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Industry 4.0 and smart manufacturing: potential environmental benefits

The case of China

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"You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete."

(R. Buckminster Fuller)

To the future.

May it be more sustainable,

innovative and brighter.

Abstract

Today we are living in a period characterized by an industrial shift, namely the Fourth Industrial Revolution, or Industry 4.0. The latter involves the manufacturing system in particular and allows a shift towards a digitalized, interconnected and integrated production. Smart manufacturing is the application of Industry 4.0 in the manufacturing field, enabling the use of technologies such as IoT, CPS, Big Data, 3D printing and Robotics to enable more flexibility, efficiency, customization as well as improving the quality of manufacturing processes in the smart factory. The revolutionary impacts it determines are several, among which one of the most interesting ones is environmental sustainability. The objective of my thesis is to carry out an analysis of the potential environmental benefits that Industry 4.0 could bring through smart manufacturing processes.

This concept is both recent and greatly discussed as we are living a global environmental crisis due to the so far carried out unsustainable growth pattern. First of all, I carry out an overview of the concept of Industry 4.0 and smart manufacturing, analysing their features from a global approach. Afterwards, I introduce the core topic of my thesis: is it possible to achieve environmentally sustainable benefits through Industry 4.0? In order to do that, I depict the concept of sustainability and other environmental concerns, afterwards I will focus on the Chinese approach towards environmental sustainability, which is closely linked to the concept of green manufacturing. Made in China 2025 initiative is the concrete example that embodies the two concepts of the core of the thesis: green development and smart manufacturing. The studies I deal with are mostly related to estimations and statistics, which show potential positive environmental results provided by smart technologies. I will refer thus to indicators such as energy and resources consumption, material waste and pollutant emissions, recycling in order to demonstrate that smart manufacturing could be a potential driver for an environmentally sustainable manufacturing pattern.

List of Contents

List of Abbreviations

AI – Artificial Intelligence

AR – Augmented Reality

BRI – Belt and Road Initiative

CE – Circular Economy

CAGR – Compound Annual Growth Rate

CO2 – Carbon Dioxide

COVID-19 – Coronavirus Disease

CPS – Cyber Physical System

EU – European Union

GDP – Gross Domestic Product

GHG – Greenhouse Gas Emissions

GVA – Gross Value Added

IEA – International Energy Agency

IFR – International Federation of Robotics

IIoT – Industrial Internet of Things

IoT – Internet of Things

IT – Information Technology

MIC25 – Made in China 2025

MIIT – Ministry of Industry and Information Technology

MVA – Manufacturing Value Added

M2M – Machine to Machine

NBS – National Bureau of Statistics

NEVs – New Energy Vehicles

OECD – Organization for Economic Co-operation and Development

PAGE – Partnership for Action on Green Economy

PwC – Pricewaterhouse Coopers

R&D – Research and Development

SDGs – Sustainable Development Goals

UN – United Nations

UNCTAD – United Nations Conference on Trade and Development

UNDESA – United Nations Department of Economic and Social Affairs

UNIDO – United Nations Industrial Development Organization

VR – Virtual Reality

WTO – World Trade Organization

前言

这篇论文研究的基础就是工业 4.0 和它制造业的用途。并且，本研究的目的是调查工业 4.0 在制造业可持续的潜力。 总之，我将介绍智能制造对环保的活力。

首先，我会做一个整体分析，谈谈全球全面情况，然后我专注于中国的情形，包括介绍中国智能制造业的实施，检验现在的状况如何、中国政府的有关目标。为此，我会介绍一下有名的 “中国制造 2025” 。检查近期现有的研究和参考文献部分以后，我就会发现工业 4.0 和可持续性之间有直接关系。因此，中心论点强调从工业 4.0 和智能制造业可以推演出绿色和可持续制造业的潜力。

可是，可持续性这个题目比较宽泛。其实它包括的有关因素不只是一个，而是三个: 经济、社会和环境，它们是可持续发展的三个支柱。意思是他们是利润、人和生态。每个因素值得分析，可是我将仅仅聚焦于环保可持续性这个概念。生态是指环境保护,尊重地球的资源约束。

为什么说环境因素呢? 首先，我对关于环境保护和大自然的事情特别感兴趣。再说，我觉得这个是最近最重要、讨论很多的话题中的一个。在气候变化、污染严重、经常发生特大自然灾害的情况下，人类正在发现它对自然、生态系统的影响。所以为了解决或减轻这些严重的后果，我们对地球的态度的改变是必不可少的，不能再等情况愈来愈恶化了。

因为工业是所有行业中第一个需要负责任的，所以为了走向可持续发展第一个必要步骤是改变我们生产方式。以前的工业革命带来了非常重要的创获，拿科技技术发展来说，它是我们现在的生活的关键。不过，可持续和绿色发展的概念就是第二十世纪末出现的，所以我们现在所在的工业过渡时期必须考虑到这些。

今天我们正在经历第四次的工业革命，所谓的工业 4.0。多亏新一代数字技术，最基础的特点就是数码化和互联化。如此，工业生产现在正在变化，变得更有开创性，更互联。这种生产方式就是所谓的 “智能制造”。

值得注意的是，特别是近期的工业和生产引起了巨大的环境问题:换句话说，工业对污染排放有很大的影响。其实，我们可以说工业是最应该对污染负责的一个行业，或者

对环境损害最重要原因之一。所以我们现在应该努力面对的环保挑战就是温室气体、全球世界变暖和气候变化。

至于这个背景，第四工业化的角色是什么呢？制造业数字化和可持续化有没有直接关系? 可不可以把智能制造和绿色制造算作代名词？

由于这个话题的复杂性，并且产业升级还没有全然和平和地结束，许多学者还没证实工业 4.0 引起可持续产业和绿色制造的思想。实际上这种看法没有得到各个研究者和学者的共识。其实，应该参酌的是这种现象在很多的国家仍然处于萌芽状态。因此，我只注重一些近期现有的研究和相关研究。

工业 4.0 的技术可以刺激制造业的升级，这样允许绿色产业和产品的制造。事实上，新技术诸如大数据，物联网和工业互联网，信息物理系统等技术工具有很大的好处。比如，他们提高制造效益和伸缩性、改善产品性能、引进个性化，这样可以把污染排放和肥料减少。

技术革新是工业升级过程的关键。在很多行业中他们已经实行了又智能又可持续制造的方式。发达和发展中国家都力求改善自己的产业结构。政府促进的计划或者方案很多: 首先德国，美国、法国、英国、新加坡、韩国、马来西亚、欧盟都促进多种计划，为了建设各个国家智能制造业。比方说，发展中国家中国和印度推进技术发展，以增进发展。他们对这个问题的积极态度从计划的实行到政策的提倡出来，目标就是制造系统的复兴。因为制造业是中国国内生产总值的大部分，中国在产业和制造这些行业是特别有名的。这是因为工业升级必不可少，特别是那些巨大、廉价劳动力的工业体系。这样他们用的产业结构比发达国家的更大，但污染的水平更高、而工艺水平更低。拿中国来说，中国有一种巨大的工业体系，生产各种各样的产品，代表全球的制造商。不过，中国制造业的死穴是技术和技术知识体系不发达，于是依赖比如美国、日本、德国这些发达国家。既然中国是投资研发和高新技术最多的国家/投资者，从技术知识的角度来看它算是不太发达。

关于绿色和可持续发展，中国的角色还是比较的奇特的。大家都知道，中国大城市的大气污染严重，这都导致人们把中国叫做污染最严重的国家。其实，数据显示 2017 年中国生产的二氧化碳为 9.84 亿吨。这是从 1970 年发生的巨量发展的不好结果。这种发展方式的确不可持续，没尊重环境和我们的生态系统和地球。

虽然中国在这个方面带来了重大损害，但是政府最近很努力地进步了。尤其是最近几年，中国应付了国家和国际环境污染问题。

数据明示在中国能源使用正在走向可再生能源使用是真实情况。二氧化碳排放最近减速，注重再造业、能耗和污染。绿色发展就站在政府发布的最重要的计划中。最基础的目标是增进高级、可持续和包容性发展。此外，中国绿色投资巨大，跟研发和技术投资一样多。

像中国这样的国家经过一种智能生产过程，可以由此得到效益。这个现代制造方式允许效率和质量高的生产，符合可持续标准。

其实，关于这个题目的最重要计划之一就是2015年中国政府发布的"中国制造2025"。这个规划是指全面四阶段的第一个，目标是得到技术独立，让中国成为领先的制造业强国。这个目标应该于 2049 年成就，配合中国共和国成立的第一百年。

所以，这篇论文的目标就是论证新技术，数字化和工业 4.0 可以达到从环保的角度来说，一种可持续制造方式。全球的前景以后，重点在中国因为我觉得是个好例子。原因是它的巨大制造业体系，还有它的绿色投资倾向。

最后是关于所有研究、调查和制造公司的企业社会责任证实工业 4.0 对生态和环保的可能性。 原因是， 技术 4.0 在智能过程中能提高资源效率 (税、能源、资料) 和循环能力，减少能耗和废渣。这样智能制造在工业 4.0 的前景下能保证无污染能源，消除公害。

论文的结构分为如下。第一个章包括导论: 我来说的是关于工业 4.0 和智能制造: 从全球的角度来说，我来审慎分析这些观念，介绍他们的环境影响。第二个章是关于可持续发展和环境问题，所以我会参酌中国对环境保护的情况。并且，我来介绍中国工业 4.0 和智能技术的发展。很可惜，关于这个题目我找到的文件不多。第三个章包括参考文献，所以我会分析所有关于主要话题的文件。最后，第四个章关于结果评鉴。

第一个原因是这个问题比较新颖，因为工业 4.0 的现象是现代的，所以研究不多; 第二个原因是题目的复杂性，所以工业 4.0 和他的环境影响无法被详细介绍。虽然在文件的查看过程中我面对了一些困难，但我很努力地分析了学者和研究者的各种看法。

Introduction

At the basis of this study there is the application of Industry 4.0 into the manufacturing industry and its potential sustainable pattern, from an environmental point of view. The approach will be primarily global, while subsequently I will focus on the case of China. I will analyse the implementation of Industry 4.0 and smart manufacturing in China, examining the objectives and its present state by focusing on the *Made in China 2025* (MIC25) initiative. With the support of recent existing studies and literature, I will support the thesis by which Industry 4.0 can lead to a more sustainable manufacturing pattern, highlighting the closer link between smart and green manufacturing both globally and in China. The concept of sustainability is actually very broad, as it is made up of three dimensions namely the economic, social and environmental/ecological dimension. My focus will be on the environmental dimension.

Today we're living the fourth step of Industrial Revolution, the so-called Fourth Industrial Revolution or Industry 4.0, characterized by digitalization and interconnectivity, thanks to the use of new-generation digital technologies. Therefore, the industrial production is now changing, and it will be more and more innovative and interconnected, creating the so-called smart manufacturing.

However, today's concerns about industry and production are closely related to the environmental crisis. As the industrial sector is greatly responsible for pollutant emissions, this leads to the conception of industrial production as one of the first causes of major environmental issues we are coping with nowadays, such as greenhouse gas emissions, global warming and climate change. Hence, the manufacturing industry needs to face these challenges by undergoing an upgrading process driven by innovation and digitalization, which may potentially represent a solution to avoid a further aggravation of environmental damage.

What is the role of Industry 4.0 in this background? Is there a link between digitization and sustainability in the manufacturing sector? Can smart manufacturing be considered as a sustainable manufacturing?

Due to the complexity of the topic and the fact that this industrial shift has not yet developed properly nor in a homogeneous way, the idea that Industry 4.0 could bring benefit to sustainable manufacturing are not unanimously shared by the various researchers and authors. Indeed, we have to consider that, as this phenomenon is still in its embryonic stage in many countries, I'm

going to focus on the few existing data and studies. I will both rely on recently reported data and statistics for the coming years.
Technologies of Industry 4.0 can enable the upgrading of the manufacturing industry, allowing a greener production and manufacturing of goods. As a matter of fact, new technologies such as Big Data, IoT, Cyber-Physical System (CPS), Additive Manufacturing and other tools increase manufacturing efficiency while making remarkable improvements in the product performance, thus reducing energy consumption, pollution and material waste.
Innovation is the key driver of the process towards industrial upgrading: patterns of smarter and more sustainable manufacturing have already been implemented in many industries, both in developed and developing countries. Moreover, governmental initiatives are several: Germany first of all, together with the US, South Korea, the EU promoted many plans aiming at building the upgrading their countries' own smart manufacturing industries. Developing countries such as China and India are now very focused on technological advancement, which is considered as the main driver of future development and economic growth. Their positive and active attitude towards this topic can be noticed through the recently released major plans and policies promoting the renaissance of the manufacturing system.
China is a well-known country in terms of production of manufactured goods, as manufacturing represents a huge portion of the country's GDP. This is why industrial upgrading is a necessary process, particularly for those countries whose industrial system is larger compared the developed ones they represent a huge pool of cheap labour, thus using larger production structures, which are much more polluting since they are less technologically advanced. China, for example, has a huge manufacturing system whose cheap labour produces every kind of product for almost every country in the world.
However, China Achille's heel lies in its technological dependence on some developed countries such as the US, Japan and Germany. Even though it stands as the first country investing in R&D and high-tech it is still considered poor in terms of know-how, national production of core components and in terms of overall quality of production and goods. Indeed, we can't avoid mentioning that the Chinese industrial manufacturing sector has great responsibilities in terms of environmental degradation.
Indeed, for what concerns green and sustainable growth the role of China is still considered as a paradox. Chinese cities with high levels of pollution created a sort of cliché, leading to the conception of China as the most polluting country all over the world. Actually, data demonstrate

that was the first emitter of CO_2 in 2019, with 10.88 billion tonnes per year (Hausfather, Z., 2019). This is the result of the implementation of a massive economic growth which took place starting from the 1970s, and which was the cause of today's environmental issues.

Nevertheless, China has made many efforts in the last decades, especially in the very last one, to cope with environmental issues both at a national and international level.

Data clearly show how energy transition is becoming a tangible fact: CO_2 emissions have slowed down and increasing attention is now given to recycling, renewables and pollution in general. Green growth is at the centre of major plans issued by the central government, which promotes a higher quality, more sustainable and inclusive growth. Furthermore, the country's green investments are huge, and they go together with R&D and technological investments.

Thus, countries like China could benefit from this opportunity by enhancing a smarter production process, which allows to produce more with a more sustainable pattern.

Indeed, one of the most important plans concerning this topic is MIC25 initiative, issued in 2015. It refers to the first stage of a comprehensive three-stage plan aiming at achieving technological independence and making China the leading manufacturing power by 2049, the year of the 100th anniversary of the People's Republic of China. This initiative points out one of the major objectives, that correspond to the rejuvenating of Chinese manufacturing through a new and green production pattern, which is also innovation driven as it involves digitization, network technologies and smart technologies in manufacturing.

The objective of my thesis is thus to demonstrate that digital emerging technologies promoted by Industry 4.0, would allow a more sustainable manufacturing pattern. The global perspective will then leave space to the case of China and its state of art for what concerns digitalization, smart manufacturing and green development.

The structure of my thesis will be organized as follows. The first chapter focuses on the introduction to the main theme: the concepts of Industry 4.0 and smart manufacturing will be deeply analysed considering a global approach: the main features, deployment and impacts of emerging digital technologies will be outlined.

In the second chapter I will outline the relationship between Industry 4.0 and environmental sustainability: environmental and sustainable concerns will be presented, as well as the situation in China with the Made in China 2025 initiative. The first paragraph of Chapter 2 focuses on the overall potential link between smart manufacturing and environmental sustainability: I will define the concept of sustainability, bringing the attention to the environment and industry-related environmental concerns. Whereas the second paragraph presents the Chinese state of art about their deployment, particularly in the manufacturing field. The green development and digitalization represent the key pillars of Chinese government, as they will drive future global competitiveness. Afterwards, the core point will be presented: is Industry 4.0 a potential enabler of environmental benefits? Can smart manufacturing allow a greener manufacturing pattern?

The literature review regarding this, is introduced in the third chapter, which includes insights, journals and papers that I used in order to analyse the topic. Following the order of the second chapter, I organized the review into two paragraphs. The first one has a global approach, whereas the second one will focus on China. The documents are organized according to the potential environmental benefits smart technologies may lead to, such as energy efficiency, CO_2 or GHG emissions and links with circular economy. For what concerns Chinese documents, I relied on surveys, insights and corporate social responsibility reports of some companies.

Lastly, Chapter 4 shows the methodologies used to assess the results, which will be deeply discussed and examined. The evaluation of results considers two research questions, whose validity will be verified throughout the chapter. The structure of the latter follows the logics of the previous chapters: in the first part I will give a global perspective and then I will consider the Chinese approach. At the end of the chapter, an overview of the final outcomes will be presented, drawing a conclusion of my study.

CHAPTER ONE

Industry 4.0 and smart manufacturing: a global perspective

The Fourth Industrial Revolution (or Industry 4.0) refers to the fourth step of industrial revolution reached so far, representing a fundamental change for almost everything and everyone. More specifically, it relates to the shift towards industrial automation that a wide range of enterprises are experiencing nowadays, or they will in the closest future. This shift involves the integration of disruptive technologies into production process, aiming at making it more efficient, flexible and smarter. This is why this stage of technological and industrial development can be described by the word "smart", the same adjective describing Manufacturing 4.0 and its digital technologies. The introduction of concepts such as *"self-optimization, self-cognition and self-customization"* into the industry makes the entire industrial process more efficient and effective, as well as less costly. (Shu et al.).
Smart manufacturing is the translation of Industry 4.0 into the manufacturing field, by which the term "smart" becomes a common denominator of an integrated information management, in line with the use of digital technologies. This advanced manufacturing system has seen a transformation unlike ever before: it is characterized by increasing flexibility and productivity, hence leading to customization and a better allocation and use of resources (De Sousa et al., 2018).

Given the premises of the introduction of Chapter one, I will give an overall but in-depth presentation of Industry 4.0. In order to have a clear vision of the concept, I will firstly outline its historical background, followed by a pool of definitions. Afterwards, I will report some governmental initiatives and actions, followed by the impacts of Industry 4.0., its benefits and challenges. Concluding, I will focus on those disruptive technologies, describing and analysing their use in the manufacturing sector.

1.1. Historical background: from the first to the Fourth Industrial Revolution

In order to understand in a better way Industry 4.0 and its role for the socio-economic development today, we have to give a closer glance at what happened before, thus getting to know what made this revolution possible. Even though we’re dealing with a complex topic, outlining the previous three industrial revolutions of the past can make it clearer.

“The word <<Revolution>> denoted abrupt and radical change. Revolutions have occurred throughout the history when new technologies and novel ways of perceiving the world trigger a profound change in economic systems and social structures”

(Klaus Schwab, 2016, p.11)

Before Industry 4.0, prior industrial revolutions happened throughout three centuries, marking innovation and technological advancement in the domain of manufacturing.

The First Industrial Revolution began around the 1780s when the steam engine and the steam power were introduced, in particular in mechanical production (Shu et al.). As a matter of fact, the greatest changes were in the form of mechanization. Agriculture was the first sector touched by mechanization, as it was little by little replaced by the tertiary sector, which started being considered as the major force driving economic growth. Not only the economy experienced a profound change, but also society, which from agrarian started tending towards a more urbanized society. The movements of people were also revolutionized, thanks to the construction of steamships and railroads, that enabled an easier transportation. Another key element emerging in this period is the factory.

Almost a century later, the Second Industrial Revolution (1850s) was represented by mass production in assembly lines. This led to a massive migration from rural areas to the urban ones, where people could find jobs in factories. New industries like the one of steel, oil and electricity started expanding and inventions like the airplane were representative of this age.

The Third Industrial revolution arose in the 20^{th} century thanks to the advent of the Digital Revolution. This revolution is the result of the huge development in technology, in particular regarding communication. Key elements are the advent of the Internet, personal computers and semiconductors, which then were used to build an automation system in production and supply chains (Britannica, 2020).

It is in this context that Industry 4.0 has emerged in the 21st century. The current Fourth Industrial Revolution has disrupted the value chain: this is why we talk about "disruptive technologies"[1], which are now leading companies to embark on a digital transformation journey. We are actually dealing with a different development stage compared to the previous ones: it is considered more as an evolution, since key components like the internet, software and hardware had already been introduced in the previous decades. If we compare the Third Industrial Revolution and the fourth one, the latter results to have little replacement of equipment. In the First Industrial Revolution, for instance, there was 100% of installed base replacement of complete loom. In the following one, there was little replacement (10-20%), as a great part of tooling equipment could be kept, whereas the further step required an almost complete replacement (80-90%) due to the use of new machines aimed at replacing the previously used traditional tools. An improvement can be noticed if we consider the rate of replacement of the Fourth Industrial Revolution, in which existing machines of Industry 3.0 were kept in order to be programmed and interconnected, with just a 40-50% of installed base replacement (World Economic Forum, 2019).

The innovative concepts it brings are integration and sophistication. Integration refers to the interconnection of machines and plants, which allows a more efficient production pattern, customized and of higher quality, thus becoming more sophisticated. Moreover, it combines the digital and the physical worlds, influencing every sector, from the economy to the industry, questioning what it means to be human. Besides, as Klaus Schwab[2] points out, its scope is wider than smart machines deployment in the production plants. This revolution involves areas which are apparently not linked one another, like quantum computing, renewables and nanotechnology. Hence, this new industrial revolution will bring several impacts on a wide scope (Schwab, K., 2016).

In the following paragraphs I'm going to give a closer glance at the dynamics of Industry 4.0, focusing on its key features and how they are changing the value chains in smart factories.

[1] *Disruptive technologies* relate to innovative technologies that deeply influence the way business are conducted, consumers and industries operate, bringing great improvements (Investopedia).

[2] Professor Klaus Schwab is the Founder and Executive Chairman of the WEF. His books "*The Fourth Industrial Revolution*" (2016) and "*Shaping the Fourth Industrial Revolution (2018)*" both reflect his knowledge about economics and engineering. (https://www.weforum.org/about/klaus-schwab)

1.2. The Fourth Industrial Revolution

The term was first coined in Germany, at the Hannover Fair in 2011, introduced a as an industrial plan made by the German Federal Government for the high-tech manufacturing industry. It refers to a new way of organizing the entire value chain in smart factories to produce in a more customized, flexible and efficient way. This is possible through the application of smart technologies, which cooperate with the physical word in a synergic way (Schwab, K., 2016).

Industry 4.0 has its basis on digital technologies like the Internet of Things (IoT), the Cyber Physical System and Big Data Analytics. These are just few of the recently emerging technologies that enable a smarter way of production, creating a network that involves all the manufacturing process and modifies the customer-enterprise relationship. It doesn't just enable interconnection among the factories, but also inside the factories within machines and digital devices, ensuring real-time communication between departments and promoting a better relationship with customers, with less need of human interaction. This "interoperability" can be translated into three forms, namely vertical, horizontal and end to end integration. Horizontal integration refers to the connection between different enterprises sharing finance and material information, while in vertical integration the connection is related to the various subsystems of the same company, which are sensors, actuators, management, manufacturing and planning. Horizontal and vertical integration lead to the creation of respectively new business models and a both more efficient and flexible manufacturing system, since machines are all interconnected. End-to-end integration refers to the various processes along a product life cycle, thus starting with customer needs, product design, maintenance and recycling (Abu-Bakr et al.).

In the following lines I will present a pool of definitions, in order to help the reader to have a complete and detailed picture of the topic.

"Industry 4.0 describes the organization of production processes based on technology and devices autonomously communicating with each other along the value chain in virtual computer models"

(European Parliament, 2016, p.7)

"Industry 4.0 offers a more comprehensive, interlinked, and holistic approach to manufacturing. It connects physical with digital, and allows for better collaboration and access across departments, partners, vendors, product, and people. Industry 4.0 empowers business owners to better control and understand every aspect of their operation, and allows them to leverage instant data to boost productivity, improve processes, and drive growth"
(Epicor)

1.3. Governmental initiatives and actions

The industrial transition towards digitalization is supported by the implementation of policies and plans by governments of both developed and developing countries.

