

A Work Project, presented as part of the requirements for the Award of a Master's degree in Economics / Finance / Management from the Nova School of Business and Economics.

The dominance challenge of European ICT companies against China and the USA

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The dominance challenge of ICT European companies against China and the USA.

The purpose of this thesis will be to understand the challenges of this rapidly developing sector with great potential and the battles being waged between the various companies involved to dominate this market.

Strategy International business, Strategy, ICT industry, Europe, USA, China

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Table of abbreviations

<u>ABBREVIATIONS</u>	<u>COMPLETE NAME</u>
5G-PPP	5G Infrastructure Public Private Partnership
AI	Artificial intelligence
AR/VR	Augmented reality/virtual reality
CAPEX	Capital expenditure
DAO	Discrete, Analog, and others
DRAM	Dynamic random-access memory
ICT	Information and communication technologies
IDM	Integrated device manufacturer
IoT	Internet of Things
nm	Nanometer
R&D	Research and Development
SIA	Semiconductor industry association
SMIC	Semiconductor manufacturing international corporation
SNS JU	Smart Networks and Services Joint Undertaking
SoC	System on a chip
TSMC	Taiwan Semiconductor Manufacturing Company

1. Introduction

The ICT industry has become one of the most essential industries in the world. In the day-to-day life of almost everybody, no matter where they live, they have at least an ICT product near them. Whether it is a smartphone or a laptop, an application to work or play, or sending a message to someone anywhere in the world through SMS, online messaging, or social network, it comes from the ICT industry and its companies. Even in other industries, their products have become the center of innovation and allow them to manufacture faster, do better or safer products, or find new solutions to problems. Nevertheless, this is only the side that is easily visible to everyone, but the technology in this industry goes even further and asked several years of development to come to more advanced products that improve the previous generation. This process is almost without end, and therefore, after each improvement, the newest technology opens many more possibilities, sometimes being totally disruptive for the world as known at that time. In the views of this importance, it is no surprise that all the stakeholders in the ICT industry want to lead it and, if possible, dominate it.

Within the framework of this master thesis, the objective will be to give a non-technical description and analysis of the different actions that the companies and the government undertake in this industry and the domination challenge in which the companies but also all the stakeholders are engaged. Given the importance of the ICT industry and the number of different categories included in it, the focus will be on two of the most important, disruptive, and always on the move segments, namely semiconductors and mobile networks (5G and 6G). These two segments have recently been under the spotlight for many different reasons. Although they are both technologies known for many years, they are still evolving rapidly and impacting society. It will also be centered on three of the biggest technologically regions in the world, namely Europe, the USA, and China, and from the most prominent companies coming from there and elsewhere if applicable. The description and analysis of these points will try to see the causes

and consequences that led to today's situation and the consequences of the future with the decisions and initiatives taken today by these tech giants.

The master thesis will be divided into four main parts. The first one will address the ICT industry as a whole. Different points will be shown to understand better the situation of each region and their main features in this industry. The second part will discuss the semiconductor segment. Firstly, an explanation of what a semiconductor is will be given, followed by an industry overview about the most prominent regions and companies. After that, some justifications will be provided to explain the reason for the position of Europe and the initiatives undertaken to change it. To conclude this part, an analysis of these initiatives will be done with the positive and negatives points and some other initiatives that could have been done. The third section will talk about the mobile network, and more precisely, the 5G and 6. As for the previous part, an explanation of what it is and an industry overview will be given, including the position of the most significant region and companies. Then, the situation of Europe and the different initiatives put in place will also be analyzed as for the semiconductors. The final part will be the conclusion that will retake essential information from the previous sections to provide further analysis of the situation. This means the strength and weaknesses of each region, the crucial points for their future in this industry, and eventually their possible position in 2030 from the semiconductor, 5G and 6G, and the whole ICT industry perspective.

2. ICT industry

2.1. What is ICT?

A definition of ICT is:

“Information and Communication Technologies (ICTs) is a broader term for Information Technology (IT), which refers to all communication technologies, including the internet, wireless networks, cell phones, computers, software, middleware, video-conferencing, social networking, and other media applications and services enabling users to access, retrieve, store, transmit, and manipulate information in a digital form.” (AIMS n.d., para. 1).

There are two big categories in the industry: Traditional ICT technologies and New ICT technologies.

2.1.1. Traditional ICT technologies

In this category, there are four segments, namely Hardware, Software, Service, and Telecom.

- **Hardware:**

“Hardware (H/W), in the context of technology, refers to the physical elements that make up a computer or electronic system and everything else involved that is physically tangible. This includes the monitor, hard drive, memory and the CPU. Hardware works hand-in-hand with firmware and software to make a computer function.” (Techopedia 2020b, para. 1).

- **Software:**

“Software is often used to describe all the functional aspects of a computer that do not refer to its physical components (hardware). Scripts, applications, programs and a set of instructions are all terms often used to describe software.” (Techopedia 2020a, para. 3).

- Service:

“Technology services are professional services designed to facilitate the use of technology by enterprises and end users. Technology services provide specialized technology-oriented solutions by combining the processes and functions of software, hardware, networks, telecommunications and electronics.” (Techopedia n.d., para. 1).

- Telecom:

“Telecommunications refers to the exchange of information by electronic and electrical means over a significant distance. A complete telecommunication arrangement is made up of two or more stations equipped with transmitter and receiver devices. A single co-arrangement of transmitters and receivers, called a transceiver, may also be used in many telecommunication stations.” (Techopedia 2017).

2.1.2. New ICT technologies

In this part, 3D printing, AV/VR, Artificial Intelligence, Internet of Things, and Robotics can be mentioned among the new ICT technologies.

- 3D printing:

“Three-dimensional (3D) printing is an additive manufacturing process that creates a physical object from a digital design. The process works by laying down thin layers of material in the form of liquid or powdered plastic, metal or cement, and then fusing the layers together.”

(Hayes 2020, para. 1).

Some industries, such as aircraft manufacturers, medical sciences, or construction, already use this technology (Hayes 2020). However, the technology is currently too slow to allow mass production. Still, the development continues, and when it will be advanced enough, it can change the functioning of many different industries.

- AR/VR:

The AR's definition is:

“AR overlays digital information on real-world elements. Pokémon GO* is among the best-known examples. Augmented reality keeps the real world central but enhances it with other digital details, layering new strata of perception, and supplementing your reality or environment.” (Intel n.d., para. 9).

The VR can be defined as follows:

“VR is the most widely known of these technologies. It is fully immersive, which tricks your senses into thinking you're in a different environment or world apart from the real world. Using a head-mounted display (HMD) or headset, you'll experience a computer-generated world of imagery and sounds in which you can manipulate objects and move around using haptic controllers while tethered to a console or PC.” (Intel n.d., para. 8).

Several industries such as healthcare, virtual travel, or professional sports use VR (Intel n.d.).

- AI:

“Artificial intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to think like humans and mimic their actions. The term may also be applied to any machine that exhibits traits associated with a human mind such as learning and problem-solving” (Frankenfield and Scott 2021, para. 1).

Within this technology, there are two categories weak and strong AI. Weak AI is systems designed for only one task, such as video games or personal assistants, while strong AI-defined systems can realize human-like tasks (Frankenfield and Scott 2021).

Numerous industries will use AI, like online shopping and advertising, smart homes, cities, infrastructure, cybersecurity, or food and farming (European Parliament 2020).

- IoT:

“The Internet of Things (IoT) describes the network of physical objects—“things”—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. These devices range from ordinary household objects to sophisticated industrial tools” (Oracle n.d., para. 1).

Among the different industries that will benefit from IoT, there are notably Manufacturing, Transportation and Logistics, or even retail (Oracle n.d.). In addition, it could help to improve worker safety.

- Robotics:

“Robotics is the industry related to the engineering, construction and operation of robots – a broad and diverse field related to many commercial industries and consumer uses. The field of robotics generally involves looking at how any physical constructed technology system can perform a task or play a role in any interface or new technology” (Techopedia n.d., para. 1).

Robotics will also impact different industries, including manufacturing, search and rescue, and environment and agriculture (European Commission n.d.).

2.2. ICT spending

2.2.1. Whole industry

Between 2006 and 2019, global spending had been increasing through the years (See appendix 1 & 2) (IDC n.d.; n.d.). However, in 2009, the year of the financial crisis, the spending remained flat compared to the previous year.

The whole industry is not on the same foot, and there are two levels of increase. On the one hand, the traditional ICT technologies account for the most significant amount of the spending. Still, they do not grow at a breakneck speed anymore because they are becoming a mature sector

(IDC n.d.). On the other hand, the new technologies grow a lot more and will give a second blow to the industry's growth.

In 2019, the global spending was \$4,912,715 million, with the traditional technologies accounting for about 84% (\$4,146,194 million), the rest being for New technologies (\$766,521 million) (IDC n.d.). Telecom was the biggest segment, followed by Hardware and Service to complete the podium. The forecasted spending in 2020 was to remain about the same (\$4,896,792 million) due to the COVID-19 pandemic, with a decline in Traditional technologies (\$4,005,032 million) but an increase in the new technologies (\$891,760 million). In 2021, growth was already expected to resume. For the next decade, the growth should be at more than 2x GDP thanks to new technologies taking more and more importance in terms of spending, while traditional technologies should roughly follow the GDP growth (IDC n.d.).

