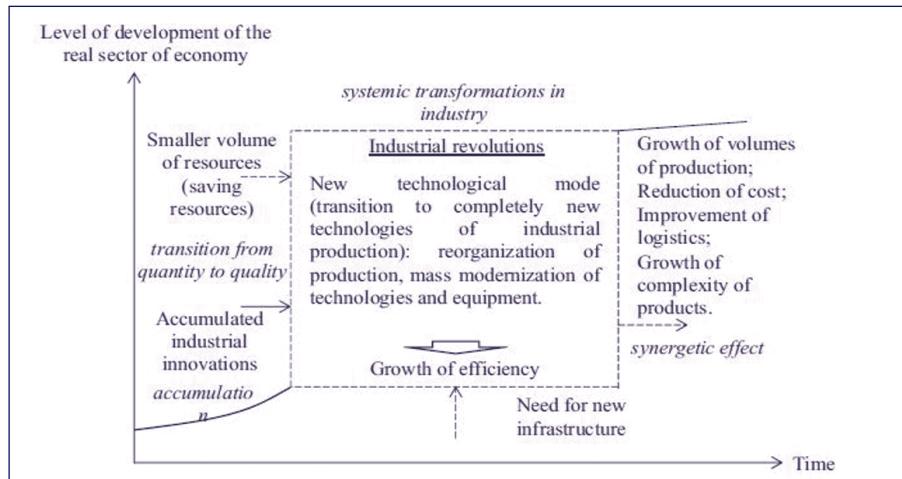
Keywords: Sustainability, Industrial revolutions, Industry 4.0, Manufacturing.

1. INTRODUCTION

Lives on this earth depend on nature. Nature always feeds the livelihood on this earth. Starting from the timeline of the Primitive human, nature has been a spine. So it becomes necessary to save the nature to save the life on the earth. By using its god given thinking power and observation skills, man started his journey towards easy life by making of wheel and discovery to fire. These were the first steps towards the engineering and technology by man on the earth. Curiosity and necessity are the reasons behind new inventions, innovations and discoveries. Fulfilment of these inventions, innovations and discoveries has eventually resulted in industrial revolutions. These industrial revolutions incorporated lots of new technologies

along with its wider spread in the world, which led to easier life of mankind. As it is shown in figure 1(1), accumulation of a sufficient volume of completely new technologies of industrial production (industrial technological innovations) is a precondition for emergence of any industrial revolution. In the process of accumulation of these technologies, evolutionary development of the real sector of economy takes place (in Fig. 1 it is shown by growing parabola in lower left part of the graph). Every industrial revolution brought with its' benefits and challenges to the world. When these technologies reach at some threshold number and receive necessary development, which prepares them for implementation (practical application) into industrial production, the process of transition from quantity to quality is started.

Fig. 1. Generalized model of the industrial revolution (1)



The World Economic Forum, in 2016, has divided these Industrial Revolutions into four different groups as the first industrial revolution, the second industrial revolution, the third industrial revolution, and the fourth industrial revolution. Recently, this Industrial Revolution process is also renamed

as Industry 1.0, Industry 2.0, Industry 3.0, and Industry 4.0. When the revolutions take place, new revolutionary ways dominated the previous revolutions. Also, Process of starting and completing the Industrial Revolutions differs from country to country. The United Kingdom was the leading country for

the Industry 1.0 with the power of its iron and coal reserves; however, another European country Germany with its strong technology has led the Industry 4.0. The countries which do not move towards for the Industry 4.0 will gradually lose their appearances in world markets. The energy demand depending on mechanization in production increased during all Industrial Revolutions. Fossil fuels were mainly used in the First and the Second Industrial Revolutions and renewable, clean or green energy technologies additionally gained importance in the third and the fourth Industrial Revolutions. (2)

During these industrial revolutions, leading economies boosted their production or manufacturing sector to make people comfortable with their daily activities and to make less manual efforts for production. These efforts to reduce man power or to make manual work easier, the balance of natural resources has been disturbed. Thirst of energy made countries blind towards the natural resources. Countries made blind destruction of trees and other natural resources available on earth, over the earth and beneath the earth. And it resulted the imbalance in nature and invited long term issues such as pollution, global warming etc. These issues gave birth to the term “sustainable development” in the field of manufacturing. The concept of sustainability has systematically emerged in all these industrial development processes by indicating natural resources are limited and exhaustive.