Countries like Germany, Japan, the US and Korea have been the first countries to launch initiatives with the aim of promoting the implementation of Industry 4.0. Germany launched the so-called *"High-Tech Strategy 2020"* in July 2010 (Kagermann et al.). As the name suggests, it is a strategy for technological development. The aim is to achieve development, throughout a cooperation between the ministries, in five key areas, which include climate change and energy, health and nutrition, mobility, security, communications.

Other European countries like France and UK published national plans too, named respectively *La Nouvelle France Industrielle* and *Future of manufacturing* (Kagermann, Wahlster & Johannes). The first one was published by the French Government in 2013: as the name suggests, it aims at establishing a new upgrading industrial system, and comprises 34 plans for the reindustrialization of France. The aim of the strategy is to bring the whole nation to a new stage of industrial development, driven by an innovative transformation of the economic model as well as in the modern sectors like autonomous vehicles, satellites, Big Data and the IoT, the imperative is the creation of a "creative industry", which promotes the know-how of the country (Gouvernement.fr).

The Future of manufacturing is a long-term project aiming at transforming the English manufacturing sector by 2050, issued in 2013 by the UK Government. The project is split int three phases, marking different objectives to pursue: efficiency and resilience (2013-2025), experimentation with new systems (2025-2050), adapting business and industrial models to a resource constrained world (2050 and beyond) (Foresight, 2013).

The European Commission itself launched "Factories of the Future" (FoF) in 2014, with the aim of innovating and reinforcing the European industry. The four key priorities include the consolidation of industrial competitiveness, addressing customization and eco-efficiency, promote green, smart and inclusive economy, strengthen the manufacturing sectors for growth and jobs (ec.europa.eu). Another EU program is Horizon 2020, the most important European program for R&D and innovation, whose major objectives are the intelligent, sustainable and inclusive growth, in order to achieve the industrial leadership (European Commission).

Two years before, in June 2011, Barack Obama implemented a series of strategies and actions, named *"Advanced Manufacturing Partnership (AMP)",* accompanied by huge investments in advanced technology (Kagermann et al.).

Many Asian countries are strongly concerned about this topic: "*Innovation in Manufacturing 3.0"* was officially presented by the South Korean government in 2014 under Park Geun-hye's administration (Shu et al.). The objectives of this plan are the development and spread of smart factories and core technologies, funding US$972 million (Jung, Suk., 2015).

The Chinese government shows great commitment for the country's industrial upgrading: *Internet Plus* was launched in 2013 by the Premier Li Keqiang, with the aim of modernizing and transform the Chinese traditional industries. The five-year plan integrates digital technologies like the IoT, cloud computing and big data in almost every sector of the industry (China Telecom Americas). Two years later the *Made in China 2025* initiative was officially implemented, representing the most ambitious national plan concerning manufacturing upgrading (Shu et al.).

1.4. The impacts of Industry 4.0

In an interconnected ecosystem in which machines and devices are all connected one another, it is easier to make the best operational and business decisions. As machines and physical objects inside the smart factory are all integrated and connected, more accurate and precise possible scenarios concerning both the internal and external environment can be forecasted. Therefore, the shift from linear to interconnected industry will lay the foundation for the production system 4.0 (Mussomeli et al.).

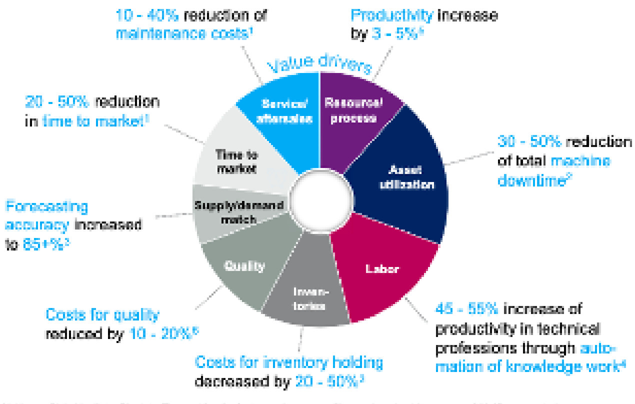
Industry 4.0 greatly impacts on organizations: as they are dealing with constant changes in the industrial and technological environment, Industry 4.0 could lead to the emergence of new businesses outcomes, which are operation improvements ad revenue growth (Sniderman et al.). For what concerns business operations, Industry 4.0 may lead both to productivity improvements and risk reduction. Productivity is improved by maximising asset utilization, focusing on labour efficiency and ensuring that schedules are accurate. In this way the risk possibility will be reduced, for instance regarding the availability of raw materials and their price, or geographical risks. Instead, business growth is driven by incremental revenue: this is possible because of the deepening of customer understandings and insights.

Even individuals, as customers and final consumers, are influenced by the emergence of Industry 4.0, as this phenomenon challenges and empowers both workers and customers.

Workers and customers are key figures in this environment. Employees may experience a change in their routine jobs, while customers will receive a more individual and customized product.

In a report by McKinsey eight value drivers are outlined. They refer to case studies conducted by the company, from which we can clearly notice that the opportunities of Industry 4.0 technologies are various, leading to the creation of a more efficient, flexible and precise manufacturing pattern (McKinsey Digital Report, 2015).

Figure 1



Source: McKinsey, 2015[3]

Different case studies by Deloitte carried out these results, which are apparently great.

As I already explained in the previous lines, productivity and efficiency are two of the main features of Industry 4.0 and each of the value drivers in the chart above do relate to them. Productivity is given by asset utilization and forecasting accuracy, which makes the process smoother, thanks to the real-time detection of potential errors that might influence the whole production. Furthermore, productivity is linked to reduction in time to market.

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[3] [Fig. 1] available at: http://www.forschungsnetzwerk.at/downloadpub/mck_industry_40_report.pdf

Efficiency in this case is given by an efficient use of the company's assets. The opportunities in terms of revenue are great, since it can be achieved up to 30%-50% reduction of total machine downtime: this means that thanks to predictive maintenance, problems related to equipment are much less likely to occur. Talking about revenues and profits, it is shown that a lot of costs are reduced, such as the cost of quality, of inventory holding and maintenance costs. In this way, digital technologies 4.0 may enable a more intelligent production pattern, which is cheaper and quicker to carry out (McKinsey, 2015).

In order to get a deeper knowledge about Industry 4.0 the following lines I will introduce what are its main benefits and challenges.

Among the main benefits, we can find flexibility, optimization, customization and costs reduction, competitiveness.

- Flexibility: thanks to the automated machines, able to work autonomously and under any condition related to time or climate, thus increasing production flexibility.
- Optimization: production is optimized thanks to the efficient communication and reduced downtime of machinery. Moreover, the right quantity of resources is available at the right time and place, making the process quicker and risks free.
- Customization: The relationship between customers and manufacturers will be closer, due to the use of real-time monitoring and analysis of customers' demand. This can be done through the use of Big Data analysis, which automatically identifies customers' needs and wants, cutting the need for manufacturers to build external relationships. Customization is a fundamental characteristics of Industry 4.0, and represents the future of customer demands, which becomes more and more personalized and of higher quality.
- Cost reduction: Implementing and programming equipment for smart manufacturing may lead to up-front costs at the beginning. However, everything is set up, business profitability will be achieved, since resources are exploited in a more efficient way, the automated production process makes machines more independent, lower amount of waste and risks.
- Competitiveness: with the deployment of smart manufacturing and digital technologies and considering the benefits they lead in terms of efficiency, flexibility and productivity, they create new and better business and production patterns, resulting in a positive

feedback by the final customer. This leads to increased competitiveness among enterprises in the adoption of the latest technologies (TXM Lean Solutions).

- Opportunities for developing countries: the low-cost labour and low-quality production issues can be solved by the introduction of Industry 4.0 technologies, which may give the possibility for emerging economies such as China and other Asian countries to leapfrog.
- Compatibility with Sustainable Development Goals (SDGs): as the deployment of technologies 4.0 brings overall efficiency, this can be noticed in terms of resource consumption such as water, energy and material. In the light of this, Industry 4.0 may be in line with sustainable development, referring in particular to SDG#9, which regards inclusive and sustainable industrialization (UNIDO, 2017).

Given the main benefits of Industry 4.0, it is necessary to explain also the challenges it may bring.

- Cybersecurity: the IoT allows several devices to be connected and communicate one another. However, the challenge is represented by the increasing need of data storage, protection and Intellectual Property (IP). Hacking and data breaches are serious challenges in today's interconnected world and they can be minimized by implementing standardized policies and procedures.
- Management approach: as we deal with the transformation enabled by Industry 4.0, a different management model has to be embraced for the business and for people in particular. Workers' role and their adaptation to emerging technologies will be fundamental in the industrial shift.
- Employment: it represents one of the main consequences of this industrial transition. There will emerge demand for new skills and competences, thus leading to the creation of a new concept of employee: adaptation and flexibility are considered as main features of these new figures. Engineering, IT and technological skills will be necessary carry out production handled by autonomous machines.
- Investment: the capital investment for the purchase and implementation of Industry 4.0 is important in terms of cash outflows. Even if they bring advantages in the long term, in the short term, the high costs of useful machines and equipment is considerable (TXM Lean Solutions).

1.5. Smart Manufacturing

With the rise of the Fourth Industrial Revolution, which is often called “Digital Revolution”, emerging digital technologies such as the IoT, AI, Big Data, Robotics, AR, are acting and will act as key players in the manufacturing field. Industry 4.0 has gained considerable momentum nowadays, as it enables technologies to upgrade the present industrial structure, changing the way products are manufactured and services are delivered. As I already pointed out, manufacturing of products and goods has already seen drastic shifts three times in the past: the steam engine of the eighteenth century was followed by the linear assembly-lines (UNIDO, 2017). Then, in the 1970s the application of electronics and the advent of internet led to a quicker and more important development in technology and increased productivity. One of the reasons for this is the drastic and increasing rate of population, that means more products and goods needed, and more resources to be used.

The Fourth Industrial Revolution is dealing both with the physical and digital world. In other words, this implies the vision by which the physical world of industrial production embraces the digital world of IT (UNIDO, 2017).

In the manufacturing industry, Industry 4.0 is translated into smart manufacturing, or manufacturing 4.0, in which the technologies promoted by Industry 4.0 are deployed to manufacture goods.

What are the opportunities and potentials associated with smart manufacturing? First of all, costs are reduced, while flexibility and customization increase (Beier et al., 2017). Manufacturers are seeking for a more efficient supply chain and production processes and proper skills to create customized products. This is why manufacturers are now relying on smart technologies to allow the upgrading of manufacturing, as they could be great opportunities to build a better manufacturing system, leading to efficiency, convenience, thus gaining competitive advantage.

The National Institute of Standards and Technology (NIST), defines smart manufacturing as:

"fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs"

(ESA Automation, 2020)

That is to say, the network created by the interconnection between machines and devices makes it possible to access to information regarding production at any time. Therefore, the traditional production pattern goes through a new re-organization and redesign.

Indeed, this smart approach to production leads to some benefits such as increased quality, productivity, energy efficiency and competitiveness (ESA Automation). A higher level of productivity is given by data accessibility during every stage of the production process, in real-time. Therefore, increasing optimization of the supply chain system is possible, for example thanks to reduced machines downtime, which increases efficiency and reduces waste, since a real-time and more accurate detection of errors is possible. This leads to a further benefit, which is energy efficiency. A more sophisticated and precise management of energy consumption is possible because the devices are all connected. As overall efficiency results are positive and the intelligent manufacturing system works well, it is more likely to gain competitiveness, since production becomes faster, efficient and cheaper.

The place in which smart manufacturing occurs is the smart factory. Today's factories are undergoing a profound change. We have to abandon the idea of a polluting, and noisy place, where thousands of workers are working for a low wage in low-skilled positions. Instead, the factory of the future is shaped by today's advances in technologies which will make it cleaner, integrated, connected and socially inclusive.

Deloitte describes the smart factory using five adjectives, namely "connected", "transparent", "agile", "optimized", "proactive". A smart factory is externally connected as it is provided with sensors and real-time data, enabling a network connecting the factory to suppliers and customers; internally, it refers to the collaboration across the various departments. It is due to transparent live metrics and special tools, that a quick, consistent and precise decision-making and customer demand can be forecasted. “Agile” refers to the concept of adaptability and flexibility of the production processes. Optimization of the smart factory lies in the concepts of reliability and predictability, increased production efficiency and reduced cost of quality and production. The smart factory is proactive, as its equipment and processes are programmed to automatically identify problems and solve them, such as restocking and replenishment or supplier quality issues, thanks to real-time monitoring (Spiegel, H.).

1.6. Disruptive technologies, the key enablers of Industry 4.0

A set of disruptive technologies will transform the manufacturing industry by the next years, enabling overall digitalization inside the smart factory. In this way, the traditional manufacturing will be replaced by a smart and digitalized manufacturing.
The solutions offered by these technologies are better, cheaper and faster.

- Better, as they solve problems in a more effective way, allowing a much more efficient use of natural and human resources
- Cheaper, as the cost of technologies (e.g. microchips and renewable energy) has decreased drastically.
- Faster, as the new technologies are spreading very fast on a global scale, stimulated by interconnection and drastic decrease in prices (UNCTAD, 2018).

According to McKinsey & Company the fundamental technologies can be grouped into four clusters:

1. Data, computational power and connectivity

Drastic reduction in costs in terms of storage, transmission and processing are some of the main advantages provided by this cluster. Thanks to the IoT, sensors are embedded and allow a wireless connection between physical objects, interoperability and machine-to-machine interaction (M2M)[4]. Advantages in costs are also evident in terms of storage (falling prices) and processing. For instance, Big data/open data reduce the cost of storage and sensors.

[4] *Machine to Machine* (M2M) is related to those technologies and services allowing an automatic information transfer from one machine to another one, without requiring any human interaction. Examples of M2M are those appliances for warehouse management, sensors and localizations. Often, M2M and the IoT are taken as synonyms. The four main elements characterizing the latter are data collection, transmission, information extraction and deployment (Tommasi, E., 2018).

Moreover, the Internet of Things (IoT)/M2M reduce the cost of hardware internet connection; cloud technology allows to centralize data and visualize storage.

2. Analytics and intelligence

Further steps have been made in this field in the last few years. Before, robot could play only basic tasks and machine learning was at its initial stage. The cluster includes both Artificial intelligence (AI) and machine learning and advanced analytics which makes it possible to have more available data.

3. Human-machine interaction

Even human-machine interaction has grown a lot in this period, due to the use of devices such as touch interfaces, gestures recognition, Augmented Reality (AR) and Virtual Reality (VR) devices. For example, included elements are touch interfaces and next-level GUIs[5], as well as Virtual Reality (VR) and Augmented Reality (AR).

4. Digital-to-physical conversion

The latter includes rapid prototyping technologies like additive manufacturing and 3D printing, which developed furtherly, as previously it was applicable to a limited range of materials (like polymers and metals) and now to a wider range of materials such as glass, bio-cells, sugars and cement. Additive manufacturing also improves precision and increases quality of the final product. Great advances in AI, robotics and machine vision are also driven by decreasing costs in energy storage and cheaper actuators.
When deploying additive manufacturing (i.e., 3D printing) materials can be of a wide range, the prices for s printer gradually decrease, but precision and higher quality are ensured.
Instead, advanced robotics (e.g., human-machine collaboration) brings improvements in AI technology, machine vision, M2M communication and cheaper actuators (McKinsey, 2015).
Given a broad description of main technologies grouped into the above mentioned four clusters, in the following lines I will analyse them in a proper way.

[5] GUIs stands for Graphic User Interface and refers to any user interface using graphic elements (instead of text based interfaces) to interact with electronic devices (TechTerms)

a) The Cyber-Physical System (CPS)

The Cyber-Physical System (CPS) is an essential technology of Industry 4.0 and plays a key role in the manufacturing system. It can be defined as a set of various technologies, characterized by an interconnected system among them, reaching also other elements and devices of the factory, even if there is a considerable distance between one another. Its utilization range varies from data generation and aggregation and also acts as a decision-making supporting technology, decreasing costs and make production operations a bit simpler. We can distinguish five functional levels of CPS:

1. Smart connection: intelligent sensors are used in order to manage data.
2. Data-to-information-connection: it aggregates and converts those data making them become value-added information.
3. Digital Twin: it synthetizes the real domain, inside the digital reality.
4. Cognition: it takes into consideration every possible scenario, in this way enabling a proper decision-making process.
5. Configuration: it is used to project a virtual realty on the physical one.

From this description we can get to know what are the enabling technologies of CPS. Integrated sensors guarantee all the information about the state of operation, whereas actuators allow to increase performance while reducing risk. In addition, decentred intelligence connects with actuators and sensors, developing and selecting the best choices and scenarios to be considered (Innexhub).

b) Big Data

The characteristics of Big Data correspond to the three Vs (Volume, Velocity, Variety), further followed by two more V2 (Veracity and Variability). The purpose of Big Data is to collect data from various sources: this requires storage, of course, and the solution to this is the deployment of clouds. After the analysis, this data can bring to many advantages, such as cost and time reduction, optimization, smart decision making and agile business decisions. When combined with analytics (data analytics), operational decisions inside the factory can be supported by the identification of failures and their causes, hence calculating risk portfolios (SAS).

Moreover, the analysis Big Data generate is also predictive. In this case it is used for predictive maintenance of machines, thus avoiding machine downtime and improve efficiency, as well as enabling a smoother manufacturing process. In addition to this, it offers the opportunity for product customization, allowing to predict the demand for customized goods. The process involves the detection and extraction of data concerning customer behaviour, followed by the gathering and analysis of data.

c) Internet of Things (IoT) and Industrial Internet of Things (IIoT)

The Internet of Thigs (IoT) allows the extension of the utilization of the benefits of internet, which so far are limited to people and things: this enables an interaction among objects and people in a digital way (Network Digital 360). In the industrial sector, the IoT connects machines and other objects through the internet connection. In this way, the various entities are all connected and cooperate in a synergetic way to reach production goals. According to the World Economic Forum, mobile IoT connections are expected to be over 4 billion by 2024, boosted by the strong diffusion in East Asia (Josefsson, E.).
The IoT monitors and manages the interconnected objects and machines more precisely and quickly. Furthermore, it could also potentially address inefficiencies in manufacturing and related processes (UNCTAD, 2018).

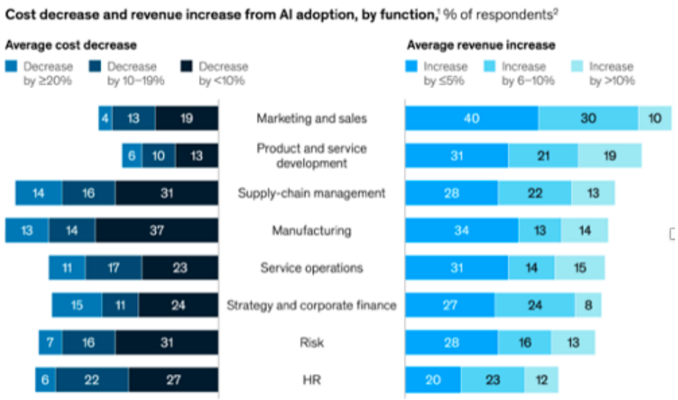
d) Cloud Computing

Cloud manufacturing is also called "Manufacturing as a service" (Maas), Collaborative Manufacturing or Virtual Manufacturing. Cloud computing can be defined as the distribution of computing services, such as server, storage sources, database, network, software, analysis and intelligence, through the Internet (which is the "cloud"). The aim is to offer innovation, flexibility and economies of scale. Advantages include cost reduction, velocity, productivity, reliability, security (Microsoft, 2020). This technology is a key enabler of other production systems such as the 3D Printing, the IoT and industrial robots (Ezel & Swanson, 2017). The opportunities cloud computing can bring to manufacturing are several, ranging from upskilling, efficiency increase and costs reduction.

e) Artificial Intelligence (AI)

Artificial Intelligence (AI) is considered as a pool of technologies (from machine learning to natural language processing) allowing machines to perceive, understand, comprehend, act and learn (Accenture). This new technology is important since it is going to transform the relationship between humans and technology, strengthening our creativity and ability. AI technology enables a more efficient collaboration between humans and robots, and also helps in reducing the risk exposure for humans in dangerous areas: for what concerns manufacturing it can reduce risk of failure in machinery or final products. Moreover, it is able to self-detect errors and carry out self-optimization. Fig. 2 shows the results of a survey by McKinsey, from which can clearly notice that using AI technology a great decrease manufacturing costs can be noticed (Cam et al., 2019).

Figure 2



Source: McKinsey & Company[6]

f) Virtual Reality (VR) and Augmented Reality (AR)

Virtual and Augmented Reality refers to the information that wides the user's perceptive horizon. This technology maximises our perceptive experience, allowing us to interact with information. AR augments reality combining the physical and digital worlds, thus helping workers to have additional information on the real-world scenario. The process is time saving and avoids major risks. Researchers have found a performance improvement of 50%, with AR:

[6] [Fig. 2] available at: https://www.mckinsey.com/featured-insights/artificial-intelligence/global-ai-survey-ai-proves-its-worth-but-few-scale-impact

hence, it is obvious that it helps industry in speeding up industrial processes, increase its efficiency, while reducing error possibility (Matt Bruner – Machine Metrics, 2019).
Virtual Reality (VR) allows to have a virtual computer-generated dimension; advantages include testing costs reduction (as the product design is visualized before the effective production) and material waste reduction. Besides, *"combined spending of VR and AR will reach $17.8 billion in 2018, up from about $9.1 billion in 2017. Global spending on VR and AR will have a compound annual growth rate of 98.8 % through 2021, IDC predicted"* (Gross, G., 2018).

g) Rapid Prototyping

Rapid prototyping is a group of complementary technologies such as Additive Manufacturing (AM*),* 3D Printing used to produce in a rapid way parts and prototypes (UNIDO, 2017).
Additive manufacturing allows to produce by building products layer-by-layer in a successive way, instead of adding different components and cutting material away (NIST). These technologies are presently used for various applications in the industry as well as other areas of society, such as medicine and education (i-Scoop). The expected growth of 3D printing opens its deployment to a wide range of sectors such as the industrial automotive, healthcare, jewellery and aerospace sectors. In addition, the market expects a future growth (UNCTAD, 2018).

h) Robotics

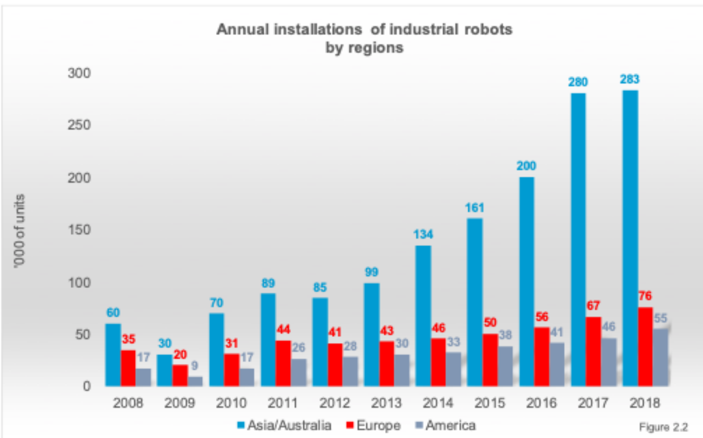
Robotics are replacing the manufacturing workforce, limiting the presence of workers in the factory. The deployment of robotics for manufacturing operations has led to great benefits, and their use will be further improved in the future. The so-called *cobots* will increasingly allow a collaborative working between humans and machines. Collaboration is not only about safety, but also means productivity and flexibility.
The International Federation of Robotics (IFR) estimates that two million new units of industrial robots will be applied and deployed globally in the period from 2020 and 2022. IFR also depicts their main trends: robots are getting smarter, improve collaboration with workers in the smart factory, and increase the level of digitalization. Robots work thanks to pre-installation installation and pre-programming by engineers and workers, who create an

increasingly better collaboration with them. As the IFR suggests, human-robots interaction will constantly improve in the future.