2.2.2. Traditional ICT technologies

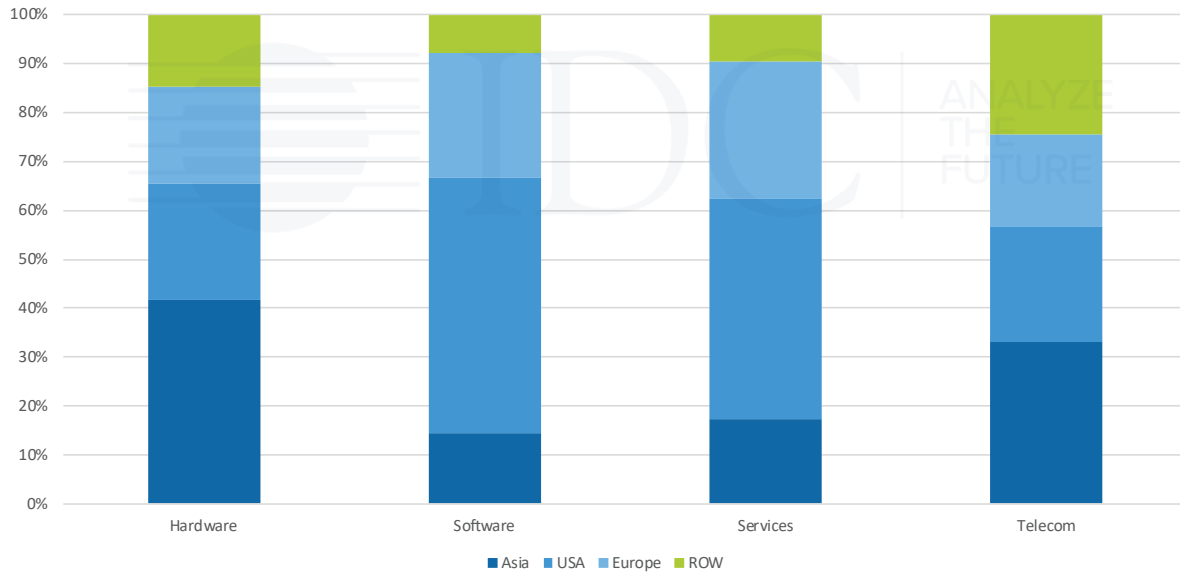
In 2017, each region had a different focus on the traditional ICT technologies, which, on the whole, accounted for \$3,857,728 million.

The USA was more focused on Software and Services, where they were the prominent leader. The development and growth of the cloud drove the spending on software solutions and services that were needed for its deployment (IDC n.d.). It also stimulated expenditures on hardware for the server and storage. The USA was also the region that spent the most, considering the whole traditional ICT technologies industry, with \$1,257,502 million against \$1,117,752 million for Asia.

Asia was essentially the leader in the Hardware segment due to smartphones, the primary sector in volume and revenues (IDC n.d.). Telecom was also a significant segment of spending for Asian firms, notably with the growth of mobile equipment, even if they were less dominant

there. This segment was also crucial in emerging markets, but the reason was the evolution of smartphones usage.

Exhibit 1: Regional share of traditional ICT markets 2017 (%)

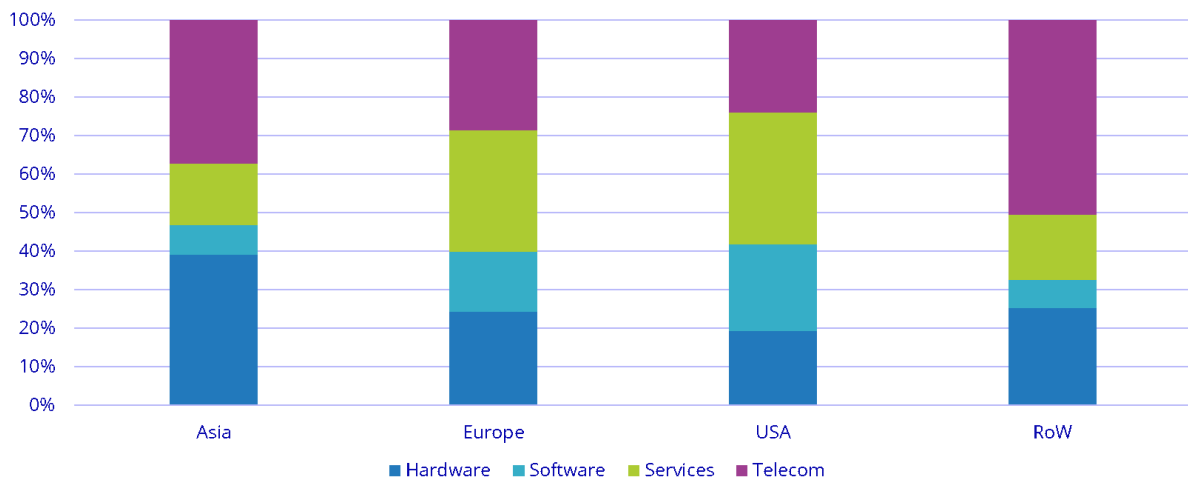


Source: IDC, n.d.-c

Europe was behind at least one of the two central regions, the US and Asia, everywhere. They were third in Hardware, second in Software and Services, and last in Telecom. Its spending was, like the USA, essentially driven by the cloud (IDC n.d.). The region accounted only for 22.4% of that year's total spending, far behind the USA (32.6%) and Asia (29%).

Looking now at the share of traditional ICT technologies by region in 2019, a similar picture can be seen.

The Service segment was the large dominant sector in the USA, followed by Software and Telecom, accounting for about the same proportion. Hardware and Telecom were the most critical segment in Asia, accounting for slightly less than 80% of the total spending. Telecom accounted for about half of the spending in the rest of the world, while hardware, the second-biggest segment, only about 25%. Finally, Europe was mainly spending on Software and Telecom followed by Hardware and finally Software.

Exhibit 2: Regional share of traditional ICT markets 2019 (%)

Source: IDC, n.d.-b

The Service segment was the large dominant sector in the USA, followed by Software and Telecom, accounting for about the same proportion. Hardware and Telecom were the most critical segment in Asia, accounting for slightly less than 80% of the total spending. Telecom accounted for about half of the spending in the rest of the world, while hardware, the second-biggest segment, only about 25%. Finally, Europe was mainly spending on Software and Telecom followed by Hardware and finally Software.

Comparing the two graphs, several elements can be taken from it¹. Looking at the second one, Hardware and Telecom had greater importance in Europe than in the USA in terms of percentage, while on the other chart this was the opposite. This observation confirms that Europe was still spending a lot less than the USA in these segments and, therefore, in the whole industry. The Telecom segment was the most important in the traditional technologies, but it was also the only segment that decreased between 2017 and 2019. Software was the smallest

¹ Since the two graphs do not date from the same year (2017 and 2019), the investments made may have changed. The hypothesis is that, given the importance of the investments required in this sector, whether in terms of R&D or CAPEX, the shares of the various regions have changed very little.

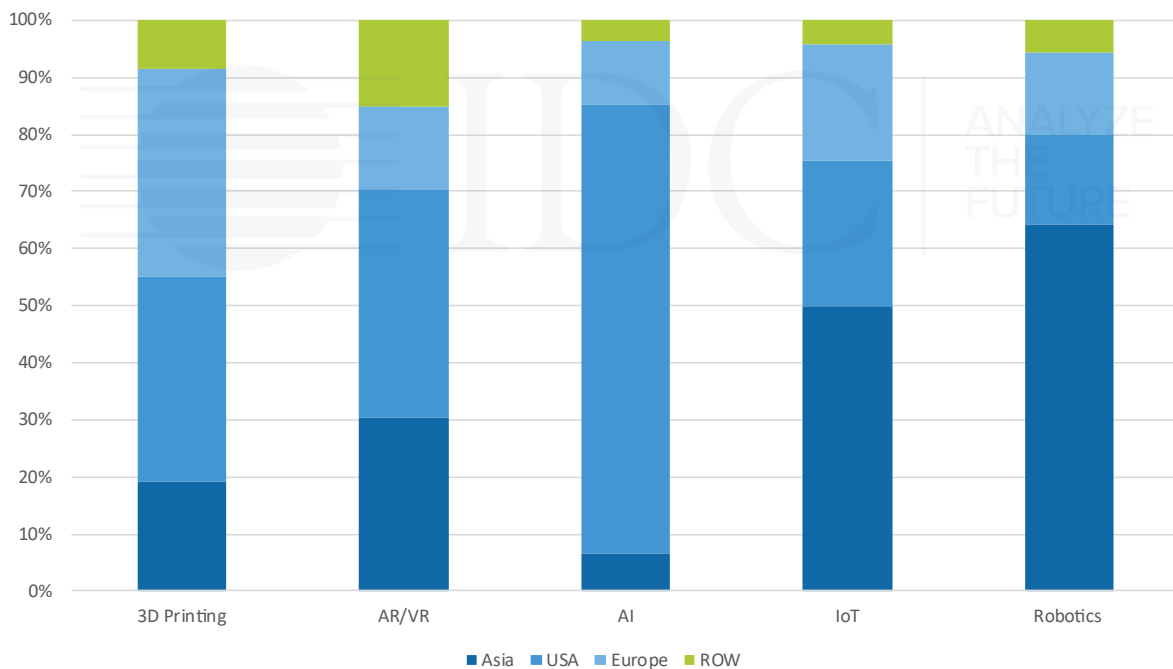
one compared to the others, and this explains why the US can have such significant domination in the Software segment while spending not a considerable amount on it.