Sustainability can be defined as “meeting our present needs without compromising the ability of future generations to meet their own needs” (3). It has three components – environmental conservation, social responsibility, and economic development. While most people primarily associate sustainability with environmental conservation, it is about people and the health of our communities.

Sustainable development is the practice of using guidelines for environmentally responsible and energy savings to create new development projects and to maintain and retrofit older projects. It can include using green materials in new construction, designing projects that can harvest their own energy to reduce the load on a power grid, or that incorporate green space in order to counterbalance the green space removed to build the onsite facilities. There is a heavy emphasis on making sure that what is built can be maintained and repaired in a way that minimizes the degradation of the original development so that the lifespan of a facility is longer than normal.

According to Wikipedia, “Sustainable development is the organizing principle for meeting human development goals while simultaneously sustaining the ability of natural systems to provide the natural resources and ecosystem services on which the economy and society depend. The desired result is a state of society where living conditions and resources are used to continue to meet human needs without undermining the integrity and stability of the natural system. Sustainable development can be defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

The United Nations Development Program (UNDP) (4), which

is the global development network of the United Nations, identified The Sustainable Development Goals based on the common action of all countries and 193 countries signed the 2030 Sustainable Development Goals in January 2016. For leaving a better world for future generations, 17 basic goals have been identified, including poverty reduction, climate change—disaster risk, economic inequality, and democratic governance— peace building. From the perspective of sustainability, unlike other Industrial Revolutions, Industry 4.0 process will make contributions in achieving these goals with more efficient use of natural resources, human power, and the advance technology.

The goals commonly stated as “Sustainable Development Goals” or “Global Goals” comprise 17 universal actions to eliminate poverty, protect the planet and ensure that all people live in peace and prosperity. In addition to the Millennium Development Goals, they also include new areas such as climate change, economic inequality, innovation, sustainable consumption, peace and justice (4).

Table 1. Sustainable development goals (4)

Goal	Aim	Sustainability for
Goal 1	Poverty	Everywhere
Goal 2	Hunger	Agriculture
Goal 3	Health	Well-being
Goal 4	Education	Lifelong learning
Goal 5	Gender equality	Women and girls
Goal 6	Availability	Water and sanitation
Goal 7	Access	Energy
Goal 8	Economy	Growth and employment
Goal 9	Infrastructure	Industrialization
Goal 10	Inequality	Among countries
Goal 11	Cities and settlement	Safeness and resilience
Goal 12	Consumption	Production patterns
Goal 13	Climate change	Urgent actions
Goal 14	Oceans and seas	Resources
Goal 15	Terrestrial ecosystems	Biodiversity
Goal 16	Peace	Justice
Goal 17	Partnership	Global

2. MANUFACTURING SECTOR DURING INDUSTRIAL REVOLUTIONS

Starting from first industrial revolution (industry 1.0) in 18th century to latest industry 4.0 in 21st century, manufacturing sector has been changed dramatically. All manual manufacturing industries change their way of working and used machines for the production of the items. This change in production started in UK in 18th century as an industry 1.0, spreaded to other neighbouring countries such as France and Germany. Later it spreaded over the seas to the United states and Japan.

The impact of changing the way of manufacturing items had affected many manufacturing units of textiles industries, mining and agriculture sector during early industrial revolutions. For

example, in the textile industry before the Industrial Revolution, textiles were primarily made of wool and were hand spun. But, with the invention of the spinning wheel and the loom, cotton was produced quicker and eventually replaced wool in the textile field. This has dramatically reduced the production time and the cost to produce material and was the beginning of many drastic changes in the textile industry.