Actually, today workers and robots currently operate sharing the same workspace, completing the tasks in a sequential way (Robotics Business Review, 2020).

Every year, the IFR releases the World Robotics Report, of which the last available document is that of 2019, showing data updated to the previous year. The graphic below shows the annual installation of industrial robots by regions, which are split into Asia/Australia, Europe and America. First of all, the evidence of an increasing trend leads to positive considerations for what concerns future investments in this sector. In 2018, robot installation at a global level increased to 422,271 units, +22,271 from the previous year. Asia represents the world's largest market, with China leading the way, even though the country assisted to a very slight increase from 2017 to 2018 (IFR, 2019).

Figure 3



Source: IFR, 2019[7]

As a matter of fact, China, Japan, the US, the Republic of Korea and Germany represent the five major markets of industrial robots, accounting for 74% of the global total.

Moreover, experts rely on positive medium-term growth expectations for what concerns both the advancement of robots and the increasing number of installations – an average growth of 12% per year is expected from 2020 to 2022 (Shaw, K., 2018).

[7] [Fig. 3] available at:
https://ifr.org/downloads/press2018/Executive%20Summary%20WR%202019%20Industrial%20Robots.pdf

CHAPTER TWO

Industry 4.0 and environmental sustainability: the case of China

In the first part of the second chapter I will give a closer look to the concept of sustainability, describing the environmental challenges related to the industrial sector. My further objective is to present a potential solution to these challenges, which may be represented by smart technologies and Industry 4.0. In order to do that, in the first paragraph I will introduce how Industry 4.0 disruptive technologies could be potential enablers of an environmentally sustainable manufacturing pattern. In the second and last paragraph of this chapter my focus will be on China. First of all, I will report the state of art of Chinese companies concerning smart manufacturing and the development of digitalization. Concluding, I will exemplify the ambitious goals pointed out by the Chinese government in terms of digital integration and green manufacturing, followed by a deep analysis of the *Made in China 2025* initiative.

Par. 1. The green transition: paving the way for an environmentally sustainable industrial development

1.1. Environmental challenges and sustainability

In the last decades, a stronger and stronger feeling and consciousness about sustainability has risen. This is due to the emergence of serious challenges such as pollution, greenhouse gas effects and global warming. These are all linked one-another and their scientifically proved negative impact is the phenomenon of climate change, which unfortunately we are experiencing nowadays. As a consequence, increasing number of people – especially young people – from all over the world are getting more and more conscious and interested about this topic. Many of them are taking actions in strikes for climate change, for example the ones promoted by the young activist Greta Thunberg[8]. Also, non-profit organizations are asking for governments to

[8] Greta Thunberg is a Swedish young activist, who inspired a huge number of students and other people around the world for protests tied to the urgence of climate change. In 2018 she started the "school strikes for the climate" ("Skolstrejk för Klimatet"), also known as "Fridays for Future" , when she was 15 years old, with the aim of demanding climate action, in front of a careless government. As a consequence, she spread the urgence of this issue, making a lot of people more conscious about the environmental damage pollution has caused so far. In 2019 she also addressed to the United Nations, asking for governmental actions to face global warming. (Encyclopaedia Britannica, 2020).

promote the reduction of carbon emissions and implement energy transition. In order to ensure a future for the Earth, which is our home, and a better future for us and the future generations, industrial upgrading is a fundamental requirement.

In order to better understand the concept of sustainability and sustainable development, I will provide a definition and try to give an overall explanation of the concept. Sustainability could be defined as:

"meeting the needs of the present without compromising the ability of future generations to meet their own needs."

(The Brundtland Commission, 1987)

The concept of sustainability involves three dimensions, which correspond to the "Three Pillars" of sustainability, mentioned in the Brundtland Commission[9], which are the economic, social and environmental dimensions.

The Sustainable Development Goals (SDGs) of the UN 2030 Agenda, have been outlined and included in international agreements in order to take action in the fight against climate change, promoting a more sustainable growth pattern. For instance, treaties like the Paris Agreement[10], the latest agreement by the UN Framework Convention on Climate Change (UNFCCC), looks at the industrial upgrading as an important driver in the fight against climate change, while enhancing sustainable development. For instance, Target 4 of SDG 9 is centred on infrastructure, industrial development and innovation: it highlights that it is necessary to revitalize the traditional industrial model, making it more efficient in terms of resources. This can be done

[9] The Brundtland Commission or "World Commission on Environment and Development" (WCED), worked for three years until 1987. The aim was to promote a more sustainability by the accomplishment of the so-called Sustainable Development Goals (SDGs). In fact, it issued the Brundtland Report, also known as "Our Common Future", in which a series of SDGs were outlined, together with some direct guidelines on how to achieve them. The above mentioned "Three Pillars", instead, refer to the three dimensions of sustainability: economic, social and ecological dimension. The SDGs are all grouped in the Un 2030 Agenda for Sustainable Development, which implemented a 15-year plan with the aim of succeeding in the achievement of those goals by 2030 (Jarvie, E. M., 2014).

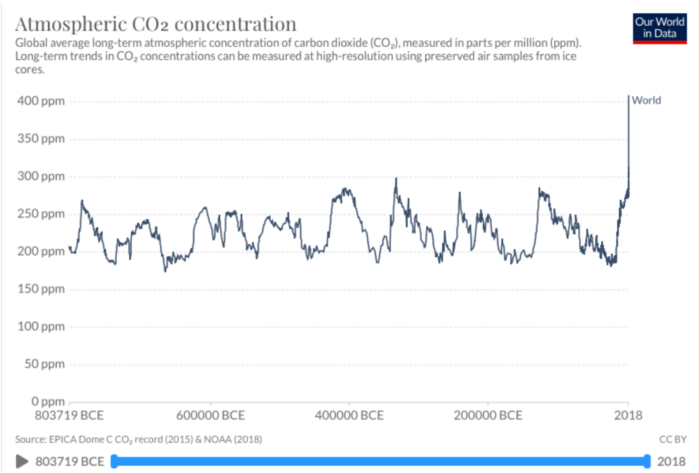
[10] The *Paris Agreement* was discussed and drafted in on December 12th, 2015 at COP 21 in Paris, where the UNFCCC reached the agreement of promoting and strengthening actions for climate change mitigation, together with considerable investments for a sustainable and low-carbon development. For the first time it brings all nations to reach a common cause, whose specific aim is to not exceed 2 degrees Celsius rise in global temperature. In order to achieve this goal, GHG emissions should be reduced and a new technological framework should be implemented (UNFCC, 2018).

through the deployment of clean and green technologies, hence realizing a more environmentally sound industry (UNDESA).

From the above provided definition we may realize that the concept of sustainability does not only refer to the environmental dimension. In fact, it comprises three dimensions, namely the economic, social and ecological dimensions (Stock & Seliger). Given the wide scope of the topic I'm dealing with, I will try to consider just the environmental dimension of sustainability.

Global average temperature has increased by more than one degree Celsius since pre-industrial times (Our World in Data), making the Earth warmer. The global warming issue is so critical that the International Energy Agency estimated emissions increase of 130% by 2050 if we continue on this trend (IEA). Atmospheric CO_2 concentrations have reached their highest levels in over 800,000 years, due to the increasing levels of greenhouse emissions. Fig. 4 shows the global average long-term atmospheric concentration of carbon dioxide measured in parts per million (ppm). We can clearly notice that in 2018 we reached the 440 ppm concentration of CO_2, which is the highest level from 803719 BCE (Ritchie & Roser).

Figure 4



Source: Our World in Data, 2020[11]

Other than CO_2, trends of other pollutants such as CH_4, N_2O and SF_6[12] are increasing year by year, making air pollution one of the main problems caused by the human footprint (Global

[11] [Fig. 4] available at: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions#global-warming-to-date

[12] CH_4, N_2O and SF_6 respectively refer to methane, nitrous oxide and sulphur hexafluoride. They are all responsible gases for global warming.

Monitoring Laboratory). Even though more information is now available, and some international plans and governmental actions have been implemented to reduce environmental damage, many improvements still need to be made. A key sector that is recently going through a revitalization is the energy sector, also because it has great responsibilities in terms of pollutant emissions: energy transition is fundamental to ensure a more sustainable production pattern, reducing the carbon footprint and promoting the use of clean technologies that allow a better and circular energetic system (IEA).

But actually, has every country in the world got the same responsibilities in terms of environmental pollution? Of course not. As we live in a world which is far to be equal, in terms of wealth, consumption and so on, we can't expect everyone to meet the same rate of pollution. We can clearly notice how, in the previous thirty years, developing countries have been responsible for increasing quantity of CO_2 emissions, among which Asian countries are the major emitters. China is a well-known country in terms of pollution, ranking as the first polluting country in 2020 (Union of Concerned Scientists), with 9.3 GT (giga tonnes) of cumulative carbon dioxide emissions in 2017 (IEA Fuel Combustion 2019 Highlights).

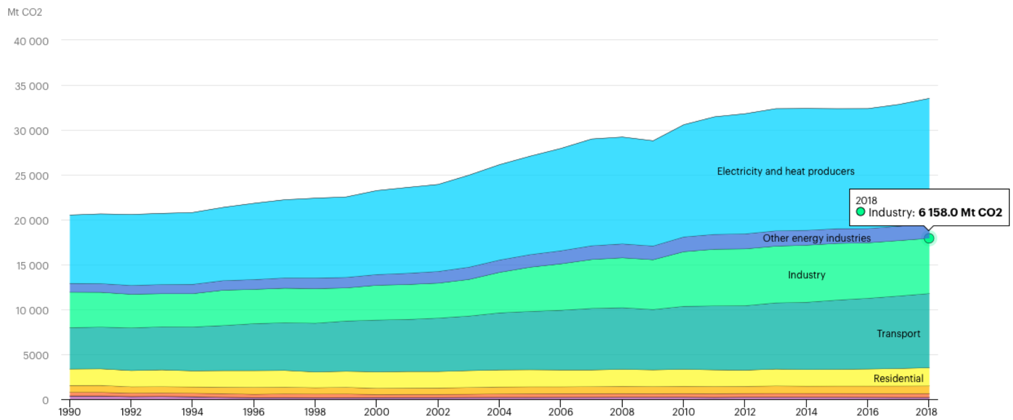
In order to stay in line with SDGs and emission standards, every sector has to be upgraded and revolutionized. As I already mentioned, major improvements have to be made in the industrial sector, which accounts for a great part of global CO_2 emissions (IEA). In order to do that, regulations concerning industrial processes have to be implemented both at a national and international level. Similarly, through the deployment of renewable energy, the overall energy efficiency has made huge progress in the last decades. Worldwide, energy intensity has decreased, both in developed and developing countries (IEA).

Energy consumption is one of the most important indicators regarding the industrial sector, particularly in manufacturing: as advanced technologies improve manufacturing process efficiency, the process system will need less amount of resources. Even though energy efficiency has advanced over the past years, it needs to be further improved in the years to come, in order to achieve the international climate change mitigation targets (UNIDO, 2017). The energy consumption of industrial sector only corresponds to 1/3 of global energy use, emitting 40% of global CO_2 emissions linked to energy consumption. Therefore, it can be stated that energy efficiency could be a key player, by contributing to the promotion of a more sustainable energy consumption. However, the accomplishment of these goals would require a gradual improvement, so the results will be clearer in the next future. Furthermore, the deployment of these technologies depends on many factors such as governmental regulations and energy costs (UNIDO, 2017).

1.2. The industrial sector, one of the main drivers of pollution

As we can see from the chart (Fig. 5) representing the CO_2 emissions by sector (1990-2018), the industrial sector is responsible for a great portion of the global pollution (IEA). If we want a sustainable and economically viable future, we need to ensure our industry is not harming the environment, by securing a resource efficient and low carbon growth and promote sustainable patterns of production.

Figure 5



Source: IEA CO_2 emissions from Fuel Combustion, 2020[13]

Our society has a lot of benefits, coming from goods and products, which improve our lifestyle and satisfy our needs and wants. However, these benefits have a high sustainability price-tag in a resource-constrained world. For this reason, production plays a key role in the way resources are exploited and products are produced. This is why policies and regulations are addressing to those activities that include production processes. The latter should aim at minimizing waste, pollutant emissions and aim to a sustainable production pattern.

Many improvements have been made, especially in the last decade, but it is still not enough to face a growing consumption, as potential 2.5 billion people would be added as new consumers in the coming next few years (The Sustainability Consortium, 2016).

[13] [Fig. 5] available at: https://www.iea.org/subscribe-to-data-services/co2-emissions-statistics

As a consequence, a revolution in this sense is needed, in order to protect the environment and ensure a better future for the next generations. This green environmental transition can be released through the implementation of various governmental measures, as well as investments in innovation, R&D and technology.

Is industry 4.0 the way to a sustainable development? Is it possible to adopt an industrial ecology approach? Does it have close links with the preservation of our environment?

The links between the Fourth Industrial Revolution and the major issues humanity is facing now, such as environmental and climate crisis, are closer than what usually people may think they are. Although Industry 4.0 has risen during a period in which the concept of sustainability is very popular, the majority of researches focus on the technical perspective, whereas just a few relate to the concept of sustainability and ecological achievements.

In order to understand where is the "green" in smart manufacturing, we shall look at the concept of green manufacturing, or sustainable manufacturing. Even though sustainable and smart manufacturing relate to two different concepts, I will try to identify the links and common points between them.

1.3. Sustainable Manufacturing and Smart Manufacturing: aiming at the same goals

A complete definition of Sustainable Manufacturing is provided by the United States Environmental Protection Agency (EPA):

"Sustainable manufacturing is the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community and product safety"

(EPA, 2020)

Sustainable manufacturing refers to a manufacturing system whose mechanism and outcomes are considered sustainable. The main points of difference from traditional manufacturing is the fact that sustainable manufacturing considers three dimensions, the "Triple Bottom Line"

(TBL)[14] assessment criteria, namely the environment, the economy and society. It can be assessed that it is based on the 6R (reduce, redesign, reuse, recover, remanufacture and recycle). "Reduce" refers to the reduction of energy and resource consumption during manufacturing. "Reuse" and "Recycle" respectively mean the reutilization of products or already used manufacturing components and the material reutilization to create new products. "Recover" refers to the disassembly of some components used for one life cycle: as they are cleaned, they will be used to for the following lifecycle. The process of "Redesign" refers to merchandise and aims at making products more maintainable and further durable. Lastly, "Remanufacture" means restoring the state of a product, by manufacturing it once again. Considering the environmental dimension, the sustainable patterns are therefore related to the allocation of the resources inside the factory, such as water, energy, raw materials and products. In this way, a virtuous manufacturing model is established, whose opportunities are several both from the macro perspective (business models, value creation networks, equipment) and the micro perspective, including human, organization, process, product (Stock & Seliger).

In the light of this, can smart manufacturing be in line with sustainable manufacturing? Do they have common points? Given the background of smart manufacturing and Industry 4.0 technologies presented in the first chapter, as well as an analysis of their main features, a sustainable pattern can be noticed, or will be noticed in the future, in terms of environmental sustainability. Therefore, in order to analyse the concept, we have to consider just the common denominator of both smart and sustainable manufacturing, which is the environmental dimension. Even though some sustainable features of smart manufacturing can be related to the social dimension (i.e. automation enabled production prevents negative outcomes in dangerous sites or operations, usually done by workers), the main common features are related to the environmental dimension.

When talking about this topic we have to deal with several different opinions. On the one hand, some studies demonstrate that digital smart technologies can bring efficiency to the production line by reducing costs, improving resource efficiency by reducing energy and material

[14] The Triple Bottom Line is a system used by businesses to measure their profits made through their sustainable solutions, and considers the three dimensions of sustainability (economic, social, ecological) to assess them (Investopedia).

consumption; on the other hand, other studies are much more pessimistic, suggesting that the replacement of new machines and equipment, together with continuous monitoring and connection, will require more amount of money and energy consumption. As the level of diffusion of smart models is currently still low on a global average, positive results of the impact of smart manufacturing model on the environment may be properly verified in the future.

Par. 2. China: from traditional manufacturing to smart and green manufacturing – MIC25

The previously outlined roadmap served as an introduction to the main topic from a general perspective. Now, the focus of the discussion will be centred on China and the development of the country's manufacturing industry. The manufacturing sector fundamental for China's GDP growth and will gain even more importance in the future decades, after the implementation of industrial upgrading. Manufacturing upgrading in China occurs at two levels, looking at both digitalization and sustainability. This is why the country can represent an evident example of how those two different concepts can be merged together.

Nowadays, China represents the leader of developing countries in paving the way towards a more sustainable development by introducing concepts like green growth and sustainable production. Even though the country's economic and industrial development cannot be considered yet as a perfect example of green and sustainable growth pattern, it definitely stands in the first position for what concerns green global investments. China is particularly involved in the fight against climate change and air pollution and has already shifted the attention from the previous unique objective of economic growth, to a more balanced one, which gives much more space to the environment, nature and the people's well-being. Even though its investments in R&D, innovation and high-tech are still under the average of many developed countries, China is striving to meet ambitious goals, in the view that innovation and technology can design the path towards a more sustainable growth pattern (OECD, 2017).

Actually, in 2015 the Chinese government launched a great initiative, the so-called *Made in China 2025 – 中国制造 2025 Zhōngguó zhìzào,* which lays out strategic objectives concerning Industry 4.0 and green development. This initiative can be considered as the first part of a greater and more ambitious plan whose goals are to be achieved by 2049, when China will celebrate the 100th anniversary of the People's Republic. This 10-year initiative aims at achieving a more advanced industrial capability by reducing its reliance on foreign technology imports, in this way allowing China to turn into the world's leading manufacturing powerhouse by 2049. With respect to the manufacturing sector, major investments have been made and will be made for the development of smart manufacturing and Industry 4.0 technologies, thus implying further investments in R&D (Zenglein & Holzmann). As I am going to explain in this section, the key words for the modern Chinese manufacturing system are innovation, quality, efficiency and customization. These concepts and further features will be properly described later. Indeed, challenges and other negative aspects of Chinese manufacturing will be outlined too, in order to depict a complete picture of the whole system.

Investments in innovation, product quality and efficiency will also lead to one of the main targets pointed out in this ambitious plan: green development. The government's objective is that of reducing the environmental and health impact of China's industrial sector, aiming at limiting pollution and combat climate change. Green production is thus one of the objectives of MIC25 (State Council, 2015).

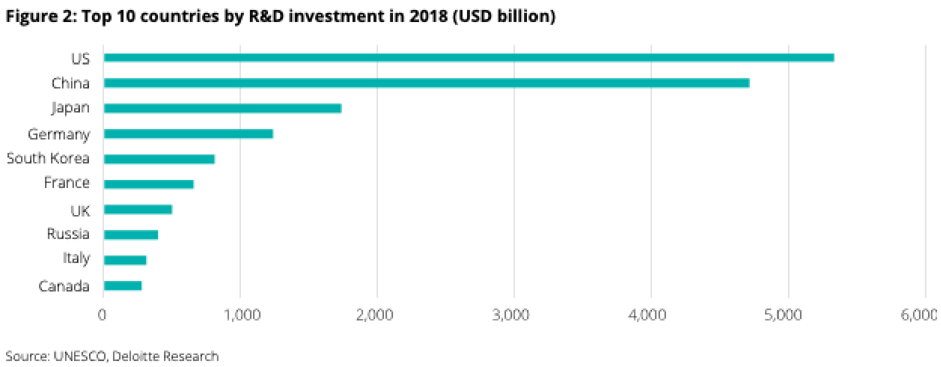
In order to screen out the actual situation concerning this topic, I will trace the innovation path China has undergone in the past few years. Moreover, in the following lines I will illustrate the challenges and main problems of the Chinese manufacturing industry and why Industry 4.0 could help its industrial upgrading. Given this background, the state of art of Industry 4.0 development in China will be outlined, followed by a deep and exhaustive analysis of MIC25 and its targets.

2.1. Innovation in China: the main problems in the manufacturing industry

Innovation is the key word in today's globalized and technological world. Obviously, we have to draw a distinction between developed and developing countries: although the pioneers of Industry 4.0 are countries like Germany, South Korea and the US, we must underline that many developing countries are now gaining the focus for the present and future markets and great innovation advancements have been carried out in countries such as India, Brazil, Russia and China. These emerging industrial economies play an important role in the manufacturing sector, being those that usually have large manufacturing industries but suffering lacks from other perspectives. China's great economic development has shifted the economic axes to East Asia, accompanied by a great annual increase in GDP. Today, China represents the focus of global attention, from many points of view, such as technology, innovation (R&D), and digital development. In Fig. 6 we can notice that China was the second country investing in R&D in

2018. These achievements are leading to an upgrading of the industrial system, which is going to be revitalized in order to reach the great ambitions the country is looking at (Deloitte, 2019).

Figure 6



Source: UNESCO, Deloitte Research (2018)[15]

However, the real scenario Chinese companies are facing is different. On the one hand, they suffer from technological dependence on other developed countries like the US, Germany and Japan. From this point of view, China is still considered as a latecomer, as it can't rely completely on its own resources. For instance, it lacks the know-how and relies on other countries for imports of core technologies such as integrated circuits and chip manufacturing (90% of imports). On the other hand, Chinese enterprises aim at catching up, implementing ambitious national plans for innovation and technological advance (Deloitte, 2019). Although China has strived to meet international manufacturing standards, important issues and challenges still exist, and menace a correct and smooth implementation of smart manufacturing and digital technologies deployment.

First of all, China's manufacturing is of large scale but not strong: the large-scale dimension of the Chinese manufacturing system made China become the "factory of the world", producing almost any kind of products for almost every country in the world, in huge quantities and at a very low labour price. The issue emerging from this is the production of low-quality goods, which has started to become the driver for low competitiveness. Reliance on foreign countries is China Achille's heel: China doesn't enjoy technological independence, since it has to rely on import of core parts, which are fundamental for the realization of advanced machineries and tools. Secondly, there is a lack in foundational technologies (semiconductors, new materials,

[15] [Fig.6] available at: https://www2.deloitte.com/cn/en/pages/innovation/articles/china-innovation-ecosystem-development-report-20191.html#

basic research). China's level of strength is a bit higher (even though the level is still low) for what concerns the so-called core technologies (electric vehicle batteries, industrial robots and AI); instead, good results can be noticed if we consider future technologies, such as autonomous driving, smart cites and facial recognition. Even though massive investments have been made in this sense, the sector should promote in a stronger way the national production of those components, which allow the access to a properly competitive and upgraded manufacturing system (Zenglein & Holzmann, 2019). Moreover, the lack of know-how, innovative capacity and core talents force China to rely on foreign competitors. This is closely linked to the investments in R&D, for which the country still lags behind the world average (Feng et al., 2018).

Furthermore, an unsustainable and low added-value pattern has accompanied the country's industrial system throughout the previous century. It was in the last decades that the government implemented a series of regulations to introduce the concepts of sustainability and environmental protection, in order to avoid the negative outcomes such as pollution and environmental degradation (Zenglein & Holzmann).

These challenges are of great importance and they are being faced in a systematic way both by the government and the Ministry of Industry and Information Technologies (MIIT), which promotes and implements countermeasures to face the above-mentioned challenges. As a matter of fact, last decade China went through a great shift in the development of emerging industries like next generation IT, advanced equipment, new materials, bio industry and new energy vehicles (NEVs), in order to promote energy conservation and environmental protection These are contributing to average one percentage to GDP in 2018, accounting for nearly 20% of total growth (Deloitte, 2019). They are well described and analysed in Made in China 2025, which I'm going to describe in detail in the following lines.