Finally, although Asia has a more significant share in the Hardware segment than in Telecom, the amount spend is about the same due to the importance of the Telecom segment.

2.2.3. New ICT technologies

As for the Tradition ICT technologies, there was once again a different focus for each region.

Exhibit 3: Regional share of new technology markets 2017 (%)



Source: IDC, n.d.-c

USA was the most dominant region in AI, with about 80% of the spending share, and had the lead in AV/AR (40%) and 3D printing (36% on par with Europe) (IDC n.d.). Thanks to their leading position in the cloud and the software, their technology-advanced infrastructure and supply chain domestically allowed them to take this advanced in AI and AV/AR. In all other segments, they are second.

Asia had the lead in IoT (50%) and Robotics (64%), the two segments with the most spending (See Appendix 3). This position was partly due to the manufacturing companies, mainly in China, that rapidly deployed these new technologies (IDC n.d.). It also demonstrated that Asian governments and companies aim to use new technologies to solve economic and demographic issues. IDC (n.d.) gives the example of robotics as a response to the labor shortage in Japan. In Europe, although they were not dominant in anyone of these segments (they are on par with the USA on 3D printing), they were still significantly investing in several segments such as 3D printing, AR/VR, and robotics (IDC n.d.). In terms of new technologies adoption, they are also behind the USA, which is the region with the most similar features.

2.3. ICT R&D investment

According to Grassano et al. (2020)², in 2019, the ICT producers industry (Hardware & Telecom (Telecommunications Equipment)) represented the most prominent sector with 23% of the total R&D investments across the world with €208.5 billion. The ICT services (Software, Services & Telecom (Mobile telecommunication)) was third with 16.9% and €152.8 billion the same year.

The amount of R&D investment was in line with the ICT spending that was shown before. Europe was not investing a lot in the ICT industries, compared to their competitors, the USA and China, looking at the share of the total investment. The USA was mainly investing in the ICT services industry, with about 30% of its R&D investment. In contrast, the ICT producers were the most significant industry for China, for about the same share. However, in terms of absolute amount, the picture is different. Due to the high amount the USA was spending across

² The 2020 EU Industrial R&D Investment Scoreboard. Analysis of the 2500 that invested the more in R&D in 2019.

all industries (€347.7 billion), compared to Europe (€188.9 billion) and Asia (118.8 billion), the country was the one investing the most in both ICT industries.

The picture is the same in terms of companies by region. The ranking was dominated by the USA in ICT services representing 50.3% of all the ICT services companies in the sample, with 162 companies. However, with 26.5% of the share and 122 companies in the top, they were not first in the ICT producers sector. That was China, with three more companies, 125, in that segment but only 70 companies in ICT services, representing respectively therefore 27.1% and 21.7%. Concerning Europe, the numbers were lower. They only had 49 ICT producers and 32 ICT services companies, accounting respectively for 10.6% and 9.9% share.

Overall USA had 284 ICT companies among the 2500 companies that invested the most in R&D against 215 Chinese companies and only 81 European companies.

R&D per firm reflected these significant disparities. The average for the ICT producers companies was € \$452.3. US and European companies were above this amount, with €699.2 million and €549 million respectively, while Chinese companies only spent €285.6 million. The observation is almost the same for the ICT services. The industry's average was €474.7 million, but this time only the US companies were above this number, with €647.5 million. Europe was close but below with €412.5 million while China was again below only €295 million.

2.4. ICT Revenue by region

In terms of revenue (See Appendix 4), the USA led the march with 31.7% of the revenue for 2020. This share has constantly been increasing since 2013. In 2021, this is expected to rise again, to arrive at 34.7%.

China was also continually growing between 2013 and 2019. However, in 2020, there was a slight decrease compared to 2019 (-0.7 point of percentage) forecasted to continue in 2021 (-1 point of percentage) to come at 11.3%.

Exhibit 4: R&D spending on the ICT producers and ICT services industry

	EU [EU28] ³	US	Japan	China	RoW	Total
<i>R&D investment compared to the total of their region (rank among the 8 industries)</i>	14.2% (3 rd)	24.5% (3 rd)	18.8% (2 nd) ⁴	30.0% (1 st)	/	23% (1 st)
<i>Distribution of in ICT producers companies by region</i>	49 (10.6%) [58 (12.6%)]	122 (26.5%)	55 (11.9%)	125 (27.1%)	110 (23.9%)	461 (100%)
<i>Distribution of R&D invested by ICT producers by region (in €bn)</i>	26.9 (12.9%) [27.8 (13.3%)]	85.3 (26.5%)	21.6 (11.9%)	35.7 (17.1%)	39.1 (18.7%)	208.5 (100%)
<i>Number of companies that entered (exited) this sample of 2500 companies in the ICT producers industry</i>	1 (3) [1 (6)]	4 (14)	1 (6)	22 (12)	4 (11)	32 (46)
<i>R&D investment compared to the total of their region (rank among the 8 industries)</i>	7.0% (5 th)	30.2% (1 st)	4.8% (7 th) ⁴	17.5% (3 rd)	/	16.9% (3 rd)
<i>Distribution of in ICT services companies by region</i>	32 (9.9%) [48 (14.9%)]	162 (50.3%)	8 (2.5%)	70 (21.7%)	50 (15.5%)	322 (100%)
<i>Distribution of R&D invested by ICT services by region (in €bn)</i>	13.2 (8.7%) [16.3 (10.7%)]	104.9 (68.8%)	5.5 (3.6%)	20.7 (13.6%)	8.4 (5.5%)	152.8 (100%)
<i>Number of companies that entered (exited) this sample of 2500 companies in the ICT services industry</i>	1 (1) [4 (4)]	12 (14)	0 (0)	6 (8)	5 (4)	24 (27)

Source: Grassano et al., 2020

³ The EU28 figures consider the exit of the UK. The figures outside the brackets are for the EU27. In addition, the EU28 figures are not included in the total count.⁴ Only 7 industries, as there is no R&D investment in the Aerospace & Defence industry.

For Europe, the situation was even worse. While there were close to the United States in 2013 (5 points of percentage less), their share decreased since then to 15%⁵ in 2021. However, in 2016 and 2020, the situation was overturned, increasing compared to the previous year.

2.5. Main takeaways

- The **USA was the biggest spender** in **Software and Services**, in the traditional ICT technologies, and **3D printing, AR/VR, and AI**, in the new ICT technologies.
- **Asia spent the most** in **Hardware and Telecom**, for the traditional, and **IoT and Robotics**, for the new.
- **Europe** was **far behind** the two other regions in **all the segments** of the traditional and new technologies, except in **Robotics, where were tied with the USA**.
- In terms of **R&D spending**, **the USA is the large leader in the ICT industry**.
- **Asia is mainly investing in CAPEX**.
- In terms of **revenue**, **the USA** is the region that **grabs the most of it** with a **constant increase** over the years. **China** is **third** but is **close to second place**. This **second place** belongs to **Europe**, but their **revenue share** has **decreased almost every year since 2013**.

⁵ The exit of the United Kingdom from the European Union has played an important role in this huge decrease.

3. Semiconductors

3.1. What is a semiconductor?

Semiconductors are an essential component of the present technology. A definition of this technology is:

“A semiconductor is a material product usually comprised of silicon, which conducts electricity more than an insulator, such as glass, but less than a pure conductor, such as copper or aluminum. [...] Also known as semis, or chips, semiconductors can be found in thousands of products such as computers, smartphones, appliances, gaming hardware, and medical equipment.” (Segal 2020, para. 1)

There are more than 30 products categories according to the industry taxonomies. (Varas et al. 2021). However, for more clarity, the categorization from Varas et al. (2021) will be used: Logic, Memory, and DAO. Logic is semiconductors that are the building blocks or the “brain” of computing. This includes microprocessors, general purpose logic products, microcontrollers, and connectivity products. Memory is semiconductors that store information needed for computation. The two most common types are DRAM and NAND. DAO is semiconductors that handles information (transmitting, receiving, and transforming). The products are discrete, analog, and others (including optoelectronics and sensors).

3.2. Industry overview

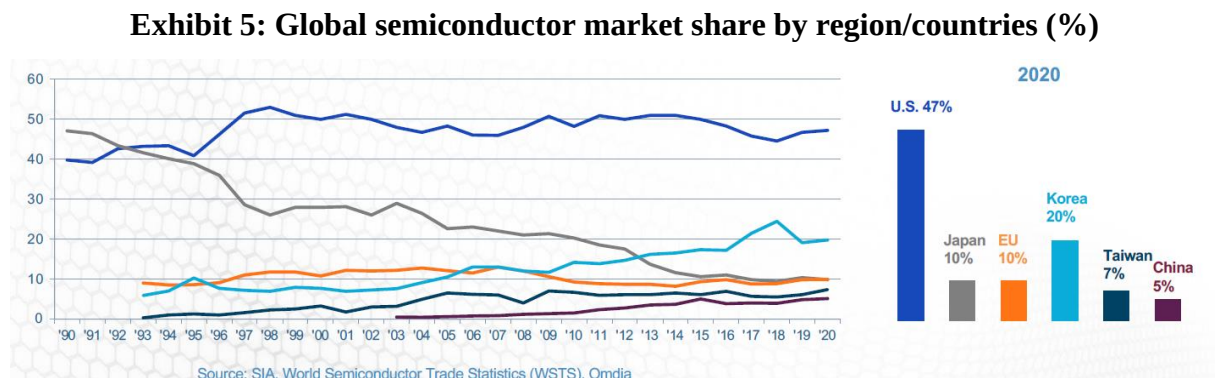
In this section, an overview of the industry will be given. A focus will be made on the market share of the different countries and on the companies' situation while explaining the value chain. The purpose is to have a clear vision of the different actors and better understand the position and initiatives presented in the following sections.