This had not only affected in textile industries, but also in the living standard of human life in terms of having better food production, improved livestock breeding and new farming techniques. People started their commutation from small villages to big cities. Population hike also took place, which increased demands of the goods, which led to increment of number of manufacturing units and thus requirement of energy also. So huge supply of coal and other fossil fuels was demanded. This resulted in more and more usage of natural resources. This created imbalance in nature during industry 1.0 and industry 2.0.

In table 2 the world census has been shown during various industrial revolutions, which gives a bird view in demand of goods and fossil fuels subsequently. During industrial revolution 1.0 the census increased from 85.4 cr. To 132.92 cr. (5) and subsequently during other industrial revolutions the same nature of increment has been observed in world census. There was a massive increase in factory jobs during the Industrial Revolution, and many changes took place in how goods were produced. From this we can understand the progress in usage of resources as well as energy. However, with materials, it is now being produced quicker and cheaper, the need for manufactured goods was greater than the supply and this material shortage forced factories to open up for greater production hours. As a result of this need of sustainable development is observed in manufacturing sector.

Table 2. World census during industrial revolutions (5)

Industrial revolution	Span of years	(World census in span (in crores
1.0	1760-1860	85.4-132.92
2.0	1860-1970	132.92-368.25
3.0	1970-2010	368.25-692.97
4.0	continue 2010	(2020)692.97-779.5

In figure 2 the demand of energy in industry 3.0 in unit of quadrillion Btu from 1980 to 2010 has been shown, where population of the world was almost 45% increased. During this period due to usage of machineries mining and its related sectors were boosted so lots of natural resources were utilized in inefficient way.

From figure 3, we can see in 2015 mostly coal, oil and gas had been used as an energy source which is available in nature. The by-products of the usage of these fossil or conventional fuels give different types of pollution which results into the lower life of mankind. It increases health related problems too among

people. This also creates long life issues related to human life, such as hole in an ozone layer. After 2005 remarkable use of renewable sources of energy can be marked.

Fig. 2. World primary energy consumption in quadrillion Btu from 1980 to 2010 by region according to the U.S. Energy Information Administration (6)

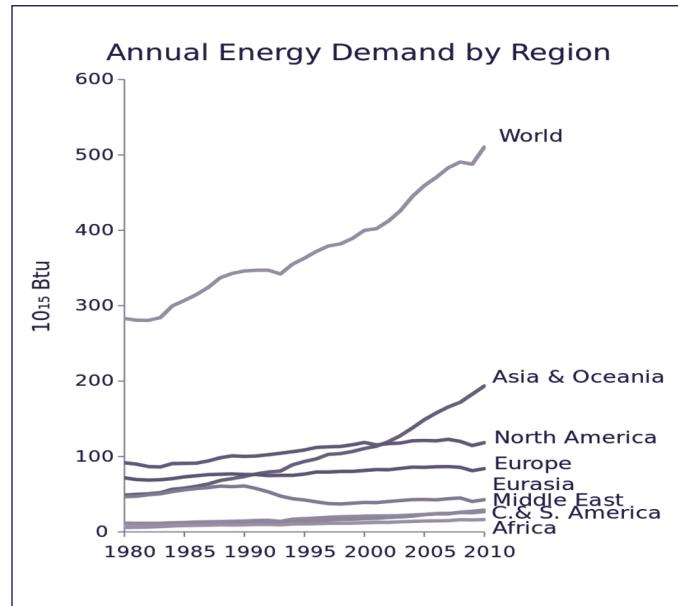
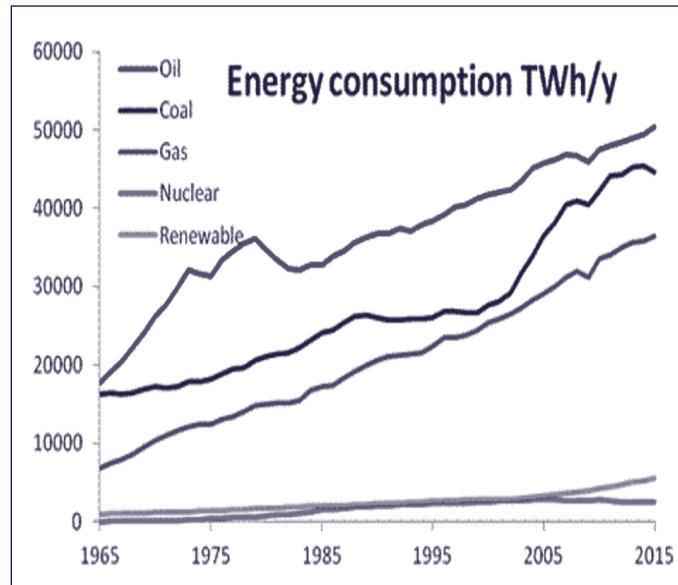