2.2. History of manufacturing in China: from traditional manufacturing to smart manufacturing

The development of Industry 4.0 in China will allow the development into a higher value-added manufacturing, gaining more independence for what concerns the national production of base components. In this way, Industry 4.0 may allow manufacturing revitalization and will lead China to gain global competitiveness and globalize national brands (Khurana et al.).

The key milestones of the development of Chinese manufacturing can be outlined as follows. In 2001 China joined the World Trade Organization (WTO): liberalization allowed China to integrate with the world economy, making it easier for trade and investment.

In 2013 the Belt and Road Initiative (BRI)[16]was announced: for what concerns manufacturing, BRI allowed China to move its manufacturing labour to lower cost countries, as China started undergoing manufacturing upgrading towards a higher value-added production. In the same year, the first smart manufacturing model ("Smart Factory 1.0") was announced by the *China Science &* Technology *Automation Alliance* at the *Industrial Automation exhibition* in Beijing, 2013 (Khurana et al.). The main objective was to implement new capabilities in the manufacturing industry, such as the application of Big Data and CPS (Khurana et al.).

Finally, *Made in China 2025* initiative was issued by the Chinese Government in 2015. This plan was designed to upgrade and transform the domestic industry in order to increase efficiency and integration, making it becoming more innovative, digitalized, focusing on quality over quantity and cultivating green development. In the same year, China's *Internet Plus* strategy was promoted by Chinese Premier Li Keqiang. This plan aims at empowering traditional industries by integrating the IT technology and internet connection, and the establishment of internet-based companies. Technologies like cloud computing, big data and IoT should be integrated with manufacturing, e-commerce, industry and finance (Khurana et al., 2019).

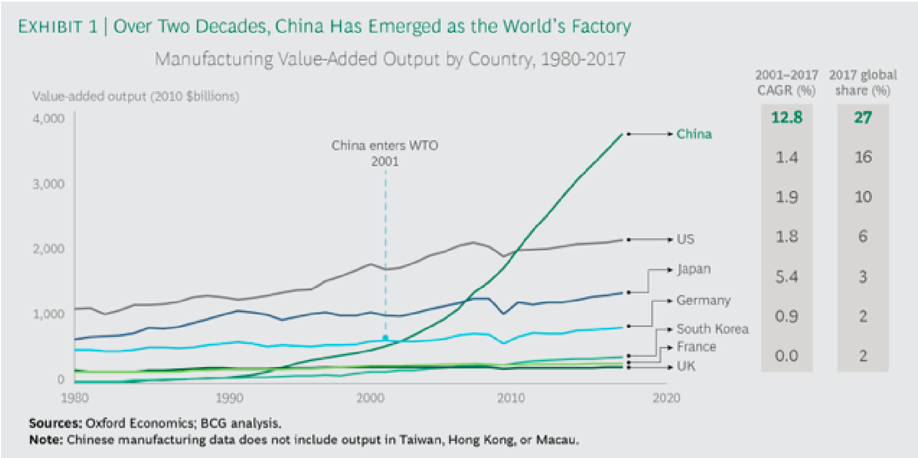
The Boston Consulting Group analyses the key points of the development of the country's manufacturing system (Fig. 7), defining how it has become "the factory of the world". As we can notice from the chart below, China's MVA[17] output has increased 12.8% annually from 2001 to 2017. Countries like the Japan, Germany and the US were all standing below China,

[16] BRI (Belt and Road Initiative) is an ambitious programme launched by Xi Jinping in 2013, aiming at investing US$ 1000 billion in infrastructures to build linkages with almost every country in the world. In particular, the initiative directly touches Europe, Russia, Africa, Indonesia, India. Infrastructures such as airports, railways, bridges, ports and roads are meant to be essential for commercial exchanges and relationships between Chinese companies and the rest of the world (Mantovani, R., 2019).

[17] MVA (Manufacturing Value Added) measures the manufacturing output of a country's economy (Investopedia).

respectively accounting for 1.9%, 1.8% and 1.4% growth in the same period (Colotla et al., 2018).

Figure 7



Source: Oxford Economics, BCG Analysis[18]

From the chart above it emerges clearly that after China joined the WTO, the consequent opening up to the international trade determined the key driver for the growth of the manufacturing sector. China is globally known as "an international hub of manufacturing" (Khurana et al.), particularly for the assembly of components for the thigh-tech industry. For decades, manufacturing has represented the largest sector of China's total Gross Value Added (GVA)[19] standing at 30.2 % in 2017 and MVA at US$ 3.59 trillion, growing year by year with a rate of 11.4%. This growth is expected to increase for the 2017-2022 period to CAGR[20]of 7.7%, reaching US$ 5.21 trillion in 2022 of MVA (Khurana et al., 2019). China's production relies mainly in the electronics, automotive, chemicals and machinery and equipment production and export. From data coming from the National Bureau of Statistic (NBS) we can understand that the tertiary has boomed too, in particular from 2014 to 2018, due to the recent emergence of the high-tech service industry. According to the report on the website of the NBS,

[18] MVA output is not included in Taiwan, Hong Kong, or Macau (BCG). [Fig. 7] available at: https://www.bcg.com/publications/2018/china-next-leap-in-manufacturing
[19] GVA (Gross Value Added) is the value created by any unit throughout the production of goods or services. It is used to measures the contribution of a corporate or company to an economy or sector, and also adjusts a country's GDP (Investopedia).
[20] CAGR (Compound Annual Growth Rate) is an index measuring the growth rate of a certain value in a determined time period (Investopedia).

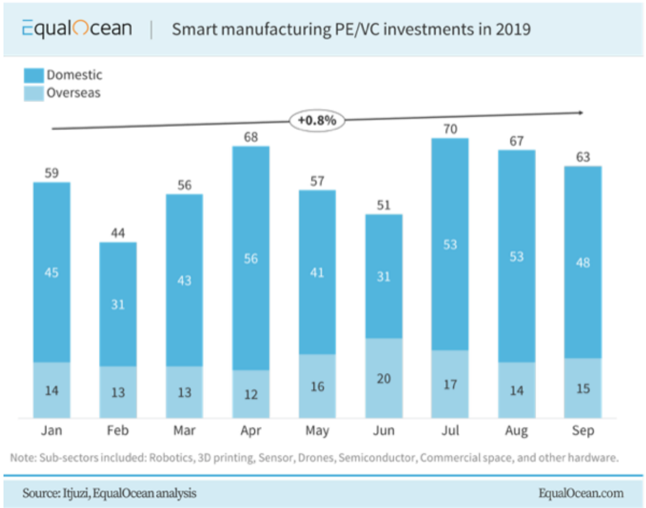
at the end of 2018, the number of companies providing high-tech services nearly tripled form 2013, reaching 2.16 billion, employing 20.63 million people (State Council, 2019). Even though the first months of 2019 registered the lowest level of PMI[21] since early 2016, the manufacturing sector is undergoing a structural transformation from the traditional manufacturing pattern to a high-tech and value-added manufacturing, under Xi Jinping administration (Khurana et al.). As we can notice, the Chinese economy is really tied to the manufacturing industry. Even though the Government already invested a lot in this sector, a further effort has to be made in adopting Industry 4.0 (Institute for Security and Development Policy).

2.3. Industry 4.0 technologies: the state of art of smart manufacturing in China

Digital technologies in China are going to gain huge importance in the coming years. As I already pointed out in the previous paragraphs, the introduction of Industry 4.0 and digitalization has come late comparing to developed countries like Germany and the US. However, thanks to strict regulations and investments by the Chinese government, the market of digitalized technologies is expanding and gaining increasing importance (Deloitte, 2019). Now I'm going to give a closer glance to the state of today's smart manufacturing industry in China. The National Bureau of Statistics focuses on the activities of smart manufacturing in 2019 (Fig. 8) and the related investments for the development of sub-sectors such as robotics, 3D printing, sensors, drones, semiconductors, commercial space and other hardware. (Huicong Y., 2020). We can notice that major improvements have been made in terms of domestic investments.

[21] PMI (Purchasing Managers' Index) measures the economic trends and market conditions in the manufacturing sector, in the view of purchasing managers (Investopedia).

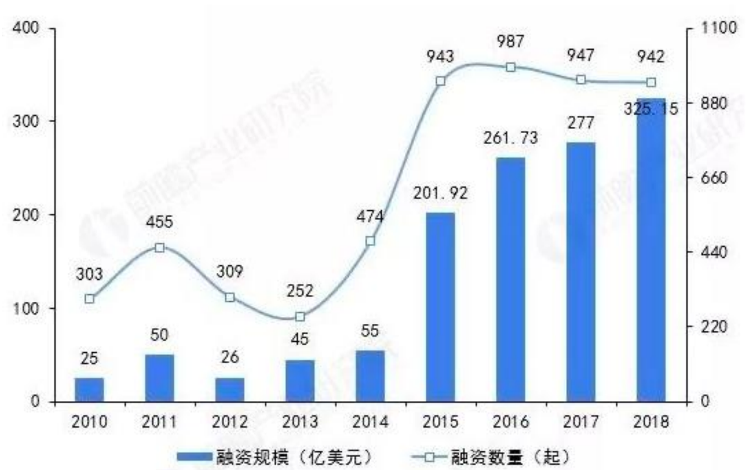
Figure 8



Source: Itjuzi, Equal Ocean Analysis (EqualOcean.com)[22]

Since the release of MIC25 in 2015, China has undergone an improvement path for what concerns the development of smart manufacturing, as the investments drastically increased in particular from 2014 to 2018 (Fig. 9). The scale of investment has grown until reaching 32.515 U$D billions in 2018, with a total of 942 investments.

Figure 9

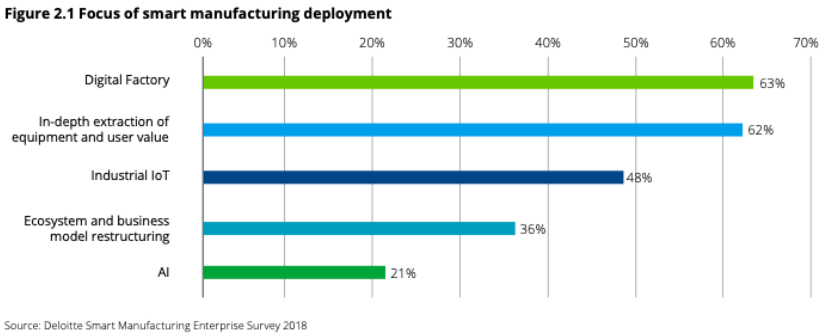


Source: Control Engineering, 2019[23]

[22] Smart manufacturing PE/VC (private equity/venture capital) investments in 2019. Included sub-sectors are Robotics, 3D printing, sensors, drones, semiconductor, commercial space and other hardware.
[Fig. 8] https://equalocean.com/analysis/2020010513224
[23] [Fig. 9] available at: http://i4.cechina.cn/19/0906/09/20190906093526.htm

In order to have a wider view of the Chinese smart manufacturing system, I present a survey regarding its deployment. The survey is updated to 2018 and involves 200 national manufacturing enterprises; an initial survey was conducted in 2013 and great results can be seen from the achievements of five years later. In 2013 smart manufacturing was at its initial stage, generating limited profits. Nevertheless, after a huge development in the sector profits started rising markedly, increasing quality and production efficiency. According to the Deloitte survey (Fig. 3) we can affirm that the application of smart manufacturing in Chinese enterprises is centred on five domains: digital factory (63%), in-depth extraction of equipment and user value (62%), IIoT (48%), business model restructuring (36%) and AI (21%).

Figure 10



Source: Deloitte Smart Manufacturing Enterprise Survey 2018[24]

The chart provided above suggests the utilization rate (still according to the survey) of smart technologies in Chinese industrial enterprises. However, as Deloitte suggests in the report, the deployment of such technologies does not represent a proper realization of smart manufacturing. In order to assess the maturity of smart manufacturing, a slower process is needed. According to the same survey, it can be noticed that emerging digital technologies gain more interest for Chinese manufacturers. After the diffused deployment of industrial software, sensors and communication technology, AI and Robotics deployments are considered as important tools, as well as IoT and Big Data in smart factories. Increasing less importance is given to cloud computing and 3D printing. However, it is necessary to state that this is just a survey, which might not be considered as a correct real situation (Deloitte, 2018).

[24] [Fig. 10] available at: https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/energy-resources/deloitte-cn-eri-2018-china-smart-manufacturing-report-en-190403.pdf

This presentation of the shift towards smart manufacturing in China leads to the consideration that, even though challenges still exist, manufacturing upgrading is playing an important role in the process towards digitalization. It can be assessed that the overall state of art of Chinese manufacturers is still behind the level of developed countries, but massive investments in this area are considered as priorities by the government. For instance, we can assess that China's deployment of smart manufacturing during the pandemic has resulted to be very efficient, thanks to the use of smart robots and cloud services, which benefited the economy but also society at large both for healthcare and manufacturing (e.g. AI and other technologies made the tracking system easier and effective). Furthermore, smart production of necessary items during the Covid-19 pandemic has accelerated production and the availability of personal protection equipment (PPE), as well as avoiding the shortage of essential items such as face masks and latex gloves. The switch in the production lines of various companies such as Gree, Foxconn and BYD was possible thanks to a higher level of automation in the factory (Chou & Li).

In order to get a deeper view about smart manufacturing in China, I provide below an overview of the deployment of digital technologies.

a) Internet of things (IoT) and Industrial Internet of Things (IIoT)

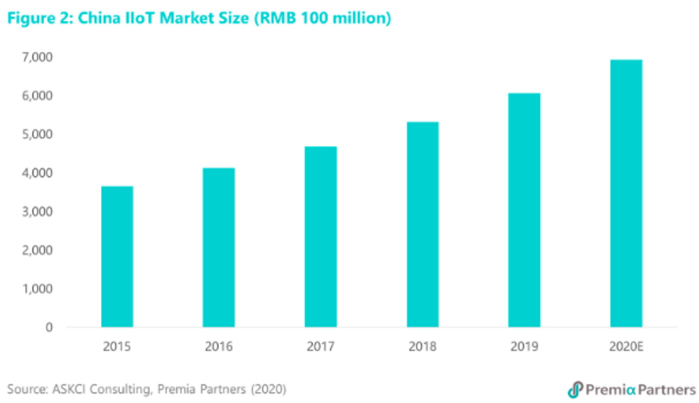
The IoT is a fundamental technology that will drive China towards a more digitalized industrial system. Accenture estimates that the IoT would contribute to add 0.3% to China's cumulative GDP by 2030, which correspond to US$ 500 million and if additional measures will be taken, this would result in 1.3% GDP annual uplift. As we can notice, the IoT market in China is gaining considerable momentum nowadays, and future trends and expectations regarding its development are very positive, especially in the manufacturing industry, which is China's most important sector driving the national economy. An analysis by Accenture and Frontier Economics revealed that manufacturing will be – by 2030 – the first sector to be considered and affected by the IoT technology, positioning first with 40%, followed by public services (12%), resource industries (10%), other knowledge intensive services (8%), retail/wholesale (7%) and other sectors (23%) (Purdy et al.).

But what will be the main benefits of the IoT? Even though manufacturing plays a fundamental role in the national economy, it is the source of some concerns such as overproduction, inefficient allocation of resources, and harm to the environment.

MIC25 initiative aims at solving those problems, employing smart and digital technologies and green production patterns. The IoT can be a response to those concerns and will play a key role in China's industrial upgrading. The "three core missions" refer to manufacturing optimization, efficiency improvement and customer experience as provisions of new sources of revenues. In order to optimize the production process, the IoT helps detecting errors, thus reducing machine downtime. For what concerns efficiency improvement, this technology allows safer and healthier production process opportunities. For instance, there are some factories in China that introduced a "smart band" that workers can wear, with the aim of alerting them, as sometimes they might enter dangerous and risky areas of the factory. The IoT may provide new source of revenue, like the digitally enabled "customer-to-manufacturing" (Purdy et al.).

Given that IIoT is the application of the IoT in the industrial sector, it represents a core instrument for industrial upgrading. China's IIoT market reached nearly 700 billion yuan in 2020, experiencing a huge growth over the past years, as we can notice from the figure below. Nonetheless, the IIoT market is expected to develop further, accounting for one third of the global IIoT market by 2025 (Fig. 11).

Figure 11



Source: ASKCI Consulting, Premia Partners (2020)[25]

Many Chinese tech giants like Tencent, Alibaba, JD and Baidu are all competing for a more and more massive use of this technology, thanks also to the rapid connection given by 5G networks, which improves real-time connectivity leading to efficiency improvements. This technology is one of the most prominent in China, as it is very supported and promoted by governmental policies (Pan & Hsu, 2020). Nevertheless, Chinese manufacturing enterprises

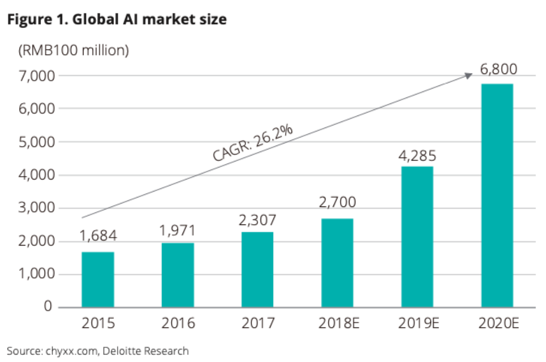
[25] [Fig. 11] available at: https://www.premia-partners.com/insight/iiot-enterprise-digital-transformation-and-industry-40-in-china

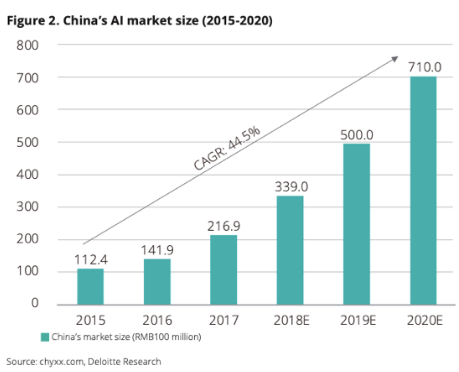
still have to deal with a bunch of issues in the adoption of the Internet of Things. First of ally, they lack the integrated communication systems and platforms required to transfer information and data both externally and across their organizations. In addition, they lack confidence in sending sensitive information or data on connected networks. The third challenge is the lack of talents, since the number of graduates in science and engineering is very low compared to the other countries considered by the Accenture study (Purdy et al.).

b) Artificial Intelligence (AI)

China is one of the world's most active countries in the deployment of AI technology, whose industry develops rapidly, needing space for a much wider market in the future. This system has been gradually applied in different industrial areas since it was put into commercial application in 2015, becoming a key factor driving the technological and economic development in 2018. Total investments and financing in AI in China reached RMB 131.1 billion, with 597 financing deals, accounting 80% of the global total (Deloitte, 2019).
The targets concerning the AI market are very ambitious: according to the National Bureau of Statistics, China is implementing a national AI development plan that aims to invest 1 trillion yuan ($141 billion) by 2030 (NBS). AI and smart manufacturing are closely linked: the development of the one is crucial for the development of the other one. The following charts show the rapid growth of China's AI market size, whose 2020 value corresponds to RMB 100 million; another chart concerning the global market size is given in order to make precise comparisons (Fig. 12-13).

Figure 12-13





Source: chyxx.com, Deloitte Research[26]

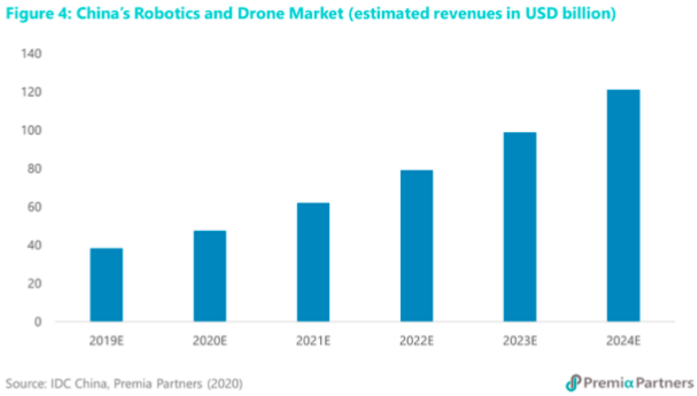
[26] [Fig. 12-13] available at: https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/innovation/deloitte-cn-innovation-ai-whitepaper-en-190118.pdf

Nevertheless, China still meets some challenges in the implementation of AI, and is still considered as “young”, compared for example to countries like the US.
For what concerns manufacturing, the benefits that AI can bring to manufacturing are related to efficiency and autonomous optimization. Moreover, it is one of the most underestimated sectors in which the development of AI achieved considerable results and a positive scenario.

c) Industrial Robots

China has become the world’s largest robot market and maintained rapid growth since 2013 (Deloitte, 2019). In 2015, China sold around 68,000 robots, 20% more than the outcome of the previous year; in addition, it aimed at producing up to 400,000 units by 2019 (IFR, 2016). China’s robot sales exceeded the total amount of the US and Europe in 2017, thus narrowing the gap with foreign brands (Deloitte, 2019).
However, Chinese production of robots still lags far behind that of the foreign leading robot-making companies, and the overall level of quality is still not enough to reach the foreign average outcome by international companies (UNCTAD, 2018). Although China is investing a lot in this sector, if we compare robot density with other countries, China stands on the eighth place, following France, Canada, the US, Japan, Germany, South Korea and Singapore, the leading one. This way, the purchase of industrial robots gains much importance, making China the first purchaser, with 35.6% of global sales (China Power, 2020). Estimations by the International Federation of Robotics outline a possible 20 % annual growth in the robotics market. The massive increase of industrial robots reflects the growth of intelligent manufacturing processes, accompanied by the increase of demand for smart factories, which is possible thanks to the financial incentives promoted by the government. According to IDC, China’s robotics and drone market will achieve US$ 121 billion by 2024 (Pan & Hsu, 2020).

Figure 14



Source: IDC China, Premia Partners (2020)[27]

As we can notice, the rapid and increasing growth in this sector has been and will be possible thanks to governmental policies, and it also listed as a priority of Made in China 2025.
Even though China's reliance on foreign imports remains high, the robot manufacturing is gaining importance. Nonetheless, the number of robots producers doubled from 400 to more than 800 in two years, between 2014 and 2016. In the years to come further improvements would be detected: according to Xinhua, 1.686 new robotic companies were established in 2017 (China Power, 2020). Hence, ambitious plans have been implemented, in particular for the robotics industry. Major plans are MIC25 and the Robotics Industry Development Plan (2016-2020), aiming at producing 100.000 industrial robots annually by 2020 (Khurana et al.).
So far, in the last pages I depicted the overall situation regarding manufacturing upgrading and the state of art of Chinese smart manufacturing. Given this background the further step is to identify another key peculiarity of Chinese manufacturing, which is its green feature. In this way we notice how the country is upgrading its industrial system by advancing in technology and operating a shift into a more green and sustainable manufacturing pattern. As I will explain in the following sections, green manufacturing and digitalization of the industrial sectors do correspond to the main targets of the Made in China initiative.

[27] [Fig. 14] available at: https://www.premia-partners.com/insight/iiot-enterprise-digital-transformation-and-industry-40-in-china

2.4. Sustainability in China: the Chinese traditional manufacturing industry goes green

In the past, industrialization brought social benefits and wealth, but later led to bad consequences such as environmental degradation: the massive economic growth that tookplace since the 1970s caused serious environmental issues which need to be solved by impleemnting a more sustainable development. This is why, especially from the last decades, China has undergone the path towards green development. The concept of sustainable development was confirmed at the World Environmental and Development Conference in Rio de Janeiro[28] in 1992, describing traditional industrialization as *"inappropriate production pattern causing deterioration of global environment"* (OECD, 2017). In 2011 the first *Industrial Transformation and Upgrading Plan* was released by the State Council, whose aim was to promote in the following years a technology and innovation driven industrial system, emphasizing environmental protection in smart manufacturing.