3.2.1. Market share

According to the SIA (2021a), the US industry was the most prominent region globally by far. With 47% of market share in 2020, they had 27 points of percentage more than their closer follower, namely South Korea. All the other regions had 10% or less. It is the case for Europe and Japan with precisely 10% and Taiwan and China with 7% and 5%, respectively. Since the early 1990s, when they took the lead back from Japan, the US holds and has consolidated its advance around 50% of market share.

On the contrary, Japan has plunged in 30 years. They were coming from a little less than 50% in 1990 to 10% in 2020. Concerning the other Asian countries (i.e., South Korea, Taiwan & China), they have experienced a slight increase over the years.

Europe, for its part, has been relatively constant since the 1990s, always around 10% of the market share.



Source: Semiconductor Industry Association, 2021a

The domination of US firms is also visible when looking at the diverse market separately (See Appendix 5). The Asia Pacific/All other markets and the Chinese market represented half of the market. This position is advantageous because these were the two biggest markets in the world (\$271 billion combined against \$169.4 billion for the rest). The domination was also marked in Europe with a little less than 50% of the market share. Nevertheless, in the Americas and Japan, they were still in an excellent position, but the domination was not as marked as in

the other. They had around 40% of the market share (41.1% for the Americas and 39.5% for Japan).

Europe, which underperformed compared to the USA on market share and the Asia Pacific on sales, are aimed to change things to become a significant player in this field. They want to double their market share to arrive at 20% and produce future 2nm chips. To come to their end, they decided to launch several initiatives that will be discussed at the end of the chapter.

China also wants to increase its presence in the sector. In 2015, when the *Made in China 2025* industrial pollical had been set out, the objective was 70% of domestic demand by 2025 (Ting-Fang and Li 2021). According to IC Insights research (2021), in 2020, the production made in China accounted for 15.9% of the domestic market, and the production made by China-based companies was only 5.9%.

Nevertheless, in 2020, Asia Pacific was the largest regional semiconductor market in terms of sales to electronic equipment makers only with 61.5%, far ahead of the second, Americas representing only 21.7% (Semiconductor Industry Association 2021a). Europe and Japan were closing the march with 8.5% and 8.3%, respectively.

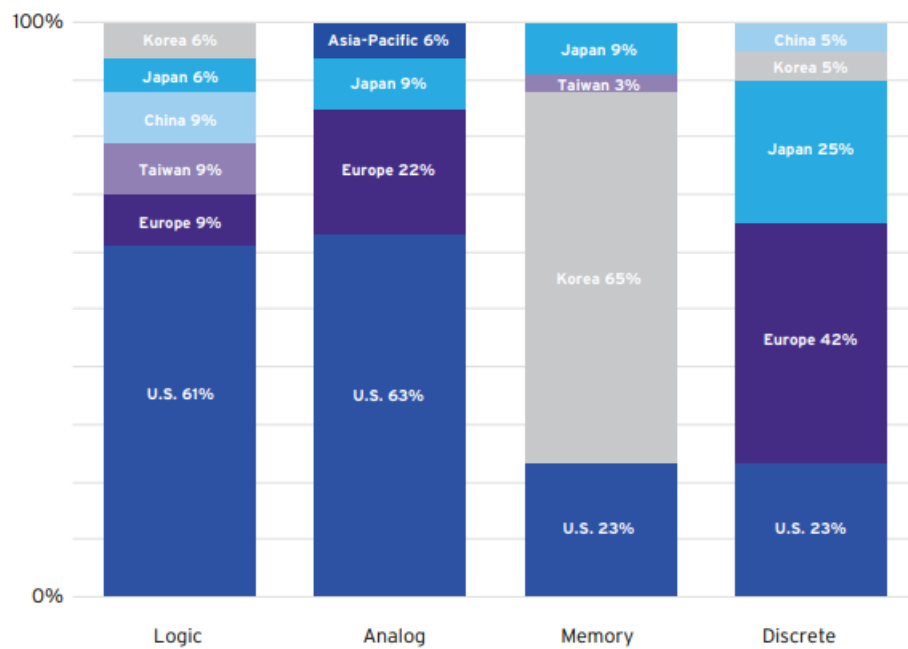
Exhibit 6: Regional semiconductor market (\$ billion)



Source: Semiconductor Industry Association, 2021a

The lead of Asia Pacific started to grow from 2001, where they first took the lead. Since then, it has almost been constant growth, except in 2019, where they fall to come at \$258 billion of sales. However, this decrease does not mean that they lose ground to other regions. The sales of semiconductors decreased globally by 12% in 2019, and all the different regions experienced a decline in their sales (Semiconductor Industry Association 2020b). Nevertheless, the following year, the situation was already better, with an increase of 6.8% of the global sales (Semiconductor Industry Association 2021b). On the one hand, Asia Pacific increased by 5.3%, Americas 19.8%, and Japan 1%. Europe, on the other hand, decreased by 6%. This better restart of America is seen in the numbers because they were catching up with market share. Comparing SIA figures for market share in 2019 and 2020 (2020a; 2021a), Americas gained 2.6 points while the Asia Pacific lost one percentage point. The same trend is visible between Europe and Japan, at a lower scale, while they respectively lost 1.2 and gained 0.4 points of percentage. The large lead of the Asia Pacific region is mainly due to China, representing 34.4% of the global sales, and therefore 56% of the Asia Pacific region (Semiconductor Industry Association 2021a). China was the largest country market in the world. Nevertheless, they also experienced a decrease in 2019 (-8.7%) (Semiconductor Industry Association 2020b) and a loss of market share (-0.6 point of percentage) despite an increase in 2020 (5%) (Semiconductor Industry Association 2021b).

One of the reasons the US industry is the biggest, but the Asian Pacific market is the leader in sales is because US firms are investing capacity in other countries (See Appendix 6) (Semiconductor Industry Association 2021a). This is notably due to incentives offered in these countries, leading to a fall in US capacity. These explanations are going to more explain in the second part of this chapter.

Exhibit 7: U.S. semiconductor industry market share (by subproduct)

Source: Semiconductor Industry Association, n.d.

Concerning the market share by product type, strong dominations are observable again. The US is dominant in Logic and Analog (part of the DAO category). These good figures can be inputted to companies like Intel or Qualcomm for the Logic category and Broadcom or Texas Instrument for the Analog (Reiff 2020). For the Memory category, South Korea, thanks to these two companies, Samsung Electronics and SK Hynix, that are the two global leading companies in this category (Lee and Yang 2021). Europe is only dominant on the Discrete and significantly present on the Analog (part of the DAO category). This is explainable by the fact that the three most prominent European semiconductor companies are mainly present in this segment.

3.2.2. Value chain

The value chain defined by Varas et al. (2021) will be used. They have broken it down into seven activities.

1. *Pre-competitive research*: As the name indicates, this concerns research to find the materials and chemical processes that will lead the next generations of semiconductors (Varas et al. 2021). This activity is different from R&D research, but they are both complementary. The government plays an important role there. The SIA & Nathan Associates (2020b) research found that funding allocated to semiconductor R&D from the federal government has a positive impact on economic growth and global technological leadership. They also discovered that the government financed eight semiconductor technology breakthroughs through a research program (Semiconductor Industry Association and Nathan Associates 2020a).

2. *Chip design*: This activity concerns the development of semiconductors (Varas et al. 2021). The R&D is the highest here because more complex chips can take several years to be developed, and the investment allocated is therefore considerable. However, this is also where the value-added is the highest.