Fig. 3. The world's energy consumption (2015 data) (7)



3. INSIGHT TO TECHNOLOGICAL DEVELOPMENTS DURING INDUSTRIAL REVOLUTIONS 1.0 TO 4.0

During industrial revolution 1.0 to 4.0 many inventions have shown below Table 3 year wise. These inventions changed life style of the mankind. But as the increase in population, the demands of such things have increased. Along with the demand, usage of natural resources increased in terms of energy (fossil fuels) and material (metal). Highlighted developments in table 3 revolutionised the journey towards sustainability in manufacturing field.

Table 3. Technological developments in industrial revolutions (8, 9, 10, 11, 12)

Technological developments in Industry 1.0			
1764	Cotton spinning machine	1825	Rocket
1775	Steam engine	1825	Electromagnets
1775	Steam powered ship	1839	Bicycle
1783	Hot air balloon, Parachute	1858	I.C. engine
1786	Threshing machine	1862	Plastic
1809	First light arc bulb	1866	Dynamite
1814	Photographic image (which took time to 8 hours to obtain the image)		
Technological developments in Industry 2.0			
1876	Telephone	1931	Analogue computer
1879	Durable light bulb	1942	Electronic computer
1879	Electric train	1944	Kidney dialysis machine
1885	Gasoline engine	1945	Atomic bomb
1902	Air conditioner	1946	Microwave oven
1903	Aircraft by gasoline engine	1947	Mobile phone
1904	Tractor	1952	Hydrogen bomb
1907	Colour photography	1955	Fibre optic
1907	Helicopter	1956	Hard disk
1908	Assembly line by ford	1959	Microchip
1911	Electric ignition system	1964	BASIC programming language
1914	Ford 1 st production model car	1968	Computer mouse
1916	Stainless steel	1968	Integrated circuit
1925	Liquid fuelled rocket	1968	RAM
1926	TV	1969	ATM Machine
Technological developments in Industry 3.0			
1970	Floppy disc	1989	HD tv
1971	Dot matrix printer	1990	World wide web and internet protocol
1971	LCD	1991	Digital answering machine
1972	Word processor	1993	Pentium processor
1973	Ethernet (LAN	1995	Java computer

1975	Laser printer	2001	I pod
1979	Cell phone	2003	Hybrid car
1979	Super computer	2005	You tube, online video sharing & viewing community
1981	MS- DOS, IBM PC	2006	I phone
1984	CD- ROM, Macintosh by Apple	2007	Light source using Nano technology as an alternative to edission's light bulb
1985	Microsoft windows	2008	Electricity from sugar
1987	3D video games	2010	A payment platform digital, credit card for shopping
1988	Digital cellular phone		