It is important to mention the Chinese commitment towards this topic took place since the introduction to the topic of "Ecological Civilization" (生态文明 Shēngtài wénmíng), presented for the first time by Hu Jintao in 2012, and included in the Constituton of the People's Republic of China in 2018. The term highlights the pursue of a new harmony between human beings and nature, as well as the choice of a modern development model which embodies the merging of economic growth and respect for the environment. Therefore, the core idea behind this is the development of a business model that aims at economic growth and sustainable development, hence promoting a virtuous cycle, that favours the economy, the environment and people's well-being (Hanson, A, 2019).

China is also strongly committed to the UN 2030 Agenda for Sustainable Development, so that in 2016 the government released *China's National Plan on Implementation of the 2030 Agenda for Sustainable Development* (Khurana et al.). Further plans concerning environmental protection and sustainable development have been issued, such as the 12th Five-Year Plan (2010-2015) and the 13th Five-Year Plan (2016-2020) for Economic and Social Development (OECD/DRC, 2017). From the table below (Fig. 15), we can notice the targets of the last three

[28] The *United Nations Conference on Environment and Development* (UNCED) or "Earth Summit" took place in Rio de Janeiro, 1992. From these conferences shared goals and strategies to achieve sustainable development were emerged. The Earth Summit issued 27 principles (the Rio Declaration), related to a new way of equitable cooperation and development between member states, the promotion of environmental policies, as well as stating the need for every country to act for environmental protection, in order to conserve the Earth's ecosystem (un.org).

Five-year plans updated to 2017. Even though we don't have a clear view regarding the target accomplishment of the last plan, positive results have emerged from the previous ones, in terms of pollutant emissions, air quality and surface water quality.

Figure 15

Environmental Indicator	11th FYP (2006-2010)		12th FYP (2011-2015)		13th FYP (2016-2020)	Management
	Target	Actual	Target	Actual	Target	
Main air/water pollutant emission reduction (%)						MEP
SO_2	-10	-14.29	-8	-18	-15	
COD	-10	-12.45	-8	-12.9	-10	
NOx	-	-	-10	-18.6	-15	
Ammonia Nitrogen	-	-	-10	-13	-10	
Energy supply intensity per unit of GDP (%)	-20	-19.1	-16	-18.2	-15	NDRC
Carbon dioxide emission intensity per unit of GDP (%)	-	-	-17	-20	-18	
Share of **non-fossil energy** in primary energy supply (%)	-	-	11.4	12	15	
Water consumption per unit of industrial added value (%)	-30	-36.7	-30	-35	-20	MWR
Water consumption per unit of GDP (%)	-	-	-	-	-23	
Total use of **water** (billion cubic metres)	-	-	-	-	< 670	
Air Quality						MEP
Days with good urban air quality in cities at or above Prefecture-level	-	-	-	-	> 80	
Reduction of PM2.5 concentration in substandard cities at or above Prefecture-level (%)	-	-	-	-	-18	
Surface Water Quality						MEP, MWR
Surface water of at least Grade III quality (% of monitored sections)	-	-	-	-	> 70	
Surface water worse than Grade V quality (% of monitored sections)	-	-	-	-	< 5	

Source: OECD/DRC, 2017[29]

Moreover, at the G20 Hangzhou Meeting China pushed the other members to adopt the *G20 Action Plan*[30] on the 2030 Agenda.

Despite China's previous unconsciousness about the environmental crisis, we can say that in the last decade huge efforts have been made by the Government in promoting a more respectful attitude towards the ecosystem as well as its protection. According to the Chinese Government's 2017 progress report, much progress has been made in the economic field, improving the living conditions and reducing poverty as well as advancing green development. As a matter of fact, the number of rural people living in poverty has reduced and major plans have been implemented concerning air, water and soil pollution. In 2016, China's energy consumption and carbon dioxide emission per unit of GDP dropped by 5% and 6.6% respectively (Khurana et al.).

The green industrial development in China has improved sharply: as a matter of fact, in 2018, CO2 emissions and energy intensity decreased by 3.1%, and 4.0% from 2017, which is a successful result for air pollution control. In the same year, 338 cities managed to enjoy 79.3%

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29 [Fig. 15] available at: https://www.oecd.org/greengrowth/Industrial_Upgrading_China_June_2017.pdf

30 The *G20 Action Plan on the 2030 Agenda for Sustainable Development* contributes to the implementation of the overall goals pointed out in the 2030 Agenda, whereas G20 stands for the group of the twenty industrialized countries such as: Argentina, Australia, Brazil, Canada, China, France, Germany, Italy, India, Indonesia, Japan, Mexico, Republic of Korea, Russia, Saudi Arabia, South Africa, Turkey, UK, USA and the European Union (G20 China, 2016).

of days in a yeas with a good air quality, which represents 1.3% points year by year (MOFA, 2019). Strong efforts have been made in order to develop smart and green industrial upgrading, making it more socially inclusive and environmentally sustainable. Moreover, the government aims at limiting and taxing those traditional energy intensive and pollutant enterprises. Instead, it is striving to encourage the development of less pollutant ones such as IT, and those deploying renewables and new energy production processes. Several actions are supporting the strengthening of the manufacturing industry, improving its green value through standardization and major projects such as the construction of green industrial parks. Positive results have been achieved also for what concerns greenhouse gas emissions, whose task to reduce the previous crazy levels was directed by major policies such as the *"Programme of Work for Greenhouse Gas Emissions Control (2016-2020)"* and the *"National Climate Change Plan (2014-2020)"* (MOFA, 2019).

In recent years, China's manufacturing has developed rapidly and the overall level has been continuously improved. However, it relies on the traditional model with high investment, high pollution and high energy consumption to maintain economic growth. This non-sustainable growth brought to excessive destruction of resources and the environment. Therefore, in order to alleviate the negative impact of this economic development, China has embarked on the road to developing green manufacturing (Khurana et al.).

2.5. Green manufacturing in China: Green Industrial Development Plan

It is widely acknowledged that the manufaturing industry has experienced three industrial revolutions and is now undergoing the fourth. Each of the first three revolutions clearly contributed to economic development and productivity, thus the fourth one is supposed to make such contributions too. Given the scale of the manufacturing industry in China's national economy, there is a urgent need to reduce energy consumption and emissions under the increasingly restrictive requirements of environmental protection.

Green manufacturing is defined as:

"the renewal of production processes and the establishment of environmentally friendly operations within the manufactruing field"

(Goodwin University, 2016)

As a consequence, this more sustainable manufacturing allows more efficient production while moderating emissions and thus pollution, encouraging recycling and reducing waste and energy consumption. This is possible thanks to the use of the so-called “green technologies” or “clean technologies”, which act in a similar way as “smart technologies” (Wang et al., 2019).
Green technologies innovation in China has undergone progress and improvement in the period from 1990 to 2015, and in the last five years it has developed further. The importance of green technologies is related to the benefits it can bring to production, improving industrial optimization, increasing quality and production efficiency (UNCTAD, 2018). These technologies can represent the solution for environmental challenges and climate change mitigation.
China’s total energy consumption reached 426 billion tons of standard coal in 2014, which represents the primary source of energy generation. This let us notice that China’s industrial pollutants are the main source of pollution at national level both for what concerns CO_2 emissions and energy consumption. Major pollutants are suphur dioxide, nitrogen oxides, accounting respectively for 90% and 70% of the national total. More than 70% of global environmental pollution comes from the manufactruing sector, which generated about 6.2 billion tons of waste per year (People’s Daily, 2019). This is why China’s adoption of green technologies in the manufacturing industry has become an imperative.
The Chinese green manufacturing system includes green factories, which are usually grouped in industrial parks, and enable green supply chains by producing green products: in November 2018 there were 391 green factories, 480 green design products, 34 parks and 21 green supply-chain management enterprises (People’s Daily, 2019). Environmental targets for 2020 are a concrete example of the Chinese government committment to green growth and environemntal protection. For example, by 2020 1 million tons of smoke dust will be cut, as well as 2.5 million tons of SO (Solphur Oxides), 1.8 million tons of NO_x (Nitorgen Oxides) per year. The utilization rate of renewable resources will reach 75%, the forging and cuttin material utlization will increase by 10%. Basically, by this year, the green manufacturing standard system will be established, with the aim of creating 100 green demonstration parks and 1000 green demonstration factories.
Given this bakground, we can understand that China is definitely undergoing the path towards an industrial green development, and it is doing it in a rigorous and rapid way. This is promoted by plans and policies issued by the Government and the Ministry of Industry and Information

Technology (MIIT). For instance, in 2016 the Industrial Green Development Plan (2016-2020) was issued (MIIT, 2016). The focus of the plan stays on the transformation of the chinese traditional industry and on green manufacturing. In a nutshell, the main objective is to *"stick the path of Green Development that is efficient, clean, low-carbon and recycled"* (MIIT – Industrial Green Development Plan).

"(…) 牢固树立创新、协调、绿色、开放、共享的发展理念，全面落实制造强国战略，坚持节约资源和保护环境基本国策，高举绿色发展大旗，紧紧围绕资源能源利用效率和清洁生产水平提升，以传统工业绿色化改造为重点，以绿色科技创新为支撑，以法规标准制度建设为保障，实施绿色制造工程，加快构建绿色制造体系，大力发展绿色制造产业，推动绿色产品、绿色工厂、绿色园区和绿色供应链全面发展，建立健全工业绿色发展长效机制，提高绿色国际竞争力，走高效、清洁、低碳、循环的绿色发展道路，推动工业文明与生态文明和谐共融，实现人与自然和谐相处"

（工业绿色发展规划 – 2016-2020 年，中华人民共和国工业和信息化部）

" (…) the concepts of innovation, coordination, "green", openness and sharing will be established in order to make a strong country, insist on resources saving and environmental protection. Through national policies, we will run the way towards a green development by focusing on a cleaner production pattern and the green transformation of Chinese traditional industries supported by green technology. Thanks to regulations and standards the green manufacturing industry will be established, which is clean, low-carbon, efficient, and will enhance international competitiveness. In this way, the his green development path promotes the harmonious coexistence between man and nature"

(Industrial Green Development Plan 2016-2020, Ministry of Industry and Information Technology of the People's Republic of China)

Green manufacturing is the main character of several recent Chinese plans and natioanl regulations. However, the close link between smart technologies, digitalization and green manufacturing is specifically described by the Made in China 2025 initiative. In view of this, I'm going to give a deep and exhaustive analysis of Made in China 2025 initiative, in order to understand in a more profound way China's objectives towards smart manufacturing and green growth. As my aim is to analyse the context of digitization, smart manufacturing and green development, I will give much more attention to these two, focusing on the targets and objectives related to these topics. As the full text of MIC25 is a comprehensive plan that includes also other objectives and analyses in detail other topics, I will mention but not dwelling on subjects which are not necessary for the development of my thesis.

2.6. Introduction to Made in China 2025 (MIC25) – 中国制造 2025.

Made in China 2025 (MIC25) was published five years ago, and it refers to the first of a three-stage overall plan, aiming at making China become a major manufacturing power by 2025, a global one in 2035 and the leading manufacturing power by 2049, when the country will achieve technological independence. The key enabler of this process towards technological independence and manufacturing upgrading is smart manufacturing, which also acts as the engine that will drive the new Chinese economy (Nadicksberndt, M. 2020). The State Council released the official document in May 2015, in which major objectives of the initiative are pointed out and are exhaustively analysed. I'm now going to look more carefully at the plan itself in order to identify the topics of interest such as digitalization and Industry 4.0, smart manufacturing and green development. The ten core industries starring in this plan are next generation IT, high-end computerized machines and robots, aviation and space equipment, maritime engineering equipment and high-tech ships, advanced railway transportation equipment, energy-saving and NEVs, energy equipment, agricultural equipment, new materials, biomedicine and high-performance medical equipment (Zenglein & Holzmann).

The overall goal of MIC25 is thus to achieve manufacturing upgrading, which is translated into smart and green manufacturing, through the use of emerging digital technologies of Industry 4.0. However, they are not all pursued with equal rigour and intensity: manufacturing is the first sector receiving most of the attention by MIC25 strategy (Xinhua).

As I already mentioned, one of the biggest challenges of Chinese manufacturing is the dependency on foreign core components such as new materials, semiconductors and components machineries. Moreover, the quality of products is still considered very low, and this creates the further issue of non-durable goods in the long-term. Low-quality issue is accompanied by labour intensive production and assembly lines: it is widely acknowledged that Chinese factories are overcrowded with underpaid workers, often working under unfair and unacceptable conditions. Another major problem is still the strong presence of pollution, which remains severe due to the massive production of the industrial sector. Made in China 2025 may represent the solution to these challenges, which are supposed to be fixed by the upgrading of the manufacturing system. The improvement of manufacturing output and quality can be pursued thanks to the development and diffusion of digital technologies and the concept of green manufacturing. In the following paragraphs I'm going to focus on the official document of made in China 2025, published by the State Council of China on May 8th, 2015 (State Council, 2015 – *Notice*).

Below I will also report some parts written in Chinese, followed by their English translation. In the introduction part, the State Council presents the overall situation of manufacturing at a global level, in order to focus later on the case of China. In order to put the basis for the realization of the "Chinese Dream" (中国梦 Zhōngguó mèng) the objectives and targets concerning innovation and manufacturing upgrading are set out.

"制造业是国民经济的主体，是立国之本、兴国之器。（。。。）没有强大的制造业，就没有国家和民族的强盛"

"Manufacturing is the core of the national economy, its basis and the tool for the rejuvenating of a country (…) without a strong manufacturing industry there would be no prosperity".

(Made in China 2025, State Council, 2015)

"新中国成立尤其是改革开放以来，我国制造业持续快速发展，建成了门类齐全、独立完成的产业体系（。。。）然而，与世界先进水平相比，我国制造业仍然大而不强，在自主创新能力、资源利用效率、产业结构水平、信息化程度、质量效益等方面差距明显"

(Made in China 2025, State Council, 2015)

"Since the founding of new China, in particular from the reform of the <<opening-up>>[31], Chinese manufacturing industry continued to develop in a rapid way, and a complete and

[31] The reform and "opening up" 改革开放 (Gǎigé kāifàng) refers to the economic reforms implemented by Deng Xiaoping in 1978, two years after the death of the leader of the Chinese Communist Party (CCP) Mao Zedong. The reforms regarded the whole economic system of the country, allowing China to be introduced in the international commercial relations. China became the objective of several investments, especially after the

independent system was established. However, compared to advanced economies, the Chinese manufacturing industry is of large scale but not strong and gaps in innovation capability, resource efficiency, industrial structure level, informatization and quality still exist".

(State Council, 2015)

"当前，新一轮科技各民和产业变革与我国加快转变经济发展方式形成历性交汇（。。。）必须按照 "四个全面" 战略布局要求，事实制造强国战略 （。。。）把我国建设成为引领世界制造业发展的制造强国"

"Nowadays, the new wave of technological and scientific reforms has intersected with the development of a new economic pattern (…) we must create a powerful strategy according to the "Four Comprehensive" strategic layout requirements (…) in order to turn China into a strong manufacturing power, which may lead the development of the world's manufacturing industry".

(State Council, 2015)

"<<中国制造 2025>>，是我国实施制造强国战略第一个十年的行动纲领"

<<Made in China 2025>> is the first 10-year action plan aiming at making China a manufacturing powerhouse.

(State Council, 2015)

My analysis will focus on four main parts: Development Situation and Environment (发展形势和环境 fāzhǎn xíngshì hé huánjìng),Strategic Guidelines and Objectives (战略方针和目标 Zhànlüè fāngzhēn hé mùbiāo)，Strategic Tasks and Key Points (战略任务和重点 Zhànlüè rènwù hé zhòngdiǎn)，Strategic Support and Guarantee/Supply (战略支撑与保障 Zhànlüè zhīchēng yǔ bǎozhàng).

establishment of the SEZ. The country undertook the journey towards a huge industrial and economic growth, accompanied by social reforms (like the one-child Policy) which made the country's GDP increase exponentially (Reuters, 2008).

1. Development Situation and Environment 发展形势和环境 fāzhǎn xíngshì hé huánjìng

The first section of the document regards the overall presentation of the manufacturing industry, from a global perspective: every country is striving to intensify scientific and technological development and innovation. For instance, major attention is given to digital solutions such as cloud computing, 3D printing, Big Data, bio engineering, new energy and new materials. Therefore, intelligent manufacturing is leading the shift of manufacturing upgrading. The Chinese manufacturing industry faces a "two-way squeeze" from developed and developing countries. This is why it has to take a global approach, step up its strategies and build a strong manufacturing system. After the new industrialization, informatization, urbanization and modernization of the agricultural sector, the Chinese manufacturing sector developed a lot; the opening-up stimulated the vitality of the manufacturing sector, promoting its upgrading. As the national economy entered a "the new normal" the development of manufacturing started facing new challenges, such as resource constraint, and the increasing cost of labour. In order to form a new driving force for economic growth and make it internationally competitive, the focus should be on manufacturing, as it is the core point, the sensitive issue, and the key of the way out. (重点在制造业，难点在制造业，出路也在制造业）. These challenges are considered as opportunities for the upgrading of the Chinese manufacturing sector.

The rapid economic growth has led to a new stage of Chinese manufacturing, which is full of challenges such as resource constraint, increase in the production costs and decrease in the export costs. The task of building a strong and resistant manufacturing industry is very ambitious, hard and urgent (建设制造强国任务限聚而紧迫). Continuous investments in innovation have pushed Chinese manufacturing system to increasing competitiveness at a global level. Even though after decades of massive economic development, the output of Chinese manufacturing has ranked first in the world, this doesn't define China as the world leader manufacturing country. In fact, it is of large scale, but not strong, relying on core technologies and high-end equipment. Moreover, the problem of environmental pollution is of great concerns, like the ack of informatization and industrial internationalization. These issues are contributing to widen the gaps between China and advanced economies: independence from foreign technology and know-how, as well as core components imports should decrease and the national production will be promoted. In order face the above-mentioned issues and turn the Chinese manufacturing industry from big to strong, the overall plan should be strengthened and special policies should be implemented.

2. Strategic Guidelines and Objectives 战略方针和目标 Zhànlüè fāngzhēn hé mùbiāo

Part 1. *Guiding Ideology* 指导思想 Zhǐdǎo sīxiǎng

The leap from a big to a strong manufacturing is the key to ensure a modern innovative manufacturing industry, characterized by the emergence of intelligent manufacturing. The shift will be driven by innovation (创新驱动 chuàngxīn qūdòng), which is put at the core of the overall manufacturing development, in order to promote digital and intelligent manufacturing.

Quality is of fundamental importance (质量为先 zhìliàng wèi xiān) rather than quantity: in this light the responsibility of enterprises will be strengthened and a higher quality production will be promoted by the government.

Green Development (绿色发展 lǜsè fāzhǎn) refers to a national development which adheres to the principle of sustainable development, an important step for a strong manufacturing industry. The application of energy saving technologies, processes and equipment will enable a cleaner production (发展循环经济，提高资源回收利用效率，构建绿色制造体系，走生态文明的发展道路).

The Structural Optimization (结构优化 Jiégòu yōuhuà) of the sector is thus necessary: the transition from product to service oriented manufacturing will be implemented.

Part 2. *Basic Principles* 基本原则 jīběn yuánzé

First of all, the basic principles include the leadership in market and governance (市场主导，政府引), that will be possible thanks to the implementation of reforms, policies and proper measures. The focus of strategic objectives is on the present, but with a long-term perspective (立足当前，着眼长远)The plan is based on the present but with a long-term view, with the aim of accelerating the shift towards an upgraded manufacturing system, improving quality and efficiency as well as competitiveness and sustainable development capabilities. The last ones regard holistic advancement(整体推进 Zhěngtǐ tuījìn) and the promotion of an open cooperation with other countries, but still maintaining the priority of independent development (自主发展，开放合作）.

Part 3. *Strategic Targets* 战略目标 zhànlüè mùbiāo

The goal setting is aimed at building a powerful country through the three steps described below.

First step: become a manufacturing power in ten years (2025) 第一步：力争用十年时间，迈入制造强国行列.

By 2020 industrialization will be achieved and the level of manufacturing will be enhanced thanks to the introduction of digitization, networking and smart manufacturing. Environmental benefits like reduction in consumption and pollutant emission of the industrial sector will be noticed. These targets will be further fulfilled by 2025, by which manufacturing will reach a new level of digitization and informatization.

Second step: by 2035 Chinese manufacturing industry will reach the average of the world's manufacturing power camp 第二步：到 2035 年，我国制造业整体达到世界制造强国阵营中等水平.

Innovation capability and overall competitiveness will be improved; and industrialization will be fully realized.

Third step: the status of China as a major manufacturing power will be consolidated and its strength will enter the forefront of the world's manufacturing powers.第三步：新中国成立一百年时，制造业大国地位更加巩固，综合实力进入世界制造强国前列.

In order to understand in a more practical and clear way which are the objectives and targets of Made in China initiative, I provide a table with indicators and targets to be reached by 2025. Starting from 2013, we have a clear view of improvements considering the below-mentioned indicators, namely innovation capability, quality， integration of the two and green development (State Council, 2015).

Table 1

类别	指标	2013年	2015年	2020年	2025年
创新能力	规模以上制造业研究发经费内部指出站住营业副收入比重（%）	0.88	0.95	1.26	1.68
	规模以上制造业每亿元主营业业务收入有小发明发明专利数(1)（件）	0.36	0.44	0.70	1.10
质量效益	制造业质量竞争力指数(2)	83.1	83.5	84.5	85.5
	制造业增加值率提高	-	-	比 2015年提高2个百分点	比 2015年提高4个百分点
	制造业全员劳动生产率增加速（%）	-	-	7.5左右（"十三五"期间年均增速)	6.5左右（"十四五"期间年均增速）
两化融合	宽带普及率(3)（%）	37	50	70	82
	数字化研发这集工具普及率(4)（%）	52	58	72	84
	关键工序数控化率(5)（%）	27	33	50	64
绿色发展	规模以上单位工业增加值能耗下降幅度	-	-	比 2015年下降18%	比 2015年下降34%
	单位工业增加值二氧化碳排放量下降幅度	-	-	比 2015年下降22%	比 2015年下降40%
	单位工业增加值用水量下降幅度	-	-	比 2015年下降23%	比 2015年下降41%
	工业固体废物综合利用率	62	65	73	79

Source: State Council, 2015

3. Strategic Tasks and Key Points 战略任务和重点 Zhànlüè rènwù hé zhòngdiǎn

In order to achieve the strategic goal of becoming the leader manufacturing power, the government must focus on a problem-oriented approach, planning the entire project as a whole, and stressing emphasis on key points. This section is considered the core part of the whole plan, divided into nine sections. Each of them includes a few guidelines aiming at achieving the above-mentioned goals.

The first task is to improve manufacturing innovation capability (提高国家制造业创新能力) which will be sustained by the cooperation among enterprises, the government, the education and research. Core technologies development and research (关键核心技术研发) is fundamental to enhance manufacturing competitiveness. This can be achieved by supporting enterprises and encourage them to strengthen their position in technological innovation, making them participate on the decision making, enabling an easier and efficient collaboration with universities and research institutions. Technology innovation roadmaps in major areas of manufacturing will be released. The third key point regards the improvement in innovation design capability (提高创新设计能力), which will be characterized by green, smart and advanced features. Furthermore, scientific and technological achievements will be introduced into the industrial processes (推进科技成果产业化).

In order to carry out improvements in manufacturing innovation (完善国家制造业创新体系), China will make full use of scientific and technological resources, build engineering data centres in key areas of manufacturing to provide enterprises a sharing system of knowledge and data. The acceleration of new generation IT and its integration into manufacturing is necessary in order to develop the smart manufacturing system as a main priority. The focus will be thus on smart equipment and products, which will be produced through an intelligent production process, thanks to great improvements that will be made with R&D.