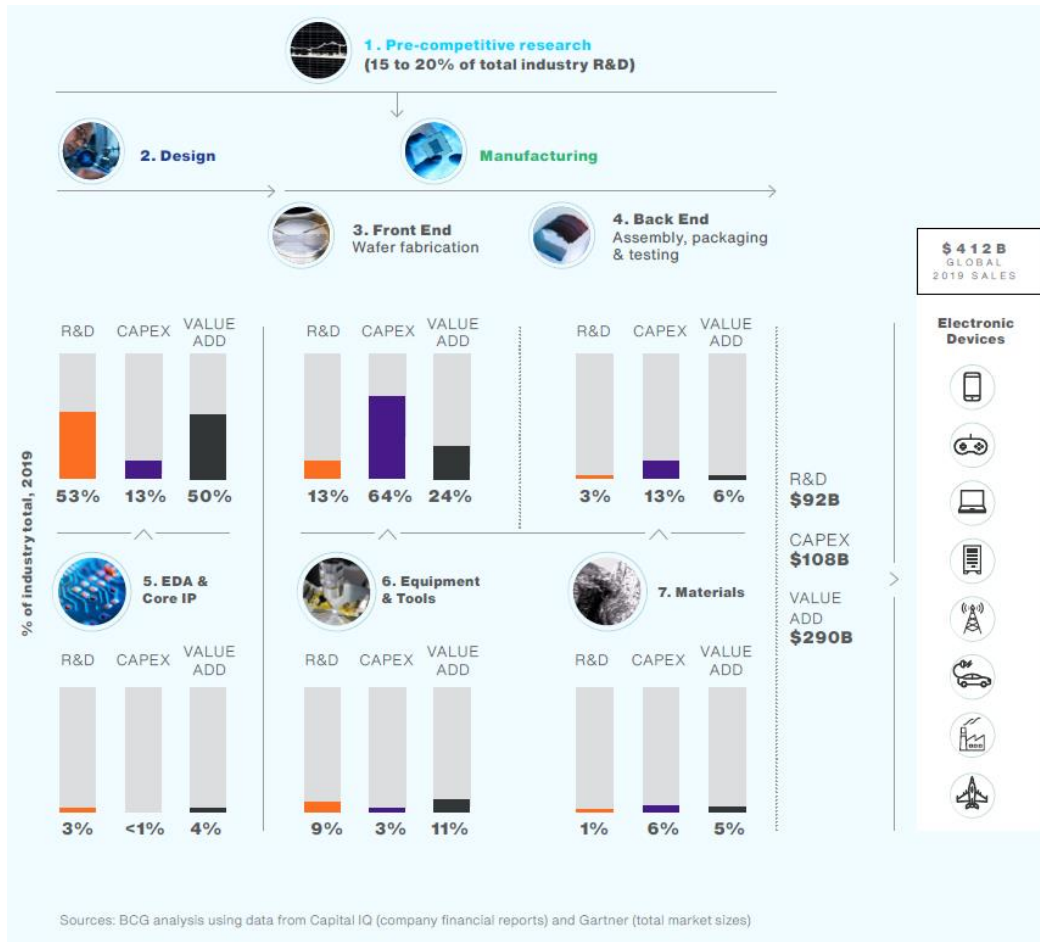
3. *Wafer fabrication (front end manufacturing)*: This is the first step of semiconductors manufacturing, consisting of printing the circuits from the chip design into a silicon wafer, each wafer containing several chips (Varas et al. 2021). The process is long, counting between 400 and 1,400 steps overall. The average time is about 12 weeks, increasing to 14 to 20 weeks for more advanced operations. The CAPEX is very high because there is a need for highly specialized inputs and equipment. The facilities where this process is done are usually called *fabs*.

4. *Assembly, packaging, and testing (back end manufacturing)*: This step is the conversion of silicon wafers into finished chips ready for use (Varas et al. 2021).

- Assembly: Separating each chip contained in the silicon wafer.
- Packaging: Packaging them into protective frames and enclosing them in resin shells.
- Testing: Testing chips before shipping them to electronic companies.

Here, specialized equipment is also essential (second highest Capex in the industry), although it is relatively less than the previous activity.

Exhibit 8: The semiconductor value chain includes seven differentiated activities



Source: Varas et al., 2021

5. Electronic design automation (EDA) & Core IP:

- EDA: This is part of the design activity (Varas et al. 2021). The software and services provided by EDA companies serve as support in the design of semiconductors.
- Core IP (also called *IP blocks* or *IPs*): It consists of reusable components designs that are licensed to design companies (Varas et al. 2021). This includes a defined interface and functionality that are integrated into the chip layouts.

6. Equipment & tools: There are more than 50 types of equipment used during the manufacturing process (Varas et al. 2021). Two equipment that has a critical role are:

- Lithography tools, that are needed to manufacture 7nm chips and below and are therefore very expensive. Having this equipment means that the fab is technologically advanced.
- Process control tools, that are used to prevent any defects in the process. Any issue could ruin all work undertaken for several weeks.

7. *Materials*: The production of semiconductors requires many different materials, no less than 300 (Varas et al. 2021). The CAPEX is still relatively high in this sector, the production of numerous materials needs advanced technology.

3.2.3. The different companies in the sector

This industry has two types of business models: being present on all the different manufacturing stages (IDMs) or being specialized on only one (fabless, foundries, and OSATs). When looking at the leading companies in the market (excluding foundries and OSATs), six companies are IDMs, and therefore 4 have the fabless business model (see Appendix 7). Among this top 10, the four leading companies are IDMs. From a geographical point of view, despite the American domination of this industry, only 1 US company is in the top 3, while there are 6 US companies in the top 10. Intel is the leader with 15.6% market share ahead of Samsung (12.5%) and SK Hynix (5.6%).

3.2.3.1. IDMs

IDM companies are the ones that integrate all the parts of the process, i.e., design, manufacturing (front end and back end), and selling (Varas et al. 2021). However, that does not prevent them from outsourcing part of their production and assembly process to more specialized companies. These companies mainly focus on Memory and DAO chips (98% and

94% of the manufacturing capacity, respectively) and about 1/5th of the Logic chips capacity primarily thanks to Intel and Samsung Electronics, at a lower scale.

In this section, the leader is obviously Intel, which mainly manufactures microprocessors (CPUs and GPUs) and NAND (see appendix 8). The company is aimed to keep its leading position. That is why they announced on March 23, 2021; a new strategy called *IDM 2.0* (Intel Corporation 2021b). This new plan has for purpose “to drive sustained technology and product leadership” (Intel Corporation 2021b). This consists of three points:

1. Continuing to manufacture the majority of their products and start producing 7nm client CPU in Q2 2021.
2. Building and expanding current relationships with third-party foundries that manufacture part of the Intel products.
3. Becoming a significant provider of foundry capacity in the US and Europe and creating a new business unit, Intel Foundry Services

To set up this strategy, they also announced an investment of \$20 billion to build two new factories in Arizona (Intel Corporation 2021b; McGee 2021). This aligns with their desire to keep their production internally, while Intel was expected to outsource a more significant part of its production to other American and foreign companies (McGee 2021). In addition to that, the CEO of Intel, Pat Gelsinger, announced a collaboration with IBM to conduct research on next-generation technologies, namely logic, and packaging. Moreover, this alliance could represent a lot for Intel to come back to the first plan in manufacturing. IBM has announced in May 2021, having produced the world’s first 2nm transistor (Gwennap 2021). The final announcement of Intel is a new industry event series named Intel On (Intel Corporation 2021b).

Exhibit 9: Information on companies of semiconductors

<i>Name</i>	<i>Nationality</i>	<i>Revenue in 2020 (in billions)⁶</i>	<i>Type of company</i>	<i>Market Cap (Stock exchange)⁷</i>	<i>Number of employees</i>
<i>STMicroelectronics NV</i>	France/Italy	USD 10.219	IDM	EUR 33.251B (EN Paris)	46,016 (as of 2020)
<i>NXP Semiconductors</i>	The Netherlands	USD 8.612	IDM	USD 57.073B (Nasdaq)	~ 29,000 (as of 2020)
<i>Infineon</i>	Germany	EUR 8.567	IDM	EUR 44.976B (Xetra)	~ 46,700 (as of 2020)
<i>Intel</i>	USA	USD 77.867	IDM	USD 217.009B (Nasdaq)	~ 110,600 (as of 26/12/2020)
<i>Samsung Electronics</i>	South Korea	KRW 142,840.934 ⁸	IDM	KRW 444.152T (Korea SE)	Not provided
<i>Broadcom</i>	USA	USD 23.888	Fabless	USD 199.452B (Nasdaq)	~ 21,000 (as of 01/11/2020)
<i>Qualcomm</i>	USA	USD 23.531	Fabless	USD 167.666B (Nasdaq)	41,000 (as of 27/09/2020)
<i>AMD</i>	USA	USD 9.763	Fabless	USD 134.093B (Nasdaq)	~ 12,600 (as of 26/12/2020)
<i>Nvidia</i>	USA	USD 16.675	Fabless	USD 503.085B (Nasdaq)	18,975 (end of fiscal 2021)
<i>TSMC</i>	Taiwan	TWD 1,339.255	Foundries	TWD 15.066T (Taiwan)	57,823 (as of 28/02/2021)
<i>SMIC</i>	China	USD 3.907	Foundries	HKD 282.375B (Hong Kong)	17,354 (as of 31/12/2020)
<i>ASML Holding</i>	The Netherlands	EUR 13.978	SME	EUR 279.218B (EN Amsterdam)	28,073 (as of 31/12/2020)
<i>Arm</i>	UK	GDP 1.491	IP blocks	Not listed	6,732 (as of 31/03/2020)

Source: Annual report or financial statement of each company, Bloomberg, SIA & Politico

⁶ As some companies have other business areas, the numbers do not reflect their semiconductor's part, which can lead to very different discrepancies (unless specifically noted). When the conversion to USD was available in the report, it was transcribed in the table. Some companies' fiscal year ends may be different.

⁷ As of 13/08/2021.

⁸ Revenue concerns only its semiconductor business. Attention: in the revenues of the consolidated accounts, there is an intercompany elimination not considered here.