4. BASES OF INDUSTRIAL REVOLUTIONS, ITS CHALLENGES AND SUSTAINABLE DEVELOPMENT

Industry 1.0 began in 18th century through the use of steam power and mechanisation of production. Mechanised spinning wheels were able to give eight time productivity than manual. The weaving looms were run by using steam power after technological invention of steam engine in this revolution. Developments such as steamship revolutionised the transportation services of goods and humans. But during this mostly fossil fuels were used, mining activity was started as never before , without keeping in mind the hazardous of it and loss in nature. As it was the first industrial revolution, people were not having much more research exposure related to pollution and imbalance of nature. Many countries were on the urge of internal disputes and human revolutions within them. UK was the country which started it as it was powerful and was having statesmanship of many countries in the world. Consequently, a new society type called industrial society emerged. (2)

The second industrial revolution began in 19th century and it crossed the boundaries of UK. It was led by the discovery of electricity and assembly line production. The idea of mass production introduced by Henry Ford. Assembly line concept was introduced in automobile production. During this era First World War also fought with the resources as coal and other conventional energy sources. Capitalism and communism regimes took birth during this industrial revolution, which fires more usage of natural resources to become the world leader among all the countries. In this period of substantial changes, countries like Britain, Germany and the USA conducted research to get more efficiency from the chemical energy in the coal. Thus, the science of thermodynamics was born and the new experiences influenced the military technology as well (13). Steel, electricity, transport, food processing, chemicals

agriculture processing played a main role in industry 2.0. Still due to lack of stabilised governments and independency of most of the nations were not aware with sustainability during manufacturing processes.

In '70s in the 20th century, the third revolution began through partial automation using memory-programmable controls, computers and its networking through Ethernet. Due to these technologies now people were able to automate the production process without human intervention. This led to introduction of computer systems in manufacturing sector, so human error could be eliminated. Oil sector had its boom now.

Drilling of fossil fuels like oil requires large capital, vertical scale economies, top-down command and its supervision. Because oil trade is not only one of the biggest industries in the world, but also collecting, processing and distributing energy is a costly business. Furthermore, automotive, modern finance, energy, telecommunications and construction industries that emerged from the oil culture have a tendency to grow for having their own scale economies, and they need large capital and have a central organization just like the oil industry (14). This industrial revolution focused on decrement of natural resources, which risen the idea of the sustainability in manufacturing. Issues like the environmental pollution and irresponsible use of resources as result of the first and second Industrial Revolutions were on the surfaces and seriously in thoughts of the world leaders and world agencies. As a solution to protect the natural life and environment and to achieve sustainable development world started it's facing to renewable sources of energy which are easily available and less harmful to the environment. Less energy consumptions with technological developments were also on the cards of industrial revolution 3.0. By keeping renewable sources of energy in mind various areas such as development of energy storage techniques, buildings' capacity to produce their own energy, transition

to zero-emission transportation with electrical transportation systems, green economy were started to explore. Synthetic goods, computer technology, microelectronics technology, fibre optics, telecommunications, biogenetics, bio-agriculture and laser technology became determining factors in this period. In brief we can say during this industrial revolution 3.0, the concept of sustainable development in manufacturing and energy saving and harvesting comes into picture. Renewable energy sources were explored to save the environment.

We are in the phase of Industry 4.0. It incorporates information technology and communication technologies to industries for their production lines. Industry 3.0 is the base of it in which information technology was among the key factor. In this revolution manufacturing systems that already have computer technology, are incorporated by a network connection and have digital twin connection on the internet so it can speak also. This enables the production system to communicate with other facilities and infirm output of information. It can be said as a next step in automation of manufacturing system. The networking of all systems leads to "cyber-physical production systems" and therefore smart factories, in which production systems, components and people communicate via a network and production is nearly autonomous. Industry 4.0 represents a fundamental paradigm shift towards individualized and decentralized manufacturing systems, which will enable totally new, internet based services and business models. (15, 16). This industrial revolution 4.0 continuously provides new opportunities in many areas ranging from finding the system failures to decrease them, environmentally friendly manufacturing techniques, energy saving by using smart devices, flexible manufacturing systems for cost reduction also.