Regarding to Intelligent Manufacturing Development Strategy (研究制定智能制造发展战略), China will establish a standard management system for the integration of IT into the industrial system. Other than in manufacturing, technologies such as IioT, cloud computing, big data will be integrated in the whole supply chain process, from R&D, to design, operation management and sales.

In addition, a breakthrough will be made in core intelligent components like sensors and meters and make plans to produce intelligent vehicles and machines and robots.

This, will be a first achievement of the promotion of intelligent manufacturing processes (推进制造过程智能化): China will implement pilot projects for the construction of smart factories or digital workshops in key areas, improve interaction between human and machines and integrate additive manufacturing in the production process, improving the overall level of intelligence in the whole production process.

In particular, deepening the application of internet in manufacturing (深化互联网在制造领域的应用) will be a core aspect for the development of smart manufacturing: China will release the integration of the Internet into manufacturing, accelerate the IoT research and application in order to improve monitoring, tracking and remote diagnosis and management. This goes hand-in-hand with the reinforcement of internet structure (加强互联网基础设施建设), whose objective is to build an industrial internet which is transparent and of wide coverage.

The document cites the “Four Foundations” (四基 sì jī), namely essential components, advanced techniques, key materials and industrial technologies, whose promotion is essential for the evolution of Chinese manufacturing.

Also the quality of products is of fundamental importance and has to be strengthen: Chinese brands have to be reinforced to gain competitiveness (加强质量品牌建设), through an improved management system and quality supervision.

The overall implementation of green production (全面推行绿色制造) is actually one of the core elements of the plan.

China will increase R&D in environmentally sustainable technologies, in order to boost the green transformation of the manufacturing industry. Production will be more and more low-carbon and efficient, thanks to recycling, a responsible resource consumption. In this way green manufacturing becomes a pillar of Made in China 2025: together with smart manufacturing, it leads the shift towards a more digitalized and sustainable and clean manufacturing system. In order to accelerate green manufacturing, China will intensify research to implement green technologies and equipment to reduce waste and increase recycling with special technologies, thus leading to an overall efficiency of the manufacturing production. Green development in emerging industries will be achieved by building green data centres to promote new energy, materials and high-end equipment, thus leading to a low carbon development.

Analysing in detail the green manufacturing system, the key points are related to the dimension of environmental sustainability.

The first one refers to the promotion of the efficient recycling of resources (推进资源高效循环利用): China will upgrade the manufacturing system by reducing resource consumption of energy, material and water. One of the means to do this is recycling and resource sharing among enterprises and industrial parks; the establishment of green factories and green parks is essential in order to reduce waste, since resources are shared and used in a more efficient way.

The second one is related to green manufacturing projects (绿色制造项目 lǜsè zhìzào xiàngmù): they are related to industrial demonstration of technologies for energy-savings, environmental protection, resource efficiency, material reproduction and low-carbon energy. Furthermore, special projects will be released to control and monitor atmospheric pollution, water pollution and soil pollution.

By 2020, a thousand green demonstration factories and a hundred green demonstration industrial parks will be built. There will be a transformation of energy and resource consumption in some heavy chemical industries. Major contaminant emission intensity in major industries will decrease by 20%. By 2025, green manufacturing development and consumption of green products will reach advanced international levels and a green manufacturing system will be set up.

Breakthrough in key areas will be carried out, first of all, for what concerns next generation IT (新一代信息技术产业) and high-end equipment (高档设备) like robots and other advanced machines. China will actively develop a service-oriented manufacturing and the product service industry (积极发展服务型制造和生产性服务业), by enhancing cooperation between manufacturing and service sectors with the aim of transforming the sector into a service-oriented manufacturing. Another important task is the internationalization of manufacturing (提高制造业国际化发展水平): the Opening-up strategy will be put forward, combining the principles of "going out" and "bringing in". In this way the internationalization of Chinese manufacturing will reach a higher level, thus strengthening international competitiveness.

4. Strategic Support and Guarantee/Supply 战略支撑与保障 Zhànlüè zhīchēng yǔ bǎozhàng

In order to build a powerful manufacturing country reforms, policies and measures have to be deepened.

“*we must cultivate the manufacturing innovation culture with Chinese characteristics*. *By doing this, we will transform Chinese manufacturing from large to strong”*

(State Council, 2015)

The government will establish a national leading group, headed by the State Council, aiming at rejuvenating Chinese manufacturing. The main responsibilities of this group are relegalization of plans, measures, policies, and the coordination the overall rejuvenation of Chinese manufacturing. In particular the group will monitor the implementation of the whole Made in China 2025 initiative with supervision and evaluated mechanisms, eventually making the necessary adjustments.

In light of this, after an exhaustive analysis of the ambitious initiative by the Chinese government, we can clearly assess that industrial digitalization and green manufacturing are two pillars of the plan. The relationship between digitalization and environmental sustainability finds, in this way, space in the manufacturing sector: there is a link between the concepts of “smart” and “green”.

CHAPTER THREE

Literature Review

The previously considered studies analysed some issues concerning the development of Industry 4.0 and smart manufacturing, both from a global and a Chinese perspective. As the core objective of this thesis is to identify potential environmental benefits through Industry 4.0 and smart manufacturing, in the following lines I'm going to explain and exemplify the core point. I thus provide a literature review, deriving from the analysis of journals, articles and insights dealing with this topic.

The core issue I explained in the chapter has a scientific value. Although Industry 4.0 is a very debated topic emerging in a period in which sustainability and environmental concerns are gaining more and more importance globally, the studies I found out relate to the technical perspective, while just a few of them consider potential sustainable implications. This is due to the fact that I deal with a topic that has not been properly faced and analysed yet by researchers and experts. The majority of the studies rely on estimations, related to possible and potential environmentally sustainable performance of smart manufacturing. First of all, I will identify what are the convergences of sustainable and smart manufacturing, highlighting the common points and benefits to the environment. As I already outlined, there is little practical proof of the sustainable pattern of smart manufacturing, even though several studies agree to its potential environmental benefits. In particular, reduction in resource consumption is the first sustainable feature. This is related to material, water and consumption, whose overall reduction will then lead to efficiency in the manufacturing process. Clearly, if these results will be achieved, the further benefit will be on climate change mitigation, as reduced consumption and material waste lead to a lower level of CO_2 and greenhouse gas emissions.

However, I think the content of the documents and surveys I analysed is enough to assess the results that I will outline in the fourth chapter. Therefore, in the following pages I propose a literature review of studies suggesting environmentally sustainable implications of Industry 4.0 in the manufacturing sector.

The structure is arranged as follows: the literature review is divided into two clusters of studies, which refer respectively to the global and Chinese approach, following the order of the previous

chapter. In this way, the first paragraph includes studies dealing with a global perspective, while the second paragraph considers studies regarding China and Chinese companies.
The order by which I present the literature review is according to different concepts, thus I will group the analysed studies and papers into two clusters: the first one deals with some general environmental considerations of smart technologies and its potential environmental benefits. However, there are also studies focusing on specific technologies and their specific positive benefit for the environment. Therefore, when considering those documents, I decided to group them according to the environmental benefits they focused on, in order to have a more rational and systematic view and understanding of the environmental effects of smart technologies. The main ones, which are often considered by those studies, involve indicators such as resource efficiency, energy saving, waste reduction, recycling. I will therefore to group those studies according to the environmental benefits they demonstrate.
Most of the documents I took into consideration are dealing with estimations and assumptions of the possible environmental potential that Industry 4.0 hides. Many of them include empirical surveys involving manufacturing companies. I will relate to reports and insights published by the "Big Four" (KPMG, PwC, Deloitte, Ernst &Young), as well as organizations like the UN (UNCTAD, UNIDO), OECD and IEA. Moreover, I relied on website articles and scientific reviews, journals and papers.

Par.1. Global perspective

Considering a general view, almost all the studies I take into account are all related to the concept that smart manufacturing goals are supposed to be in line with sustainability. Even though the majority of them consider the overall concept of sustainability, made by the economic, social and ecological dimensions, I will analyse just the ecological one.

For instance, Bonilla et al., developed a theoretical analysis aimed at understanding the environmental positive or negative impacts of Industry 4.0 underpinning technologies. In order to carry out the analysis, the authors considered four different scenarios, and each of those scenarios include different variables and time frame, thus representing four different contexts in which environmental effects could be verified. They are respectively the Industry 4.0 Deployment Scenario (focusing on the near future), Operation (medium-term and future), Compatibility (compatibility to SDGs) and Long-Term Scenario (long-term future). The

analysis was implemented through the use of *"an integration platform"* integrating Industry 4.0 and environmental sustainability (Bonilla et al.).
The four scenarios went through comparisons, in order to clearly evaluate the positive or negative effects.

> "*We think that the technology has not been sufficiently explored from a sustainability perspective due to its novelty and the different degrees of implementation within countries, and although it seems promising, its long-run impacts are uncertain".*
>
> (Bonilla et al.)

The variables considered are material, energy and information consumption, product and waste disposal. In particular, the scenarios are described as follows.
Industry 4.0 deployment refers to the current level reached by Industry 4.0, including the necessary infrastructure to reach operational conditions. The industry requires automation and digitization (IoT, CPS, real-time data acquisition) in order to enhance flexibility and productivity, as well as vertical and horizontal integration.
Industry 4.0 operations relate to the operational level reached so far, in which companies lead the transformation from inputs to outputs. Technologies composing the operational scenario are for example additive manufacturing, data analysis, blockchain and smart contracts
SDG compatibility it analyses the possible impacts on the Sustainable Development Goals of the Paris Agreement, in particular Articles 7, 9, 12, 13. Concluding, the Long-Term Scenario discusses the positive and negative long-term effects on the environment.
The structure of the investigation made by the authors of this article is organized as follows. The considered underpinning technologies of Industry 4.0 are CPS, the IoT, 3D Printing, Big Data and Cloud, whose role is analysed in each of the four previously mentioned scenarios. Considering the input and output flows occurring in the manufacturing process, respectively related to raw material, energy, information (input) and products, waste, end-life (output), the evaluation illustrates the related amount of necessary input to have a certain output. In this way, the productivity level of the smart integrated manufacturing system will be assessed (Bonilla et al.).

Jena et al. analyse the sustainable potential of Industry 4.0 in the manufacturing sector. The framework developed in this article considers different functions like maintenance, energy and water consumption, as well as waste reduction. The results derive from a case study regarding a cement plant, where a sustainable manufacturing pattern can be noticed through the use of CPS, IoT, cloud computing and cognitive computing. The authors agree that the opportunities of the integrated systems of Industry 4.0 are great since the output is maximized and the operational costs decrease. In addition, the sustainable manufacturing model is described. The latter is characterized by smart water, smart energy, smart maintenance and smart production, which are integrated and managed thanks to digital technologies in the smart factory. The model is outlined in the article, together with its environmental implications (Jena et al.).

However, advantages and disadvantages are two sides of a coin: if Industry 4.0 represents an opportunity in terms of environmental benefit, it is also possible that it represents a challenge and bring even worst outcomes, thus harming the environment. Abu-Bakr et al. present two possible outcomes: it is very likely that Industry 4.0 concepts may lead to benefits in the sphere of the environment by reducing resource usage and waste. However, this can be argued since emerging technologies may lead to additional environmental liability. This is a consequence of the necessary wider connections, that require more material to produce devices and a larger amount of energy consumption. Nonetheless, thanks to the flexible and dynamic connection between physical and digital devices, it may be possible to get a more sophisticated and real-time management of energy (avoiding overproduction or shortage), since it is possible to interface with suppliers and manufacturers, hence giving positive feedback to the market (Abu-Bakr et al., 2020).

The confutation is shared also by Waibel et al. In 2017, the authors conducted an investigation of the effects of the smart production system on the elements of sustainability. The authors agree on the fact that smart manufacturing will enable a more intelligent management of the whole process of manufacturing, from the utilization of raw materials to the accomplishment of finished products. However, they also present a confutation of their thesis, underlying a possible negative scenario given by the massive energy consumption in data centres.

Instead, Müller et al., elaborated a study which is not properly in line with the previous ones, as the relationship between Industry 4.0 and the context of sustainability in reversed, meaning that he examined sustainability as a potential driver for the implementation of Industry 4.0. In this way he switches the role of the two concepts. In order to carry out the analysis, Müller took into account Triple Bottom Lines (TBL) which include the economic, social and ecological dimension. From results of the empirical research it emerges a positive consideration of the relationship between them.

The previously mentioned studies all dealt with the analysis of the potential environmental benefits that can be achieved by implementing Industry 4.0 and the smart manufacturing system. Actually, they gave broad considerations, without focusing on the application of particular technologies, nor distinguishing their environmental outcomes. In the following pages I will group the various insights, journals and articles, according to the environmental opportunity they are supposed to demonstrate, such as energy efficiency, CO_2 savings and links with Circular Economy (CE).

1.1. Energy efficiency

Since almost all the studies use energy consumption as key performance indicator, I will then mention in this sub-paragraph the studies regarding that, in order to show its various aspects, as for its consumption and renewable transition in the manufacturing sector and their possible positive impact on the environment. If smart technologies allow a reduction of energy consumption, then a more energy efficient production would become a real matter and a cleaner manufacturing pattern will be introduced. Therefore, below I'll present some studies focusing on the relationship between smart manufacturing and energy efficiency.

In one report published in 2017, IEA highlights the link between digitalization and energy, explaining the application of digital technologies for resources and energy efficiency. The report highlights that the application of digital technologies greatly influences how products are manufactured: in this way, it may lead to energy related benefits since it could improve storage and assist smart grids in matching energy demand, exploiting in the best way the energy of the sun and the wind. Experts agree that in the European Union alone, these benefits would cut up to 30 million tonnes of CO_2 emissions by 2040 (IEA, 2020).

Nagasawa et al. write about smart applications in the production process, highlighting their potential for what concerns energy efficiency in smart factories. The report explains that transparency is a positive feature of smart technologies, and if applied to manufacturing procedure, it may lead to increased optimization in the company's energy management.

Another feature is temporal flexibility, offered by the automation-enabled manufacturing processes such as the smart grids, which contribute to reduce the energy consumption, carrying out a more efficient management system (UNIDO, 2017).

The robotics industry is closely linked to the manufacturing sectors, as the so-called *cobots* (collaborative robots) allow a very flexible, fast and efficient human-machines collaboration. Their performance is characterized by optimization and efficiency. Robots are contributing to the implementation of sustainable manufacturing since they allow energy saving processes. For example, as they are not humans and don't feel the cold or the heat, they can even work in dark and cold places, which are couldn't even need the heating or cooling. In this way, a great amount of energy and costs are reduced. The added value provided by robotics is thus linked to the energy efficiency, representing a huge opportunity to cut energy bills: according to recent estimations, the possibility of energy saving is 8% every time there is a reduction of 1°C (flex.com).

A review concerning energy and environmental science published by the Royal Society of Chemistry regards the positive impacts of CPS on the environment, assessing that it may lead to energy decarbonization. The authors firmly state that reducing dioxide pollutant emissions such as CO_2 in energy is fundamental to run the path for the achievement of the targets outlined in the Paris Agreement. The latter requires a reduction of CO_2 of over 300 giga tonnes, from the energy sector by 2050 (Zhang et al.). Such a rapid decarbonization of the energy system is an ambitious goal to be achieved, and according to the authors, the redesign of the redesign, improvements and optimization of our energy system should be implemented, as well as a greater introduction and deployment of disruptive technologies. In particular, the article focuses on the Cyber-Physical System. As a matter of fact, the authors agree that the CPS would allow the transition of the energy system, making it more sustainable by enhancing its efficiency, thus avoiding environmental harm. Especially, it facilitates energy storage and enables an integrated energy management through collecting data in real time, with the 3V of Big Data (high volume, high, velocity, high variety). From the authors' analysis it emerges that when the CPS is used, it influences the Margin Abatement Cost Curve (MACC), thus leading to a *low-carbon energy system.* The assessment of this statements is given by case studies, which show the benefit of CPS and its subsystems for the environment (Zhang et al., 2020).

The positive results emerged by deploying the 3D Printing are showed in an OECD report. The latter gives an overview of the opportunities driving the revitalization of the Chinese industrial system, in particular focusing on the manufacturing field. These drivers are represented both by the implementation of a more sustainable production pattern and by the use of modern digital technologies promoted by Industry 4.0, and whose convergence may lead to a green growth pattern. Going back to the 3D Printing, it refers to an analysis carried out by OECD: it is stated that its environmental potential benefits are high. With comparison with traditional manufacturing, this technology may reduce the environmental impacts. In particular, it allows the production of lighter goods, thus improving its energy efficiency: the lower the weight, the higher the performance. Energy saving outcomes could really be great: an example in the aerospace sector confirms this, regarding General Electrics' jet engine. The new LEAP engine by General Electric reports energy efficiency results in the use of rapid prototyping, as well as positive outcomes in terms of costs and velocity. This was possible thanks to lighter 3D printed parts which and this improved fuel efficiency by 15% (OECD, 2017).

As energy efficiency can be noticed and emissions are reduced, then we may assist to future important positive implications on climate change mitigation. Technologies used in smart manufacturing provide new possibilities for environmental protection, while enhancing environmental sustainability and mitigating climate change.
One insight focusing on climate change mitigation examines the link between Industry 4.0 and the environment. Erik Josefsson, head of Advanced Industries at Ericsson, presents smart manufacturing and disruptive technologies as a pool of opportunities for environmental protection, while enhancing environmental sustainability and mitigating climate change, thus identifying digitalization in the industrial sector as a possible driver to achieve the targets of the 2030 Paris Climate Agreement. The same article describes the green potential of AR and the IoT. Concerning AR, sustainable benefits have been proved, resulting in efficiency increase and reduction of fault detection time: this is due to the use of remote experts, who interact and collaborate with on-site technicians from different parts of the world in order to solve problems related to machines and the production processes. If used properly, the carbon footprint of the company will be reduced. The IoT is found to contribute to resource efficiency, in particular for what concerns energy consumption, thus reducing climate impact. If leveraged in a proper way, it could help reducing global emissions up to 15% by 2030 (Josefsson, E., 2020).

1.2. CO_2 savings

Energy consumption is closely related to CO_2 emissions, as the latter is a direct consequence of the massive use of energy: the more energy is used, the higher amount of CO_2 is emitted from factories. Therefore, if efficiency is found to be a direct consequence of the deployment of digital technologies in the smart factory, then carbon dioxide and other pollutant emissions will be drastically reduced. Below I provide some literature relating to the potential CO_2 pollutant emissions savings, through the implementation of Industry 4.0.

For instance, one point to be considered is the supply chain process: a potentially sustainable redesign of the supply chain may be represented by the choice of local suppliers as the main providers of raw materials and components. As they are closer to the production site, this would lead to logistic costs, fuel consumption and pollutant emissions reduction. Moreover, if products are remanufactured, required components are reused and waste products will be used as feedstocks (Lisa de Propris, 2016). This could also help to reduce carbon emissions by release production in a single process, thus avoiding every component to be added. If less parts and components are needed, thus transportation costs and potential pollution will be reduced, while reducing resource use (UNCTAD, 2018).

Some studies suggesting environmental benefits related to air pollution are also present. As a matter of fact, one of the main drivers for atmospheric pollution is the industrial sector, resulting in degraded air quality and environmental damages like deforestation (OECD, 2020).
At the end of Klaus Schwab's review about the Fourth Industrial Revolution, some surveys have been included, in order to provide a review of the applications of Industry 4.0 technologies in manufacturing. In the adequately described positive and negative impacts, some environmental positive and negative impacts have been considered. At the end of his overview, he provides an example of 3D Printing and its environmental advantages and disadvantages. Among the positive impacts of 3D printing analysed by Klaus Schwab, it is found out that environmental benefits refer to the reduction of transportation. Since additive manufacturing is able to produce products in one single process, it doesn't require to add different kinds of materials to get the final product. Thus, suppliers will be less, leading to a great reduction of transports and consequently of fuel consumption and pollutant emissions like CO_2 for example.

However, as he states, negative environmental impacts do exist, Schwab refers to the possible growth in waste for disposal using 3D Printing (Schwab, K., 2016).

The logistics concern has been considered, leading to the assessment by which environmental benefit of the IoT in the industrial sector is related to transport logistics. In this sense, the IoT allows the logistics services to adapt routing in real time, thus making every load worth, and avoiding empty runs. In this light, this technology acts as a potential tool for fuel, time and pollutant emissions savings. For instance, the German company *Transporeon GmbH*, applied IoT based solutions for a more optimized production. Both economic and environmental opportunities have been recognized by the "Supply & Demand Chain Executive Green Supply Chain Award" in 2018, such as the 10% reduction of GHG emissions.

Digital instruments promoted by Industry 4.0 hide several potentials for the management of pollution and carbon emissions. For example, satellites have been programmed to track air pollution in a specified area. Besides, they have the task of carbon capture storage (CCS).

Moreover, the report raises evidence of the potential environmental benefits of technologies like 3D printing: if used properly, it could lead to a reduction of carbon emissions (Ranghino, F.). For instance, a recent study was developed, concerning additive manufacturing components in the US aircraft fleet (IEA, 2020).

If the positive effects of Industry 4.0 on the environmental dimension sometimes remain potential outcomes, it has to be said that at least, emerging technologies could avoid pollution to be further severe and limit the dangerous effects on the ecosystem and our health. Indeed, some specific technologies have been created in order to capture the CO_2 particles. Carbon Capture and Storage (CCS) is a technology that allows to catch up to 90% of carbon dioxide emissions, that derives from the use of fossil fuels in the industrial sector. The steps followed by the CCS are three: firstly, the pollutant particles are captured, then transported (by ship or pipeline) and ultimately stored underground. The deployment of this technology is gaining more and more importance, since it avoids the total output of CO_2, drastically removing a great part of the total industrial pollution (CCSA, 2011-2020).

1.3. Links with Circular Economy – waste reduction

Circular Economy (CE) is another wide concept that deserves a deep analysis. However, as it is not included in the scope of my thesis, I will just give rough background. CE refers to an alternative approach to the systems of production and consumption, which is the opposite of the linear economy "take, make, use and dispose". CE gives a higher value to products, as they are supposed to be made and reused through disposal and recycling. The three core principles of CE are (i) conservation of natural resources, which is achieved by balancing renewable and non-renewable natural capital, (ii) improving and extend the lifespan of resources, by enhancing circularity of energy and (iii) reduced damages to the environment, by enhancing a closed-loop management of resources and production.

On this concern, Waibel et. al (2017) examine the effects of smart manufacturing focusing on waste reduction and recycling: as the authors state, smart manufacturing avoids overproduction and related concerns such as energy and material waste. One reason for this is the realization of an efficient and digital logistics management system, by which inventory and raw material are requested "on demand". This means that the manufacturing company orders components and necessary materials from its suppliers thanks to technologies like the IoT, which automatically orders them when needed. Therefore, overstock of both semi-finished and finished goods would be limited or even avoided (Weibel et al., 2017).

Accordingly, for what concerns the overall principle of CE, De Sousa describes its linkages with Industry 4.0. In the latter, even though the authors agree that the linkages between CE and Industry 4.0 have not been properly investigated yet, they proposed the deployment of digital manufacturing as a potential enabler for the implementation of the circular business model. The authors developed a matrix of the relationships between CE and Industry 4.0, in which technologies like the IoT, CPS, cloud computing and additive manufacturing allow opportunities like regeneration, sharing, optimization, virtualization and exchange business models in the manufacturing process (De Sousa et al., 2018).

Several other papers suggest environmental benefits from Additive Manufacturing, one of them is outlined by Ranghino, F. Throughout his review, he analyses the positive sustainable impact of Industry 4.0 by considering a group of technologies organized by the Boston Consulting Group (BCG). Additive Manufacturing is said to bring huge environmental benefits in several manufacturing applications. Compared to traditional manufacturing, it can achieve up to 30-40% weight reduction, like the one of defects and scrap by up to 90%.