The second biggest semiconductors manufacturer and leader in the memory chip segment, Samsung Electronics, is also heavily investing. They first announced in April 2019 an investment of KRW 133 trillion (Lee and Yang 2021; Samsung Electronics Co., LTD 2021b). However, in May 2021, they increased this investment by KRW 38 trillion to arrive at KRW 171 trillion (\$151 billion) through 2030 in the System LSI and Foundry business. The purpose of this investment is also to become the world leader in the logic chip segment. They also started the construction of a new production line in order to produce 14nm DRAM and 5nm logic semiconductors. The construction should be finished for the second half of 2022. Through this investment, Samsung wants to be more competitive with TSMC and Qualcomm, respectively, the contract chip manufacturing and the mobile processing chips segment (Lee and Yang 2021). Concerning Europe, there are three companies in the top 20 (see Appendix 8). These are STMicroelectronics, NXP Semiconductors, and Infineon.

STMicroelectronics has planned an investment of between \$1.8 to \$2 billion in 2021 (Fouquet 2021). The objective is to add capacity in Singapore, France, and Italy to respond to the shortage of semiconductors. This is an increase compared to 2020 and the 2021 forecasted spending, which was respectively \$1.28 billion and \$1.47 billion. The company has also seen his name cited in a potential takeover of one of its concurrent, the Norwegian company, Nordic Semiconductor, in May 2021 (Reuters 2021c). However, the CFO of Nordic Semiconductor said that he had “no knowledge” of any interest from STMicroelectronics.

Infineon had, in 2018, invest \$1.9 billion (€1.6 billion) to construct a new chip plant in Austria (Knolle 2018). The construction began in early 2019, and the production was planned to start in early 2021. The company also announced the expansion of its production capacity in response to the shortage (Reuters 2021a), and with this new plant, the company should be able to meet the needs of its customers (Reuters 2021b). The opening of the new plant should finally be in late summer 2021 (Reuters 2021a)

3.2.3.2. Fabless

The fabless companies are specialized in design and commercialization while outsourcing the manufacturing, assembly, packaging, and testing parts to foundries and OSATs (Varas et al. 2020; 2021). While their partners have lower manufacturing costs, fabless companies can spend only on R&D for design.

Qualcomm and Broadcom are the two most prominent players in this category. They are ranked 5th and 6th (see Appendix 8). However, as Katharina Buchholz (2021) points out, they could have reached third place on the podium if their merger had not been aborted. In 2018, former President Donald Trump vetoed the deal for national security threats and fears that it would allow China to gain control of mobile communications because Broadcom was, at that time, headquartered in Singapore (Reuters Staff 2018). In addition, Qualcomm was essential in the eyes of the US because the company had emerged as one of Huawei's biggest competitors in the sector. Qualcomm already had an important position on the 5G market with a critical part of the patent in this industry. Furthermore, the company was also expected to provide 5G chipsets to many smartphone makers. If this deal had been finalized, it would have been the largest ever and would have been so crucial that in reaction, Intel had thought about diverse possible acquisitions, including Broadcom itself (Mattioli and Cimilluca 2018).

Concerning Huawei, and its subsidiary HiSilicon, through which it produces its chips for smartphones, the company first started working on a chip manufacturing plant in Shanghai potentially in collaboration with Shanghai IC R & R&D Center (Hille, Yang, and Liu 2020). The goal is to enable the company to supply themselves to cover the demand of their primary business, i.e., smartphone. This initiative is obviously in response to the US sanctions, although it is not the only reason. This project could help them survive in the long run, but it will start a long way. The production would begin with a technology that is about 15 years old, but they could make rapid advances and, according to their expectations, produce 28nm chips by the end

of 2021. However, according to a semiconductor industry executive interviewed by the Financial Times, “The planned new production line will not help with the smartphone business since chipsets needed for smartphones need to be produced at more advanced technology nodes,” (Hille, Yang, and Liu 2020, para. 9). “But if it succeeds, it can become a bridge to a sustainable future for their infrastructure business, in combination with the inventory they have built and which should last for two years or so.” (Hille, Yang, and Liu 2020, para. 10). In addition to this new factory, Huawei is investing in Chinese chip companies that can supply them with chips but not only (Hille 2020b). Through another subsidiary, Hubble Technology Investment, they acquired minority shares in three small Chinese semiconductor equipment companies in 2020: Skyverse, which makes test and inspection tools for semiconductor production; Ningbo Allsemi, which makes machines for etching wafers and removing photoresist layers, and finally Epiwold International, which makes inspection tools for silicon carbide.

Among this category, Intel has two fabless competitors in the CPUs and GPUs segment. For the CPUs, the competitor is AMD. This year, the company has closed the gap to 18 points of percentage down on all CPUs sales in Q3 2021 (See appendix 9). When separating the sell into two segments, Intel's advance is made on the laptop segment with 50.7 points of percentage up (see Appendix 10) while it is about 50/50 between the two in the desktop segment (see Appendix 11).

Concerning the GPUs, AMD is once again present, but also Nvidia⁹. Intel is a clear leader with about 51 points of percentage more than the follower, AMD (see Appendix 12). The second and third place is shared between AMD and Nvidia, both being close and overtaking the other one often enough.

⁹ They also have a major segment on SoCs. (Cerulus 2021)

3.2.3.3. Foundries

The foundries manufacture for the account of fabless companies but also some IDMs companies (Varas et al. 2021). Most foundries only manufacture for other firms, but some IDMs, such as Samsung Electronics (through Samsung Foundries), manufacture for them and third parties. These companies have a more significant market share more the technology is advanced. Considering the whole industry, foundries have 35% of the global manufacturing capacity (50% if the memory segment is excluded). In addition, only three companies can manufacture logic chips at 10nm or below, and two of them are foundries (TSMC and Samsung), Intel being the third company. These two foundries are also the only ones able to manufacture the most advanced node, namely 5nm chip.

The company that stands out as a colossus in the category and also in the industry is TSMC, the largest contract chipmaker in the world (Hille 2021). Like its two most significant competitors, namely Intel and Samsung, the company is investing heavily. To better respond to the growing demand for chips, especially in this period of shortage, the company announced, in early April, an investment of \$100 billion over three years to improve its production capacity (Jung-a and Olcott 2021; Olcott 2021). In addition, a new plant in Arizona is already under construction (Reuters 2021e), where the company has spent \$12 billion (Drozdiak 2021). This new fab will allow TSMC to better serve some of their customers, such as Apple, Qualcomm, and Nvidia, by being closer to them (Drozdiak 2021). Nevertheless, a change in their investment strategy has been seen. They first announced a \$25 billion to \$28 billion plan for 2021 to increase its lead (Reuters Staff 2021c; Wu 2021). The significant increase in the investment occurred a week after the announcement of a significant investment from one of its main rivals, Intel (see above).

SMIC, one of the largest foundries in the world and the largest producer of computer chips, has also been impacted by the US sanctions, being subject to export controls on shipments from

U.S. companies (Hille 2020a). However, this has not stopped them from also investing. The company plans to build a \$2.4 billion production plant that will produce 28nm and above chips from 2022 (Kharpal 2021; Bloomberg News 2021c).

3.2.3.4. OSATs

The OSATs companies insure the remaining services to fabless and IDMs companies, namely assembling, packaging, and test services (Varas et al. 2021). Among the companies present in this category there are the Taiwanese firm ASE Technology Holding, which ranked in the top 10 semiconductors companies by revenues in 2019, and the Chinese firm JCET Group, which is ranked 30 (see Appendix 8).

3.2.3.5. Other

In this category, there is first the SME, which is also a significant category because it is worth \$64 billion (see appendix 8). Among the major segments, in 5 of them, namely Deposition, Dry/wet etch and cleaning, Doping equipment, Process control, and Testers, there is a US domination (more than 50%) (Varas et al. 2021). The biggest US company is Applied Material, ranked in the top 10 of the biggest semiconductor company by revenue (see Appendix 8). Their product concerns the Deposition (Applied Materials n.d.), Material removal (Applied Materials n.d.), Doping equipment (Applied Materials n.d.), Analysis (Applied Materials n.d.), and Packaging (Applied Materials n.d.). However, in some other segments, the domination by a country is even more important, as in Photoresist processing Japan has more than 90%, and in EUV lithography sector Europe almost 100% (Varas et al. 2021). This good result for Europe is only due to ASML Holding. The company has been the leader in this market for the last two decades (Alper, Sterling, and Nellis 2020).

Concerning the EDA software, the market is once again dominated by US companies, this time for more than 85% (Varas et al. 2021). The three companies are Cadence Design Systems, Inc., Synopsys, Inc., and Mentor Graphics Corporation, a Siemens Business (Grand View Research 2021). The last company is a subsidiary of Siemens. Siemens announced in November 2016 the acquisition of Mentor (Siemens and Mentor Graphics 2016). The deal was finalized in 2017, and the newly acquired company was integrated into Siemens' product lifecycle management software business (Siemens 2017). The company is now called *Siemens EDA* (Cerulus 2021). Finally, for the core IP, the significant leader (see Appendix 8) is Arm, a UK-based company (Varas et al. 2021). In September 2020, Nvidia and SoftBank, the Arm owner, agreed on the sell the company for \$40 billion (Inagaki, Waters, and McGee 2020; Inagaki and Pickard 2020). However, the deal was under many political concerns. Peter Mandelson, former EU trade commissioner and former UK business minister, asked, in October 2020, the European Union to block this takeover for competition and geopolitical reasons (Larger 2020). Qualcomm, Google, and Microsoft have also raised concerns about the deal, saying that Nvidia could limit the supply and raised the price (Shead 2021b). However, Broadcom, Marvell, and MediaTek, other big companies indirectly concerned by the deal, have given their support to Nvidia. Antitrust regulators review the agreement worldwide, namely in the US, Europe, China, and the UK. Qualcomm has also already announced that they were ready to invest in Arm if antitrust regulators blocked the deal and that the company becomes listed on the stock market (Shead 2021a).