The main pillars of industry 4.0 are described in table 4 along with its contributions to sustainable development in manufacturing with compared to previous revolutions.

Table 4. Pillars of industry 4.0 and its contribution to sustainable development (17, 18)

Pillar of industry 4.0	Contribution to sustainable development
Big data and analytics	<p>Big data analytics is the process of examining all data sets collected from different areas such as postings on the Internet and databases, photograph archives and transactions recorded in the Internet to organize them in a practical format.</p> <p>This kind of analysis allows organizations to use their data to have new opportunities. It also helps them to have more efficient operations, smarter business moves, higher profits and happier customers.</p>
Autonomous robots	<p>This kind of robots are capable of making their own decisions just like humans and act accordingly. An autonomous robot has the ability to perceive their environment, depends on programmed decisions to know this environment and can start a movement or manipulation in that environment.</p>
Simulation	<p>These virtual models developed using real-time data create the virtual reality of the physical world as well as machines, products and humans. Thus, operators expect to have the opportunity to virtually test machine parameters for the goods in the production line before arranging in a physical setting, cut down on setup times and improve product quality.</p>
Horizontal and vertical system integration	<p>This system aims to ensure that companies, units and competences become more compatible with each other with the development of company-wide universal data integration networks.</p>

The industrial Internet of things	IIoT, also known as industrial Internet of things, involves sensor data in industrial settings, machine learning that uses machine-to-machine communication and automation techniques, and big data technology. Smart machines can capture data and communicate more accurately and consistently compared to humans. Therefore, they can enable companies to predict inefficiencies and problems earlier. Sustainable Development and Industry Revolutions save money and time and support business intelligence work. Furthermore, IIoT has great potential in terms of quality control, sustainable and green practices, traceability of supply chain and supply chain efficiency in general.
Cyber security	Effective cyber security reduces risk of cyber-attack and defends organizations and individuals from the unauthorized use of systems, networks and technologies.
The cloud	Due to the cloud technology it has become possible to store and access large data sets on the Internet. In line with these opportunities,
Additive manufacturing	The concept of additive manufacturing (3D printing) refers to the production by the addition of materials like plastic or liquid resin on top of each other. This reduces loss of materials and saves the material in a sustainable way.
Augmented reality.	Augmented reality enables to feel and experience a physical setting in the real world live, dynamically and real time with computer-generated sensory inputs. By using it the perception of reality is enhanced.

However various issues such as primary investment cost, lack of standard guidelines or road map to implement industry 4.0 in manufacturing sector, privacy and interoperability are yet to be focussed in effective manner (18). Industry 4.0 deals with the sustainability in manufacturing sector in an efficient way. It incorporates various concepts such as shown in table 4. This enables manufacturing sector to have high performance production, zero-defect, reduced cost, material savvy, energy efficient, smart, faster productivity, automation, heat management, resource efficiency and re-configurability. These all benefits makes industry 4.0 superior in sustainable manufacturing (19).

5. CONCLUSION

Starting from industry 1.0 in 18th century, mankind started its journey to uplift their daily life, to make it easy. But until the third industrial revolution it did not take care of the nature in the blind race of capitalism and industrialisation. And it resulted in some serious concerns related to environment and the whole nature, which could be the reason of the end of the all lives on the earth. Later, in third industrial revolution it was realized to take care of nature also which feeds human being since the era of the first man on the earth. And then industry 3.0 started to take care of environmental concerns and took first step towards sustainable manufacturing or in a broader term sustainable development. Industry 4.0 can be called as the revolution having a big jump in the direction of the sustainable manufacturing by incorporating smart systems, automation, information technology and communication system through internet.

So, in this paper the attempt of showcasing the gradual improvement in sustainability in manufacturing sector from industry 1.0 to industry 4.0 has been made. The technologies imparted in industry 4.0 are the core boosters behind the drastic improvement in sustainability in manufacturing sector.

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