Furthermore, in line with the overview of technologies pointed out by the BCG, the same report presents an overall description of Machine Vision. Machine Vision refers to a group of technologies aimed at collecting and elaborating visual information in the whole industrial process (Ranghino, F.). Today, this technology offers huge opportunities in terms of accuracy

and speed of data acquisition. In doing this, it is found to be completely autonomous and independent on central systems. Let’s now focus on its environmental opportunities: for example, considering waste management, machine vision allows an accurate management of waste and recycling.
Robots are the future of the factory workforce and they can also represent opportunities for the realization of the circular economy: according to “flex”, one of their main features is precision, which allows limit errors in the manufacturing process, avoiding raw material waste. A demonstration by Apple assess that robots improve the recycling level in manufacturing. Liam is the name of the robot by Apple, and its task is to extract reusable parts from discarded iPhones. In this way, if every component has the possibility to be reused, less raw material will be wasted (Rujanavech et al., 2016).

2. The Chinese perspective

In the first paragraph I outlined the set of studies explaining the core point of the thesis, sharing the view that the application of a smart manufacturing pattern could lead to a better use of resources, energy and material efficiency and promote re-utilization of products, thus reducing the negative impacts on the environment.
Instead, there remain some studies reporting confutations about the main thesis. In this section I’m going to focus on China. Some of the studies and papers I found considering the Chinese perspective are actually presenting this contrast.
The literature review I will rely on is relatively limited, compared to the previous one that was carried out with a global approach. There are many reasons for this. First of all, Chinese documents and official data concerning China are difficult to recover. Secondly, the topic I’m dealing with has not been deeply analysed yet (in particular in China), also because there, the stage of development about Industry 4.0 and smart manufacturing is relatively low comparing to other countries.
The literature concerning China is formed by insights of famous consulting companies such as McKinsey, PwC and Deloitte, providing articles and surveys regarding the development and diffusion of smart manufacturing in Chinese companies. I will also refer to the Corporate Social Responsibility (CRS) reports of Chinese companies such as Huawei and Foxconn, which highlight the outcomes resulting from the deployment of smart technologies in their

manufacturing processes. I addition I report some case studies by Chinese companies like for example Baowu Steel Corporation.
The link between sustainability, in particular the environmental dimension, and Industry 4.0 emerges from many documents, in which green manufacturing is considered as the point in which digitalization and environmental protection converge.
Previously, I mentioned the role of the Chinese government in the development of Industry 4.0 and its deployment by Chinese enterprises. The related governmental department issuing laws and regulations on this regard is the Ministry of Information and Industrial Technology (MIIT). The department is now massively promoting the deployment of smart digital technologies, by giving incentives to those companies implementing smart patterns and sanction those who are still deploying traditional and polluting systems.

The Chinese website *China Economic Net* reports an article issued by the Centre for International Economic and Technical Cooperation and the MIIT by Wang Xiwen (王喜文 wáng xǐwén), who underlines the concept that green manufacturing is the common point between Industry 4.0 and the MIC25 initiative. In particular, it focuses on energy consumption, highlighting the potential of Industry 4.0 for the implementation of a green manufacturing system. In this way production efficiency will be achieved, also due to the consequent reduction of energy use. Key technologies allowing a more sustainable pattern are part of the IT sector, as they collect and analyse data concerning energy consumption, identify energy consumption problems and then solve them. In this way, an intelligent management of energy consumption will be achieved, which will involve also the use of other disruptive technologies such as cloud computing. At the end of the article the author points out that, in order to accelerate the upgrading of traditional manufacturing into a high-end one, it is necessary to establish an efficient, clean, low carbon and green manufacturing system (Wang Xi Wen, 2018).
According to a PwC report, we can get more deeply into the recent investments that China is actively promoting for the development of smart manufacturing. China is trying to exploit the advantages of 5G: in March 2019 the first 5G industrial park for intelligent manufacturing in Shanghai was inaugurated (PwC, 2020).

Beier et al., discuss the social and ecological impact of digitalization. In his study he examines the potential of sustainable development considering two different countries, which are

Germany and China. The authors conducted a study by using the survey method, whose objective was to determine the potential impact that digitalization has on environmental sustainability, comparing the two different countries. The survey report points out some estimations concerning the role of Industry 4.0 in the development of a further sustainable manufacturing system, leading to benefits such as energy and material saving, and a better use of resources. But, if we look at the results, the potential environmental benefit digital technologies could bring is not direct and obvious yet. Nevertheless, as the authors state, the potential sustainable outcome generated by industrial digitalization may be remarkable, particularly for energy and material consumption (Beier et al., 2017).

A Whitepaper by SAP relates to "Technology and China's Green Development" and describes the relation between technological innovation development and the role of sustainability in China. The paper describes the environmental benefits of cloud computing, big data, machine learning and robotics and drones are outlined. For what concerns cloud computing, it is said to enable a more flexible system, that allows enterprises to update on the latest technologies and adapt to new business models and processes. As a matter of fact, cloud computing limits the use of hardware, in this way energy consumption will be reduced. Big Data plays a fundamental role in sustainability, with its main feature of increasing transparency. Thanks to its ability of extracting and managing different types of information in a quicker way, this helps the company in conducting operations in a more efficient way. For instance, this technology plays a key role in collecting and examine environmental data for China's Institute of Public & Environmental Affairs (IPE), which promoted green development (Mc Comb, M., 2018).
The Italian company Pirelli, whose plants are located in China, leveraged SAP HANA[32] as the key technology that allowed, in 2014, to operate a shift in the business model: from product seller, the company became a tire-performance seller. This type of data management and monitoring system brought a lot of benefits for the company. For example, it leads to optimization of the tire performance and waste reduction thanks to installed sensors. The IoT, using a broad network connectivity and sensors and acting a real-time monitor, has the ability of identifying existing errors or problems (Mc Comb, M., 2018).

[32] *SAP HANA* is a "in-memory computing" technology which allows real-time analysis data and a high level of predictiveness. It has been developed and commercialized by SAP society (SAP).

As I already stated in the previous chapter, the Chinese robotics industry is gaining considerable momentum nowadays. Advanced robotics and drones use technologies such as AI and sensors to face always new environments. Some of the positive outcomes they bring about are "*productivity, profitability and performance, while reducing overall operating costs".* Advanced and recently installed robots also take care of the impacts on the environment. For what concerns environmental protection and sustainability, one of the tasks they are supposed to accomplish is to monitor environmental and weather conditions, eventually informing the company if necessary. Moreover, these "new generation" robots are "green" since they can be powered using renewable energy and reduce riskier operations that otherwise would be humans' task.

Drones can be defined as autonomously or semi-autonomously human-piloted robots, which, from a sustainable point of view, could bring several advantages. These include monitoring pollution levels and particles identification, and the ecosystem in general. A wider adoption of drones may reduce the number of vehicles on the roads, consequently reducing carbon emissions (UN Global Compact, 2017).

A Chinese enterprise in Dongguan, namely Changying Precision Technology deployed robots in its factories, aiming at replacing the 90% of the current workforce. The positive outcomes are related to energy savings and consequently to decreased carbon dioxide emissions. Thanks to their adaptability to the workplace conditions and their enhanced labour precision, they reduce defects during production, therefore avoiding the waste of non-saleable products (medium.com).

Alibaba Group (阿里巴巴集团 Ālǐbābā Jítuán), the Chinese B2B giant recently implemented the use of AI and machine learning algorithms, with the aim of optimizing the whole supply chain process and ensure a sustainable manufacturing pattern (Alibaba Cloud, 2018).

On September 16th, 2020 the group established in Hangzhou its "Xunxi Digital Factory", a new manufacturing factory offering a fully digitalized supply-chain system managed by cloud computing and the IoT. Thanks to this new production pattern, the factory is able to increase production efficiency and at the same time reducing operational costs, as well as offering customized products in short time deliveries. Moreover, the site promotes new technology and new energy systems and lowers the inventory overstocking (Alibaba, 2020).

The Chinese Haier Group[33] (海尔 Hǎiěr) represents a good example of a company facing the Fourth Industrial revolution by being one of the first Chinese enterprises leading the way in the shift of consumer goods, meeting the recent but increasing demand of customized goods. Moreover, the company looks carefully at achieving sustainable outcomes: Haier made this thanks to the use of technologies like the IoT (UNIDO, 2020). The government played an important role by promoting and withstanding the shift to the Haier smart factory, which is based in the Sino-German industrial park in Qingdao, Shandong. The cooperation between the two countries favours an efficient "exchange" of capital resources, such as knowledge and know-how about COSMO. However, even though the transition to the smart interconnected factory was fast and run smoothly, several challenges have occurred, such as making workers change their mindsets, following the shift of business models.

We can find an example of the introduction of smart production in the steel industry, by the case study regarding China Baowu Steel Group Corporation[34] (中国宝武钢铁集团有限公司 Zhōngguó bǎo wǔgāng tiě jítuán yǒuxiàn gōngsī）, which can benefit from upgrading and by introducing an intelligent production process. The company enjoys popularity among Chinese steel production companies and it can be considered as a digital pioneer, since it has been deploying digital technologies for thirty years; in particular it introduced the use of enterprise resource planning (ERP) and manufacturing execution system (MES). Even though the company still lags behind foreign competitors, it is striving to improve its smart manufacturing and the application of a further improved advanced digital production (ADP). The transition to ADP brought many positive results regarding operational costs, resources utilization and overall efficiency, as well as higher quality products. Indeed, the implementation of this system can bring contribution to environmental sustainability: other than driving the decrease of energy costs, thus avoiding the risk of negative environmental spillovers (UNIDO, 2019). A greater development stage for Baowu was possible thanks to the partnership with the German company Siemens, which allowed further efficiency, precision, speed, and a higher automation rate thanks to the application of COMOS, which is a smart software. Bearing this in mind, we can notice how Chinese companies are still positioned at a lower stage from the world average in the field of innovation and industrial digital upgrading, as they can't completely rely on their

[33] The case study has been carried out with the support Hongfei Yue, in collaboration with the MITT of China.
[34] This case study has been carried out in collaboration with MIIT of China.

R&D to implement the best smart production systems: the cooperation between Baowu and Siemens. As the author states, there is another factor that lead to the success of the Chinese company, which is represented by the fundamental role played by the two governments. As I already stated the Chinese government plays a crucial role in the business environment and in the relationship with national and international companies.

Huawei Technologies Co. Ltd. (华为技术有限公司 Huá wéi jì shù yǒuxiàn gōng sī) global leader in smart devices and ICT[35] (Information and Communication Technology) sector, is getting more and more environmentally friendly. The company pays attention to CO_2 emissions for the whole production process through the use of new generation technologies. Their integration is enabled by 5G, whose energy efficiency is 50 times than that of 4G. For instance, the fully outdoor 5G solution implemented by Huawei avoids the use of air conditioning, thus reducing consumption by up to 40%. Besides, energy consumption is reduced by upgrading production plant facilities and equipment. Moreover, it has provided a solution to avoid the continuous running of high-power equipment: intelligent energy meters monitor consumption and when the machine is not scheduled for production, they automatically switch it into idle mode. Therefore, smart applications like smart energy meters save energy, thus reducing carbon emissions.

The 2019 Corporate Social Responsibility report of Hon Hai Precision Industry Co., Ltd. (鸿海精密工业股份有限公司 Hóng hǎi jīngmì gōngyè gǔfèn yǒuxiàn gōngsī), commonly known as Foxconn Technology Group, is a Taiwanese multinational electronics manufacturer. The Group is recently showing great commitment in terms of environmental sustainability and protection, giving way to environmental management, energy management and climate change sections. Moreover, the company wants to achieve the targets of SDGs, establishing mid and long-term goals, in particular for what concerns the energy system. For what concerns energy management inside the factories across China, the group fully exploits the opportunities offered by IT. As a matter of fact, the company's energy consumption is managed by the IoT, which allows a precise monitoring of internal energy usage thanks also to the establishment of an Energy Management Centre. In addition, the Group is striving to promote low-carbon growth by using technologies, with the aim of upgrading the manufacturing system and increase

[35] ICT consists of all the digital technologies concerned with information and communication.

benefits at the same time. After all, the massive investments of 2019 aimed at upgrading the factories manufacturing system, in order to optimize equipment, and through the introduction of emerging technologies, the production system will be transformed.

CHAPTER FOUR
Research methods and Results

1. Research Methods

This fourth chapter is focused on data showing the results of my research. However, I will first leave some lines in order to explain the methodologies used to assess them.

In the previous chapters I already presented the background of my thesis: in the literature review, my focus was on studies demonstrating the potential positive impact of digital technologies on the environment, in the context of smart manufacturing. In the first paragraph of the review the approach was global, whereas in the second one I analysed the case of China. Therefore, I will follow the same order in the paragraph including data presentation and results discussion.

Eventually, at the end, the results related to China will be compared to the ones relating to other countries.

The literature review concerning Industry 4.0 technologies and their impact on environmental sustainability involve the utilization of several different approaches and methods, used to carry out the analysis of the topic. The methodologies used by the previous mentioned journals and papers include explanatory cases, state of art review, surveys, analysis with statistics, empirical studies, theoretical analysis and bibliometric reviews. The publication of collected documents is from 2015 to 2020.

First of all, my primary objective is to evaluate the environmental benefits that smart technologies show or is expected to show. Secondly, I will focus on China, outlining the state of art concerning Industry 4.0 and showing that the recently emerged Industry 4.0 and smart manufacturing systems are somehow tied to the concept of environmental sustainability. In this case, data is related to surveys, insights and reports by Chinese companies.

In order to address to the subject, I read and analysed the various reviews, considering different opinions and approaches by different authors.

The collection of data has been challenging since the core topic I deal with has recently emerged, thus the documents examining the link between Industry 4.0 and the environment are not several. Moreover, the results they show are of great part referring to potential outcomes and

estimates that will be verified in the future. One reason for this is that, globally speaking, the development of Industry 4.0 and smart manufacturing is still a “work in progress”, meaning that it has not been fully adopted yet in the industrial sector. Secondly, just a few studies conducted empirical researches on this topic, so it has been quite difficult to recover verified and exact data. However, as Industry 4.0 digital technologies and environmental sustainability will be increasingly debated topics in the future, hence more linkages between them will be established and more detailed researches carried out.
The aim of this fourth chapter is thus to assemble already existing data, previously analysed in the group of studies I rely on.
Basically, the research considers the following two questions:

Q1: Globally speaking, is there a link between smart manufacturing and environmental sustainability? Are smart technologies capable of providing some positive outcomes from an environmental point of view, and how?
Q2: Focusing on China, is the link between digitalization and environmental sustainability a discussed issue by Chinese companies? Can we notice positive implications on the environmental dimension?

The first question is related to the first cluster of studies, considering a global approach. The results will be followed by the related explanations on how Industry 4.0 may lead to potential and effective benefits on the environment.
The second question focuses on China and aims at describing the state of art of Chinese companies in the development of Industry 4.0 and smart manufacturing. In order to do that, I will refer to case studies and insights regarding particular companies which recently introduced digital patterns in their plants. The two concepts of environmental sustainability and digitalization go hand-in-hand, and their linkages will be exemplified in the following paragraph.
In order to reply to these questions, I will consider a series of indicators regarding the environmental dimension of sustainability: they are almost the same or similar to the ones used by the authors of my literature review: they range from energy consumption, CO_2 savings to waste management and will be further analysed in the following lines.

Therefore, my purpose doesn't correspond to the creation and evaluation of data - since many of the studies I deal with already carried out those results - nor to the measurement of indicators. Instead, I will rather deploy a systematic and explorative approach, and then develop an analysis of those studies providing results. Concluding, I will give my final considerations about the topic.

2. Results

Throughout the literature review I identified the positive implications of Industry 4.0 on environmental sustainability. In this paragraph I will thus group and analyse the results of my thesis, which correspond to a systematic approach on the positive environmental results already demonstrated by other studies.

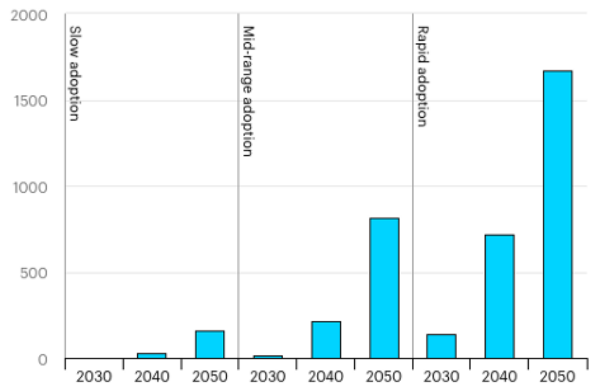
2.1. Global approach

Q1: Globally speaking, is there a link between smart manufacturing and environmental sustainability? Are smart technologies capable of providing positive outcomes from an environmental point of view, and how?

2.1.1. Energy efficiency

The results from the IEA report regarding the US commercial aircraft fleet, showed that from 9% to 17% of the total mass of the aircraft could be reduced by using lightweight components in the near term, through the deployment of 3D printing. If this process will be fully implemented, it could reduce metal demand by 2050, cutting up to 20.000 tonnes/year of metal demand. Thus, also fuel consumption is estimated to reduce up to 6.4% (IEA, 2020). This example suggests a sustainable outcome provided by the deployment of additive manufacturing.

Figure 16



Source: IEA[36]

A Deloitte report identifies the potential of the digitalized smart factory, underlying improved asset efficiency and sustainability (3%-20%). These benefits are based on case studies made by Deloitte. Deloitte outlines the value potential from digitalized smart factories, identifying four value drivers such as improved asset efficiency (10%-20%), improved quality (10%-35%), reduced costs (20%-30%), improved safety and sustainability (3%-10%). These benefits are based on case studies made by Deloitte (Spiegel, H.).

2.1.2. CO_2 savings

The German company *Transporeon GmbH,* applied IoT based solutions for a more optimized production. Both economic and environmental opportunities have been investigated and greta results have been noticed, such as the 10% reduction of GHG emissions (Ranghino, F.).
The emission of pollutants is reduced also thanks to the deployment of additive manufacturing, which avoids unnecessary transports to provide components produced in different places to the manufacturing plant (Schwab, K.)

2.1.3. Links with Circular Economy – waste reduction

Compared to traditional manufacturing, smart manufacturing can achieve up to 30-40% weight reduction, like the one of defects and scrap by up to 90% (BCG, 2018).
Jena et al. developed a sustainable manufacturing model based on smart production, maintenance, energy and water, whose deployment is supposed to bring sustainable benefits.

[36] [Fig. 156 available at: https://www.iea.org/reports/digitalisation-and-energy

Thanks to the use of CPS, smart production refers to the integration of machines and the various devices into a single dashboard, whose performance is regularly monitored. Output thus increases, and potential material wastage is reduced due to the precise monitoring.
Considering that productivity is the ratio between saleable product output in tons (m) and material input in tons (M).

$$P = m/M$$

Given this, the following assumptions should be considered:

M_1 = total input
m_1 = total output — before the implementation of smart manufacturing
Productivity = P_1

M_2 = total input
m_2 = total output — after the implementation of smart manufacturing
P_2 = Productivity

Consequently,

$$P_1 = m_1/M_1 \text{ and } P_2 = m_2/M_2$$

If we consider the same input ($M_1 = M_2$) the productivity improvement is assessed when $m_2 > m_1$. Therefore:

$$P_2 > P_1$$

The last result means that using P_2, the smart production pattern, wastage is lower than using traditional manufacturing (Jena et al.).

Liam is an Apple R&D project for the disassembly of technological devices, whose purpose is to disassemble the various components in order to eventually recycle the reusable materials. Throughout the presentation of this case study by Apple, my purpose is to assess the environmental positive benefit that (industrial) robots may lead to. The traditional industry relies on shredding machines to disassemble devices and separate parts in an easier way. However, new devices even though they are smaller compared to the previous ones, contain a much wider range of materials than what the shredding machines are able to recover, thus making it very hard to separate components.

Robots like Liam are a valid response to this e-waste recycling problem. Unlike traditional shredding technologies, Liam is able to accurately remove components from technological devices and divide them according to the various materials they are made of. In doing so, material recovery and recycling is maximized. Besides, since some components enjoy a determined purity level, it is worth giving it a new life by maintaining it for a new device.

As a result, Liam's pre-processing output can lead to a more accurate, specialized and efficient material recycling, even working with modern devices made up by several spare parts. Actually, what he does is to enhance recycling, by recognizing the material of the specific component and send it to recovery according to its type (Rujanavech, C.).

In this view, we may assess that the work performed by modern robots like Liam is fundamental in order to reduce waste and then implement a sustainable re-manufacturing process through recycling.

Bonilla et al., developed the study based on four scenarios, in which Industry 4.0 may have impacts on environmental sustainability. For the Deployment Scenario the authors provided the characteristics of Industry 4.0 and their environmental impacts (positive or negative).

At the deployment phase, the authors analysed the impacts that automation, digitalization and integration (implementation) may have on the environment, by considering the needs required for each area. Concerning automation, the need of more machined and so equipment increases , as well as the possibility of end-of-life machines. The introduction of digitalization inside a factory requires increased demand of technological devices, as well as the possibility of their obsolescence. The results deriving from the authors' research regard the possible implementation of a digitalized production system, in which all the previously mentioned needs might lead to increased energy and material flow, as well as increasing fuel consumption due to more transport loads. However, the results appear negative, meaning that the requirements of a digital manufacturing system does not require more material, energy and fuel consumption, with respect to the traditional pattern. The results avoid the possibility that smart manufacturing might lead to further environmental damage.

The Operation Scenario describes the expected impact trends regarding energy flow, related to the requirements of the considered technologies. The integration of CPS and the IoT demands for massive data centres and thus a considerable amount of energy. Even though increased energy flow is required, the impact trend is negative, meaning that there is no overconsumption of energy. Also, on-demand production and customization need dynamically configurable processes, with the effect of increased energy flow. However, the result is negative, meaning that on-demand production and customization don't have an environmental negative impact on energy flow.

Below, the table still refers to the Operation Scenario and presents an overview of the most representative feature of Industry 4.0 and their impact on environmental sustainability.

Figure 17

Industry 4.0 Elements	Opportunities	Effect on Flows	Impact Trend
Smart production: • IoT and CPS integration • Real-time data control	Vertical integration	Availability of reliable data about materials flows	Positive
		Availability of reliable data about energy flows	Positive
	Horizontal integration	Availability of reliable data about material consumption along the life cycle.	Positive
		Availability of reliable data about energy consumption along the life cycle	Positive
	Collection of data from consumers	Availability of subjective data	It depends
Big Data Analytics	Optimization of material consumption/ecoefficiency	Decreased material flow in manufacturing	Positive
	Optimization of energy consumption/ecoefficiency	Decreasing energy flows at the factory	Positive
	Predictive maintenance/Remote maintenance	Decreased energy flows	Positive
Additive manufacturing	Prototyping Tool and mold manufacturing Final product manufacturing Part manufacturing	Decreased waste	Positive
		Decreased materials flow	Positive
		Decreased waste	Positive
		No cutting fluids and forging lubricants	Positive
		Increased energy flows	Negative
On-demand production and customization	Elimination of the undesired functionalities of products	Decreased material and energy	Positive
	Disruptive business model/functionality and services	Extended life cycle of products/decreased end-of-life products	Positive
Smart contract/Blockchain technology	Transparency/decentralization/reliable information	Increased energy flows	Negative

Source: MDPI Sustainability, 2018[37]

As we can see from the table above, the integration between IoT and CPS for smart production and real-time data control allows to get information about reliable data on material and energy flows and material and energy consumption along the PLC. The only uncertain result involves the availability of subjective data from customers, which depends.

In the second line we can notice that Big Data Analytics leads to opportunities are tied to optimization of material and energy consumption and predictive maintenance. The related results are all positive, leading to the consideration by which optimization processes by Big Data really use decreasing material and energy flow in the smart factory.