3.2.4. The shortage of semiconductors

The current shortage of semiconductors is another source of concern on the world stage. These small components become an indispensable element in many objects used daily and therefore in many industries. It is the automotive industry that has been mainly affected, car

manufacturers among the first worldwide (Volkswagen, Ford, Renault, PSA, etc.) have all announced a slowdown or even a stop of their production (Dèbes 2021a; Steinmann 2021a; 2021b). This, then, spread to other electronic industries; among them, Apple, which had to postpone the launch of the iPhone 12, or Sony, which has difficulties restocking its new console (Sweeney 2021). Moreover, this situation is expected to last in time; TSMC predicted that this shortage lasts until 2022 (Jung-a and Olcott 2021), while the CEO of Intel said in May this year that it could last several more years (Reuters 2021d). The different companies in the sector have already planned various investments to alleviate this situation, and the politicians have also proposed diverse solutions. Among them, Intel has planned in April 2021 to start producing chips for U.S. car plants within six to nine months (Reuters, Bose, and Nellis 2021a).

This shortage is due to a strong increase in demand due to several reasons. The Covid-19 crisis and the containment and teleworking measures taken led some factories to close down (Davies 2021). It was combined with an explosion of the demand for computer hardware, which had to put under pressure the different production lines of these chips until arriving at a moment where these could not follow the vast demands anymore (Touzani 2021).

However, there are also reasons related to the strategy of some companies during the pandemic, mainly car manufacturers, who, during the first containment, reduced their orders, anticipating a drop in car sales and, therefore, too many chips to stock (The editorial board 2021; Touzani 2021). But the situation turned around for them. The economic recovery and the increase were faster than expected (Nellis and Weber 2021). They placed orders again but found themselves at the end of the list due to their earlier reduction of orders and because other industries have more buying power. This is due to their importance compared to the automotive industry (\$37 billion in total purchases for all companies in the automotive industry) (Sweeney 2021). This explains why they were the first to be affected by this shortage.

Finally, geopolitics also played a role. The decision of the United States to ban exports to certain Chinese companies led them to build up stocks quickly, which was also imitated by some of their competitors (The editorial board 2021; Touzani 2021).

3.3. The lag of Europe

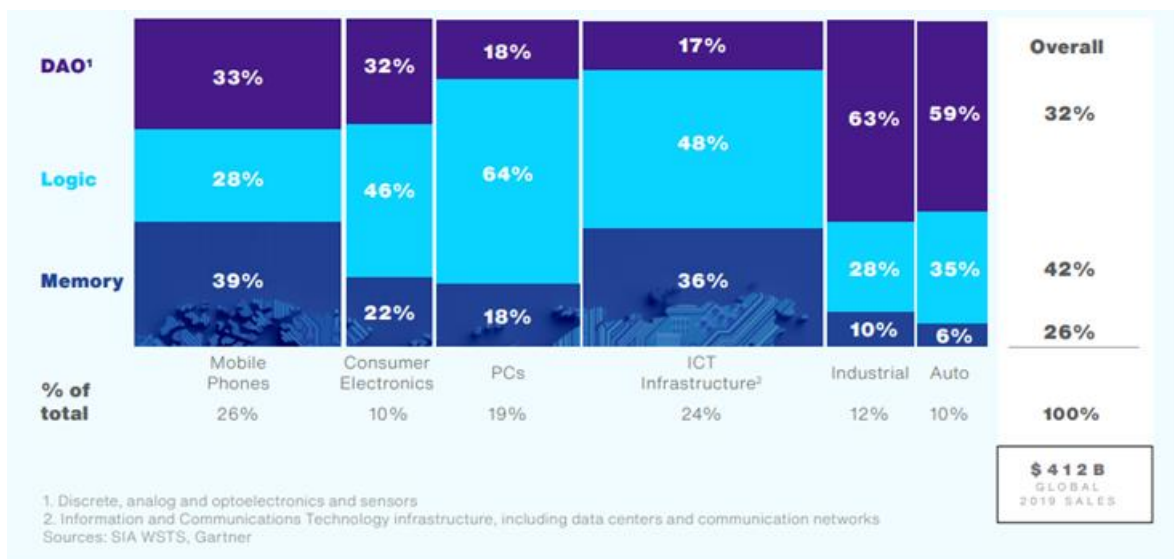
Here, the focus will be on the situation of Europe and European companies compared to China and the USA. With the different observations made, several questions arise. First, how did Europe get to this point and fail to either keep or gain market share over the years? Second, what are the different problems that this implies today? And finally, what can Europe do about it, and is it doing well to catch up?

3.3.1. The reasons for the lag of Europe

3.3.1.1. Bad strategic choices?

In 2019, in the semiconductor industry, the most important one was Logic (42%), followed by DAO (32%) and Memory (26%) (Varas et al. 2021).

Exhibit 10: Global semiconductor sales by application market, 2019 (%)



Source: Varas et al., 2021

As mentioned before, the European companies are mainly in the DAO category without being a very dominant player. Therefore, the painting on this point is nuanced. On the one hand, they are one of the most significant regions in the second-biggest category. On the other hand, they are still not important enough in that category, which explains the 10% of the market share of Europe. And this hypothesis can be confirmed, looking at the USA and South Korea. The US industry is the biggest globally, and they strongly dominate the Logic and Analog category. For South Korea, the Memory category is their main one, and although it is the smallest one, their intense domination allows them to be the second industry in Europe.

Therefore, why has this choice been made, and why is Europe not more dominant?

The answer is in the other industries in Europe. The five most considerable manufacturing activities in Europe¹⁰ in 2019 are Motor vehicles and other transport equipment; Food beverages and tobacco; Basic metals and fabricated metal products; Machinery and equipment n.e.c.; Rubber, plastic, and other non-metallic mineral (see Appendix 13). Two of these industries use semiconductors, namely Motor vehicles and other transport equipment, and Machinery and equipment. The primary type of semiconductors needed in this industry are DAO, and by far. However, they also represent two of the three smallest industries for semiconductors.

When comparing both industries with other regions, the picture is different. Starting with motor vehicles (see Appendix 14), overall Europe is 2nd but far behind Asia-Oceania and close with North America. Their results are mainly done on the passengers' cars, where they are again the 2nd region, thanks to companies such Volkswagen, Renault, PSA. However, they are behind North America (1st) and Asia-Oceania (2nd) for commercial vehicles with respectively more than 7.7 million and 6 million less.

¹⁰ EU-27

Concerning the manufacturing and equipment (see Appendix 15), Europe is once again far behind North America and China in terms of sales. The forecasted sales are even worst for Europe because they decrease. However, it is also the case of China, on a bigger scale, while North America approach and even exceed them. Therefore, the position of Europe is not easy. They are blocked in third place, too far away from China and the USA to hope to catch them up and but even with a decrease in their sales, and they are still in a good position with no countries close to them.

Another problem from this strategic choice is that Europe has now felt behind other regions in terms of advanced manufacturing. The DAO category does not require the most advanced technology as their nodes do not need to be very small compared to Logic and Memory (See Appendix 16). Therefore, about half of the European manufacture is semiconductors of $\geq 2\mu$ while only 7% are $< 20\text{nm}$ (see Appendix 17). To compare, the semiconductor manufacturing of $< 20\text{nm}$ represents 31% in North America, 56% in South Korea, 25% in Taiwan, and 23% in China, and 51% in Japan. This incapability to produce more advanced chips is a problem because the investment needed later will be even higher as it has not been done before, as it will be shown just later.

In conclusion, the problem was not the strategic choice. Indeed, the option to focus on the DAO category was rational for the European companies because of the manufacturing activities situation. The issue was more about the status of these activities. For the European semiconductor companies, this is difficult to become a major player (in the top 10) and for Europe to have a more significant market share with the current situation because the potential European buyers of semiconductors are not big enough compared to others of the world. In addition, the fact that Europe does not have a leading company in Mobile phones or Computers

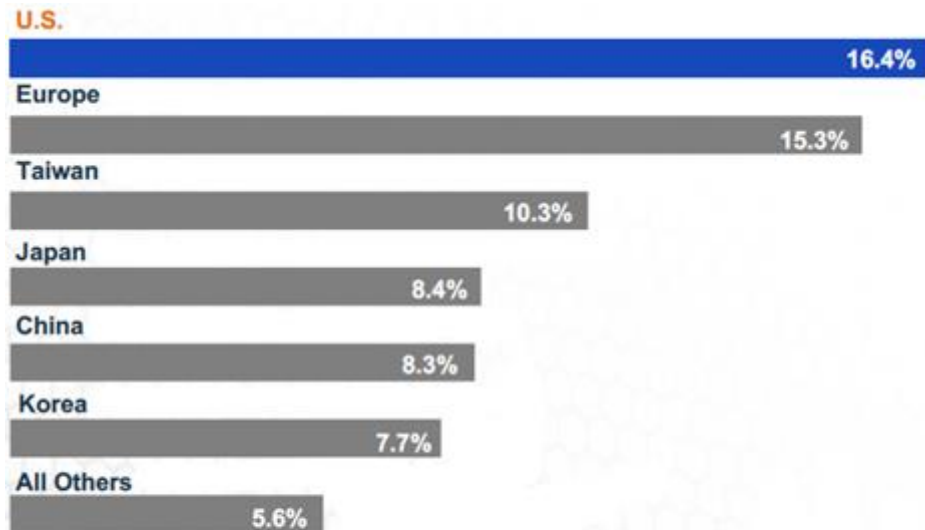
did not give the opportunity to semiconductor companies to invest in chips adapted to this category, which are the most advanced ones.