[37] [Fig. 17] available at: https://doi.org/10.3390/su10103740

Moving to additive manufacturing, the effects on flows are related to decreased waste and material flow and the impact trends are all positive.
On-demand production and customization mean a more personalized production, which leads decreased material and energy consumption, since non desired parts of the products shouldn't be added. Furthermore, customized production generates a new business model, which leads to extended life cycle of products, since quality is high and customers are very concerned on them.
Concluding, the scenario of Industry 4.0 and sustainability integration regards the integration of the approaches between the SDGs and underpinning technologies, underlying the opportunities for sustainable manufacturing improvement emerging from their integration.
SDG#7 regards affordable and clean energy, whose integration with Industry 4.0 includes digitization with IoT and CPS, real-time data collecting and monitoring and Big Data analytics. 5he enhanced opportunities refer the implementation of smart grids, which leads to decreasing energy flows.
SDG#9 regarding industry, innovation and infrastructure adds additive manufacturing to the previously mentioned elements, enhancing opportunities such as integration with the circular economy. As a matter of fact, the effect on flows is positive, since energy, material waste and end-of-life products are decreased.
SDG#12 is about responsible consumption and production. Real-time collection and monitoring of data, digitization customized production leads to positive results for what concerns transparency and data reliability, while decreasing waste and material flows.
SDG#13 regards climate actions. Blockchain makes GHG emissions decrease and the implementation of smart grids through IoT and CPS decreases energy flows (Bonilla et al.).

Given the results of the previously analysed studies, the link between Industry 4.0 and environmental sustainability can be assessed. Therefore, we can state that smart manufacturing allows a more environmentally sustainable manufacturing pattern, thanks to the use of emerging digital technologies. Those smart technologies allow a more flexible, efficient and sustainable manufacturing system thanks to the interconnected network among various devices (Deloitte). In particular due to their precision and accuracy, they can reduce material waste (Jena et al.): after the implementation of smart manufacturing, the results considering waste reduction and productivity increase are positive, since the output after smart manufacturing implementation is greater than the output in traditional manufacturing.

Also, an example is the 3D printing technology, that can produce lightweight components, reducing the mass, thus the need for raw material and fuel decreases drastically. As a consequence, less transportation fuel is necessary, thus reducing pollutant emissions (Ranghino, F., Schwab, K.). Besides, material waste can be avoided or considerably reduced thanks to the precise and smart recycling operations by robots like Liam, who introduces the concept of recycling the different components of Apple devices. Moreover, robots contribute to cut energy bills (and thus consumption) as they adapt to wok in every temperature condition.

CPS and IoT integration enable real-time and reliability of data about energy and material consumption during the production process. Indeed, Big data leads to a decreased flow of material and energy inside the factory, thanks to predictive maintenance, and optimization of resources. Additive manufacturing reduces waste and material flow. Moreover, on-demand production (available thanks to real-time monitoring and collection of data from consumers), avoids or drastically reduces the possibility for overproduction, as customized products may not require undesired functionality or components of a specified product.

Notably, the common agreed environmental benefits they hide are material waste and energy flow reduction, thus being in line with the path towards the achievement of SDGs.

Below I provide a table that sums up the potential environmental aspects of Industry 4.0 disruptive technologies in smart manufacturing, identifying the involved technologies and the potential environmental benefits they could enable.

Table 2

ENVIRONMENTAL ASPECTS	INDUSTRY 4.0 TECHNOLOGIES	ENVIRONMENTAL EFFECTS	MOTIVE
Overall production outcomes	AR	Efficiency increase and reduction of fault detection time	Transparency
Energy consumption	Smart grids Rapid Prototyping Robotics	Better energy management Reduction of energy consumption Energy savings	Great adaptation to work conditions
CO2/GHG emissions	3D printing IoT CPS Carbon Capture and Storage (CCS)	Reduction of transports. Real-time acquisition of data. Energy decarbonization; promotion of energy transition. Drastic decrease of CO2	Every load is worth 3V of Big Data (high velocity, variety, high volume) May catch and store up to 90% of pollutant particles
Links with CE	IoT Additive manufacturing (3D Printing) Machine vision Robotics	Avoids overproduction, overstocking and transport fuel Less material waste and fuel consumption Recycling patterns introduced Recycling of disassembled components	Thanks to real-time and on demand orders The weight of products is reduced Waste reduction Disassembling precision and accuracy

Source: The Author

2.2. The Chinese Perspective

Q2: Focusing on China, is the link between smart manufacturing and environmental sustainability a real matter for Chinese companies? Can we notice positive implications on the environmental dimension?

2.2.1. Resource savings

The indicators considered by the analysis of Beier et al., correspond to material efficiency and energy efficiency, own renewable energy capacity and environmental strategy/standards. The results are related to the already mentioned three environmental elements: transparency, material efficiency and sustainable energy (Beier et al.).

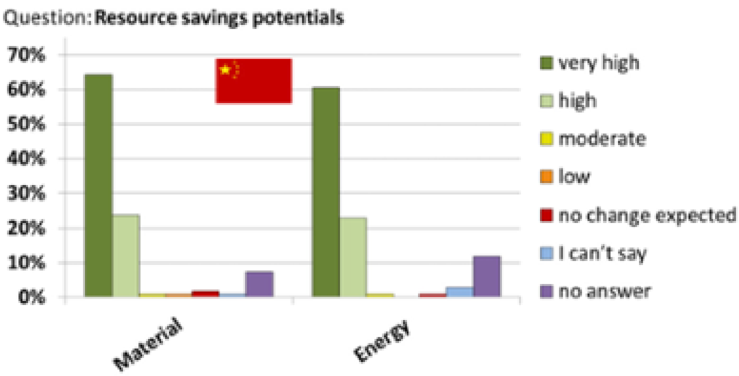
The survey regarding Chinese companies was carried out in three steps, between November 2015 and January 2016. The questionnaires were 120, distributed via e-mail. When all of the questionnaires were returned, the responses were collected. After a documentation, the complete ones were 109 on the original 120 sent questionnaires. The sample by which the survey focuses on, thus relies on the 109 complete questionnaires, in particular of medium and large sized enterprises, of which most of them located in Liaoning Province (nort-eastern industrial zone), with 102 returned questionnaires, 7 from Jiangsu and gansu provinces. The main branches are machine and plant engineer (24%), automotive (22%), information and communication technologies (17%), electronics (15%) and aerospace (12%). Participants are mainly male (73.4%) and work in the two engineering domains of development (34%) and manufacturing (66%).

The German survey was made with a questionnaire created with the tool LimeSurvey, with the participation of 102 people. Most of them work in the automotive sector (20%), information and communication technologies (20%), machine and plant engineering (18%) and aerospace (10%). Given the premises of the study, the results appear to be as follows.

The results of the survey indicate a positive trend of IIoT both in China and Germany. In order to measure the impact digitalization has on the companies performance, greater and more positive results are achieved by Chinese companies: the 90% of the chinese companies retain that digital transformation has a “big” or “very big” would impact on their companies. Moreover, Chinese companies are more inclined to assess long-term impacts rather than short-term of digitization, meaning that they expect results to be seen in a long period of time. The same results are achieved by the German companies, but with a much lower ratio (66.7%,

N=69), but for what concerns the expected results, german companies think they aree going to be noticed for the mid-term agenda.
Skipping the analysis of the social thematic block, I'm going to focus on the results of the ecological dimension. Results show that little more than the half Chinese participants have an environmental stategy (53.2%) and apply environmental standards (53.7%). Results are more positive for german participants, of which the 57.1% (N=70) have implemented an environmental strategy.
For what concerns the link between digitization and environmental sustainability, both countries' surveyed companies agree that digitization will have impact on aspects like energy consumption.
In China, energy and material efficiency are considered as important factors for the future of production processes: the 80.7% of the companies assess that material efficiency is important, while the 89.88% stated that energy efficiency will gain much importance. 83.5% of Chinese surveyed enterprises expect great outcomes for what concerns energy saving, thanks to digitization. Instead an even higher ratio, 88.1% are expectong very good results in material savings (Fig.19).
Considering Germay, 91.6% of the participants to the survey assess that resource efficiency is an important factor for production processes. German companies are then asked if they expect an increase in electricity consumption due to digitization. 20.3% of them do not expact any changes, 34.8% expect an increase in consumption and 23.2 a decline (N=69). Talking about renewable facilities, 31.9% of the participants are considering to rely on their own production of renewable energy (N=69), whereas in China only 3% intend to generate renewable energy with their own facilities in the next five years (Beier et al.).
The green outcomes coming from the Changying factory based in Dongguan are related to the use of robots: productivity has increased by up to 250% and product defects are reduced by 80% (medium.com). Hence a great portion of material waste is reduced, avoiding the unnecessary production of goods.

Figure 18



Source: UNIDO, 2017[38]

2.2.2. Energy efficiency and decreased CO_2 /GHG emissions

The fully outdoor 5G solution implemented by Huawei avoids the use of air conditioning, thus reducing energy consumption by up to 40%. Besides, energy consumption is reduced by upgrading production plant facilities and equipment: as a matter of fact, in 2019 the company saved 19.2 million kWh of electricity and achieved reduction of 16,065 of CO_2 emissions during manufacturing. Moreover, it has provided a solution to avoid the continuous running of high-power equipment: intelligent energy meters monitor consumption and when the machine is not scheduled for production, they automatically switch it into idle mode. Therefore, smart applications like smart energy meters save energy, thus reducing carbon emissions: as a matter of fact, in 2019 the company saved 19.2 million kWh of electricity and achieved reduction of 16,065 of CO_2 emissions during manufacturing (Huawei).

The application of the IoT to for the energy management has been noticed by Foxconn Technology Group, which promotes low-carbon production by exploiting IT opportunities into the manufacturing system (Foxconn CSR, 2019).

Results about energy consumption have been noticed also by Haier Group, after COSMO Plat[39] was launched in the company's smart factories in 2016. One year later, the output of the air conditioning factories increased by 300,000 units, and the same amount was achieved every year. Operation efficiency increased too, compensating about 60% of the investments used to

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[38] [Fig. 18] available at: https://www.unido.org/sites/default/files/2017-08/REPORT_Accelerating_clean_energy_through_Industry_4.0.Final_0.pdf

[39] A modern type industrial platform, whose aim is to lead to mass customization in the future manufacturing.

buy digital equipment and machineries. Haier's energy consumption was reduced by 50% compared with traditional factories (Haier).

The CCS technology has risen also in China and it is gaining increasing importance to cut down the greenhouse gas emissions derived from fossil fuels in major pollutant industries. As I already stated, the industrial upgrading state of art in Chinese companies is improving year by year, but the number of traditional polluting factories is still too high: one way to avoid the further damage caused by GHG to the environment and people's health is the implementation of the CCS technology. The first large-scale CCS facility to be built in China (and in Asia) was made in 2017, by the Sinopec Qilu Petrochemical and applied to a fertiliser plant, and the results corresponded to 400,000 tonnes of captured CO_2. However, as the Global CCS Institutes states, the CCS capacity in the country does not overcome 2 million tonnes per annum of CO_2 capture. Thus, the technology has to be widely promoted and the allocation has to be spread nationwide in order to notice more important results (Global CCS Institute, 2018).

Table 3

ENVIRONMENTAL ASPECTS	INDUSTRY 4.0 TECHNOLOGIES	ENVIRONMENTAL EFFECTS	MOTIVE
Resource savings	Digital technologies in the smart factory	Potential material savings	N.S.
	Robots	Material savings/waste reduction; increased productivity	Precision, accuracy and flexibility during production.
Energy efficiency and decreased CO2/GHG emissions		Promotion of renewable energy	Fast diffusion of renewable energy deployment; application of environmental standards
	5G connection	Energy savings and decreased carbon emissions	Enables efficient and fast connection among machines and devices
	Intelligent energy meters		Automatically turn machines into idle mode.
	IoT	Low carbon production	
	COSMO Plat. (Mass customization)	Decreased energy consumption	Operation efficiency
	CCS (carbon capture and storage)	Drastic decrease in GHG emissions	Avoids pollutant particles to scatter into the atmosphere by storing them.

Source: The Author

2.3. Overall discussion and interpretation of results

The above outlined results depict the situation concerning the development of Industry 4.0 in China and the positive environmental outcomes showed by studies and manufatcuring companies through the implementation of smart technologies in their manufacturing process.
Even though the results are relating to survey considering limited concepts and elements, a positive trend for Chinese manufatcurers can be outlined. Moreover, even though just the half of the Chinese participants follows environmental strategies or standards, they agree that digitalization woud bring benefits such as an efficient management of resource consumption.

Resource efficiency is thus considered as very important and it will be even more in the future. As the authors state, considering the large scale of the Chinese manufacturing sector, and if the expectations will be verified in the next years, the implementation and development of Industry 4.0 will reach higher levels, and digitization will have a very important effect on the ecological dimension of sustainability. This is particularly true for what concerns energy savings: as oil and coal are still the leading source of energy in China – especially for the industrial sector – the implementation of digitalization will potentially lead to a more sustainable development and production.

Even though surveys results cannot be taken as an accurate depiction of a real situation, it can be stated that the most common environmental benefits correspond to energy and material savings, corresponding to the results the other documents provided (Deloitte).

Even though this survey points out notable results, further and more complete studies have to be carried out, since resource efficiency is not the only factor to be considered. Moreover, in China, nor renewable energy systems nor digital production are of common occurrence yet (Beier et al.).

So, in order to analyse in a deeper way the link between Industry 4.0 and environmental sustainability, further research and studies have to be carried out, as the survey presented above shows only some tendencies regarding the topic. In addition, the study was carried out from the end of 2015 and the beginning of 2016, so a period in which MIC25 initiative had not been implemented yet. Given the political pressure on industrial digitalization and the implementation of a more sustainable industrial pattern, it would be interesting to see the results of this survey by 2025.

The results regarding the adoption of smart devices in Chinese smart factories are generally positive, even though I just considered a few cases of manufacturers. The adoption of 5G is increasingly fostering the deployment of smart devices in Chinese factories, and the digital pattern is increasingly spreading among them, raising the attention towards the potential environmental benefits it hides.

The overall consumption of energy can be reduced thanks to the interconnected devices that allow to upgrade the whole production. Interconnection is possible thanks to the wide and fast network provided by 5G (Huawei), which enables the use of intelligent platforms such as COSMO Plat (Haier). Therefore, the environmental results showed by these companies are positive: a more efficient managament of resosources such as material and energy leads to decreased pollutant emissions, and contributes to the improvement of environmental standards. This is possible also thanks to the deployment of digital patterns in the context smart manufacturing, where devices, interconnected by smart technologies, design a new concept of manufatcuring, which is innovative, fully-digitalized and respectful to the environment.

2.4. A comparative analysis of the global and Chinese perspective

The documents referring to the global and the Chinese perspective are both showing positive results concerning the potential environmental opportunity embodied by Industry 4.0 and its application in the manufacturing industry.

In particular, I could draw my conclusions thanks to the already provided survey results, authors' opinions basing on empirical studies and company experiences related to the application of smart patterns in their plants. Other than increased revenues, IT enabled smart technologies provide environmental benefits such as energy and material savings, thus reducing pollutant emissions. Therefore, the development of Industry 4.0 is becoming essential both inside the companies and among companies, nationally and internationally, because it provides a window of opportunities to enhance competitiveness, increases revenues and it is sustainable, since it may reduce the environmental burden caused by the traditional manufacturing pattern.

In the light of this, the fourth industrial revolution is embracing the sustainable sphere. This is happening globally, and also in China, which is the first country for green investments, and a great investor in R&D.

Nevertheless, as I already outlined in the Chapter 2, the level of China's manufacturing cannot be compared to developed countries, such as Germany and the US, for example. Despite the commitment of manufacturers towards digitalization, Chinese manufacturing needs to further develop and upgrade and cannot be considered as advanced as the one of developed countries like Germany. This is why the trend of many Chinese manufacturers (such as the Baowu Steel Corporation) is to build partnerships with foreign companies, in particular from Germany. Indeed, the Sino-German industrial cooperation ends to be strategic from both sides and beneficial for Chinese enterprises, which still lag behind foreign competitors for what concerns know-how, patents, proper infrastructure and overall advancement level. However, it has to be stated that China has already achieved remarkable results in IT technologies and overall advancement in innovation; moreover, greater improvements can be recently noticed in the field of sustainable development. The Chinese commitment on environmental degradation caused by pollution has raised the attention of the government towards the industrial sector, which has a lot of responsibilities from this point of view. Therefore, we can depict the image of a country that looks at the future by embracing digitalization and sustainability, which are both increasingly becoming the core requirements for international competitiveness.

CONCLUSIONS

The shift towards the Fourth Industrial Revolution is now happening, in a period where many changes are occurring from the social and economic perspective. Industry 4.0 has brought and will further bring major impacts mainly in the industrial sector, but it is actually influencing almost everything surrounding us. The distinctive feature of Industry 4.0 is the combination of the physical and digital domains, that allows interconnection between digital devices, which are able to interact in our real world (Schwab, K.). The industrial sector, in particular the manufacturing one, is touched by this revolution and should leverage its opportunities for industrial upgrading and revitalization of the manufacturing system.

This shift is something that has to occur, in order to adapt to the several challenges of today's globalized and constantly evolving world: these dynamics refer to the increasing demand for higher quality and customized goods, which have to be available in short time. This is to be done in a resource constrained world. Thus, production efficiency and flexibility are main requirements to be fulfilled by the modern industrial sector: as a matter of fact, sustainable development is one of today's most discussed topic, as nature and our ecosystem are suffering the unsustainable footprint caused by mankind. It is thus necessary to change the way we live and produce, implementing greener sustainable patterns, especially for the industry.

Indeed, the diversified opportunities Industry 4.0 hides are related to sustainability. Specifically, I focused on the environmental dimension of sustainability, by analysing the impact Industry 4.0 has brought and will bring regarding manufacturing. Even though the approach of a great part of my thesis was global, the focus country has been China, with its vast but not fully upgraded manufacturing system.

After having analysed various surveys, papers and studies regarding the main topic, I could draw the conclusion by which the positive environmental benefits of smart manufacturing and digital technologies are a real matter. These green opportunities of emerging technologies are related to production efficiency, which can be achieved through a more sustainable consumption of resources such as materials, water and energy. As a matter of fact, by installing an interconnected and intelligent system of machines and devices (thanks to the deployment of disruptive technologies such as the IoT, AI, AR, 3D Printing, etc.) in the smart factory, manufacturers have observed reduction in energy consumption, waste material, and thus decreased overall pollutant emissions. In addition, recycling patterns can be observed, by the upgrading of machines such as robots.

At the same time, decreased costs in production and maintenance and increased return on investments can be noticed after the implementation of the smart manufacturing model. This accomplishment can be achieved thanks to the interconnected network between digital devices, sharing real-time data and information, monitoring the production process and eventually solve potential errors, automatically.

Nonetheless, these positive environmental outcomes are not direct, nor taken for granted by experts and researchers. Moreover, the opportunities of Industry 4.0 are debated due to the presence of some challenges regarding it. Indeed, the opinions of some of the authors include the view that the smart manufacturing system would lead to negative environmental outcomes, since additional material is needed to build those intelligent machines and digital devices. Moreover, energy consumption would increase, as a higher amount of it is needed for storage, in particular.

Chinese manufacturing enterprises are currently facing the emergence of Industry 4.0 and its related implications: their feedback is generally positive, since the Chinese government is promoting the implementation of both digitalization and green development, and Chinese companies are striving to adapt to these new patterns. However, the advance stage of Chinese manufacturing system still lags behind the one of developed manufacturing powers like Germany, Japan and the US, as for the gap in terms of know-how, quality and production of core components is still wide (Zenglein & Holzmann). Nevertheless, the massive investments in industrial innovation and digitalization, together with the speed of technological development, are leading China closer and closer to the achievements of MIC25 targets.

Industry 4.0 for sure will lead to a wide range of future implications. Since almost everything we are dealing with every day is affected by digitalization (e.g. smartphones), it is quite obvious that a further development in this sector will occur. Indeed, other than manufacturing, the deployment of digital technologies has already reached other areas such as health, even in particular situations like the COVID-19 pandemic. The coronavirus pandemic has been and is still one of the most unexpectable events the world has dealt with in the last decades. It still represents a serious challenge for both developed and developing countries, as for its negative repercussions for our health, the economy and workplaces. This is why many countries are struggling to return to normality and to re-boost the economy through investments and reforms regarding overall digitalization and sustainability.

The consideration of sustainability, in particular environmental protection, is becoming increasingly important, as it represents fundamental requirement for national and international competitiveness, as well as the key to enhance a virtuous growth.

As industrial production is the key driver for the economic growth of almost every country, it represents the sector deserving most of the attention. Companies using digital solutions in their operations are for sure better-positioned and will be favoured in the future, especially if they incorporate also green solution. Therefore, the integration between the "green" and the "digital" is the winning card for gaining competitiveness in today's interconnected world.

For sure, digitalization, Industry 4.0 and sustainability are the principal drivers for transformation of manufacturing and will have an increasingly significant role in determining the global economic and industrial competitiveness. Therefore, this requires massive investments in modern advanced equipment and emerging technologies.

Smart manufacturing future trends are thus characterized by increasing quality demand and customization, as consumers are demanding for personalized products: this requires a higher level of efficiency and productivity in the manufacturing process. Mass customization implies that the customer plays an active role in the design of the desired product, hence allowing a more precise production, whose final product perfectly corresponds to the one desired by the customer. Therefore, using technologies such as the 3D printing, unnecessary components do not need to be added, thus avoiding excessive material waste. In this scenario, the relationship between the consumer and the product will be improved, as he or her is more inclined to show attachment to the product, thus minimizing disposal habits. Quality is another factor to be considered, since the higher the quality, the higher the durability of the product: sustainable outcomes are therefore related to the reduced material and energy waste required to produce more. Moreover, this may also enhance a circular product life cycle, since high quality goods are also more likely to be repaired recycled or reused, avoiding thus more waste of energy and materials, as well as costs and time to produce again. The relationship between producers and the final consumers will change too, as the gap between them will become thinner little by little and will be more trustful (Dissanayake D.G.K., 2019).

The priorities of manufacturers are mostly related to the requests posed by the customers and the business environment, whose degree of competitiveness depends on their level of fulfilment. The future of IT is creating a lot of business opportunities today, both globally and in China.
Considering the estimated growth of Chinese smart manufacturing, the results in terms of manufacturing upgrading can be confirmed. Indeed, manufacturing remains one of the most important sectors driving the country's economy, and its future appears bright: *"the future of China's manufacturing represents the future of emerging economies and the future of the world"* (Lu, C., 2011). Hence, China will be ready to lead the way for developing countries regarding industrial upgrading, which embodies both the digital and the environmental aspects. Green manufacturing and smart manufacturing are thus paving the way to the future of Chinese manufacturing.

Even though the future of Industry 4.0 looks bright for it brings advantages in various dimensions (e.g. the environmental one), a more critical view concerning the impact on people should be considered. As the adoption of modern technologies reaches higher and higher levels, what people do and what defines people will further change. It is of great concern the fact that technology will little by little limit human-human interaction, which will be replaced by the human-machine interaction. Therefore, in my opinion, moral and ethical boundaries have to be re-defined (Klaus Schwab, 2016).

Nevertheless, it can be assessed that future trends are ruled by the development of Industry 4.0 and the implementation of a more sustainable growth pattern, making digitalization and environmental sustainability the key actors of the future. As a matter of fact, the main priority governments should consider is sustainability, in terms of green investments for environmental protection and the fight against climate change. These are tough challenges and need great cooperation among countries, in terms of innovation, R&D and smart technologies, which are found to have a green potential.

Therefore, in the light of a potential collaborative integration between Industry 4.0 and sustainability, further improvements will be made in various sectors like the manufacturing one, by which an increasingly direct linkage "sustainable" and "green" will be noticed in the coming years.

In this way, the Fourth Industrial Revolution will guide and assist us to provide a better future for the Earth and the future generations.

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