3.3.1.2. Lack of investment?

European semiconductor companies are responsible for only 4% of capital expenditures compared to 63% for the Asia-Pacific region (Alexander and Kirschstein 2021). This is reflected in the different investments that companies are currently making but also in the past, TSMC has invested \$100 billion over the last ten years (Martin and Samain 2021).

However, the investment is not only in the construction of new plants but also in R&D. Intel has invested \$15 billion in Europe, both in R&D and in manufacturing, since 1989 (Gelsinger 2021). In 2019, in terms of relative investment compared to sales, Europe ranks 2nd well ahead of the Asian nations and very close to the United States. However, it is essential to note that

Exhibit 11: R&D expenditures as a percent of sales



Source: The 2019 EU Industrial R&D Investment Scoreboard.

Source: Semiconductor Industry Association, 2020

European sales represent about 10% while those of the US are 47% in 2019. This shows a big difference in investment, in favor of the USA. Nevertheless, this observation can also be made for Asian countries. They have lower sales than Europe (except for Korea), and therefore, the fact that they are behind Europe shows fewer R&D expenses.

According to IC Insight figures (2020), Intel was the biggest spender in terms of R&D. The company spent \$13,556 million during the 2020 fiscal year, which accounts for 17.4% of its total net revenue (Intel Corporation 2021a). The second place comes to Samsung, followed by Broadcom, Qualcomm, Nvidia, TSMC, MediaTek, Micron, SK Hynix, and AMD (IC Insights 2020). The total amount of R&D spending from these ten companies accounted for 64% of the industry's total.

This ranking is mainly dominated by US companies (6), followed by South Korean (2) and Taiwanese (2). In addition, except for TSMC, there are only IDMs (4) and Fabless (5) companies in the ranking. This is explained by the fact that they are involved in the Design, which is the most R&D intensive activity of the value chain.

Although these figures allow us to understand the previous graph better, there is still a question about Europe. They should indeed be on the top of the R&D spender, but no European company is in the top 10. They are not far away from the 10th company. AMD spend \$1,983 million in R&D (20.3% of their total revenue) (Advanced Micro Devices, Inc. 2021), while NXP \$1,725 million (20%) (NXP Semiconductors 2021), STMicroelectronics \$1,272 million (12.4%) (STMicroelectronics N.V. 2021), and Infineon €1,113 million (13%) (Infineon Technologies AG 2020). In addition, several research companies at the forefront of R&D in the world are located in Europe, such as IMEC (The Interuniversity MicroElectronics Centre), which is located in Belgium, and CEA-Leti, in France (Varas et al. 2021). These two companies, in particular, allow Europe to be at the forefront of R&D. As Luc Van den hove, CEO of IMEC,

said: “Asia is the main producer, but Europe is far ahead in terms of research and development.” (Martin and Samain 2021, para. 2). Being at the forefront of technology is very important because once you fall behind, it is hard to catch up.

In conclusion, as already mentioned in the previous point, European companies did not invest more advanced technologies and, therefore, in the more expensive equipment required to manufacture it due to their strategic choice. This explains why they have such a low Capex. However, the spending in R&D is quite good in comparison to other regions, even if they are still far behind the US. Although the European semiconductor manufacturers are not the biggest spender globally, Europe can count on their research companies, such as IMEC and CEA-Leti.

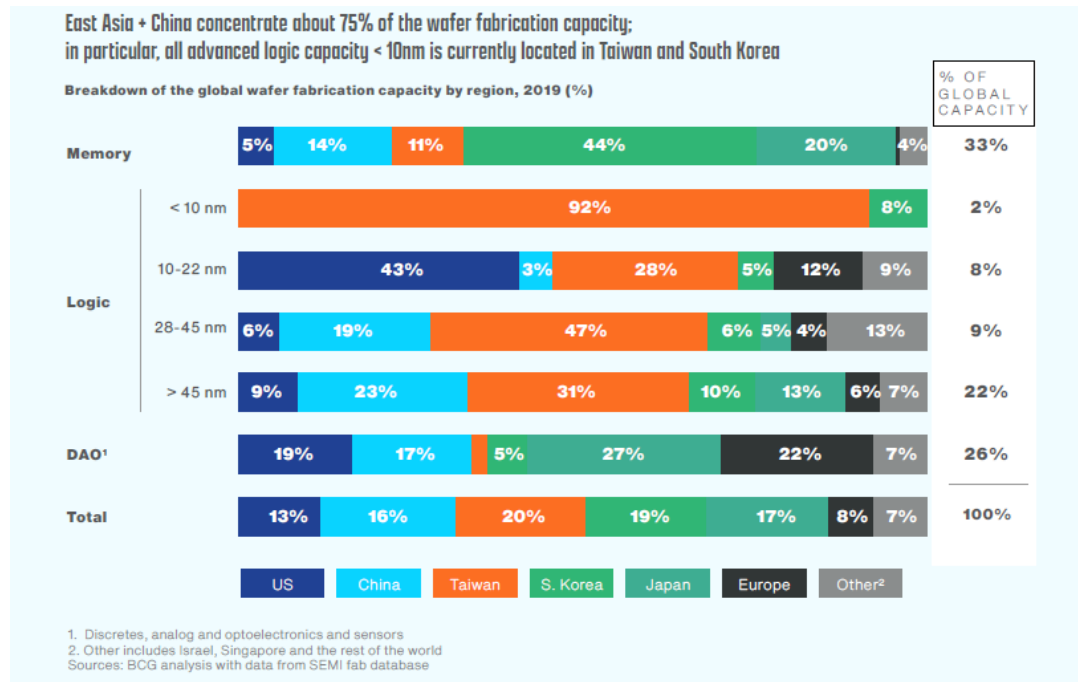
3.3.1.3. Low manufacturing capacity?

Looking at the manufacturing capacity, Europe is far behind in all the different segments. The only one where they compete is DAO. As has been shown earlier, this is the central segment of the three European companies of semiconductors. The part of Europe on the total capacity is low, only 8%, making them the last “big” region.

Taiwan is the leading region in terms of capacity, mainly thanks to two foundries firms, TSMC, the leading foundry globally, and UMC, which is in the top 5. This is also thanks to TSMC that Taiwan has a large percentage for chips lower than 10 nm. The company is the only one with Samsung to be able to produce this kind of semiconductor.

South Korea, the country with the second largest manufacturing capacity, ought its place mainly to dominate the Memory. As mentioned earlier, thanks to Samsung Electronics and SK Hynix, the two leaders in that market (Lee and Yang 2021).

Exhibit 12: Breakdown of the global wafer fabrication capacity by region, 2019 (%)



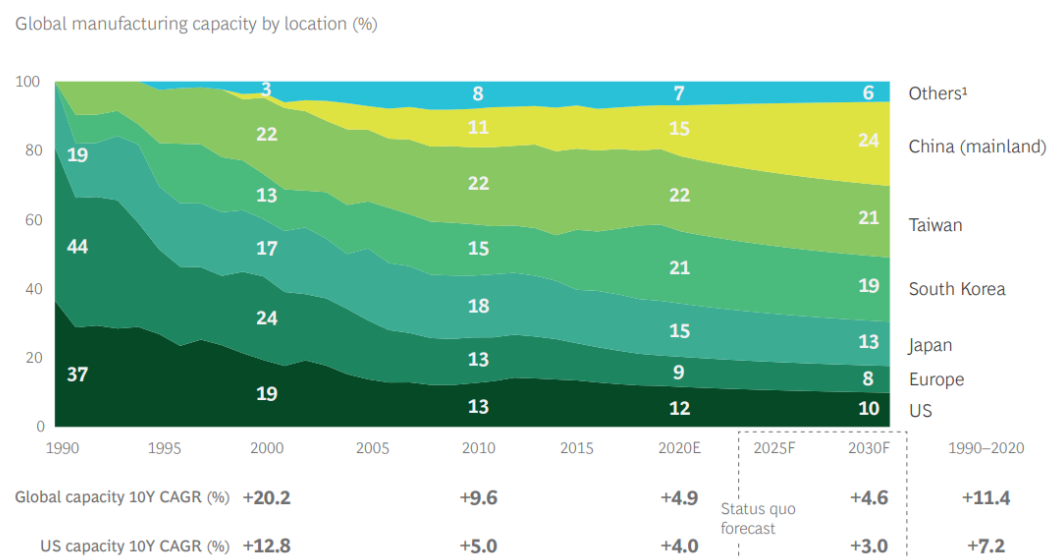
Source: Varas et al., 2021

The capacity of the US company is also very low compared to the other region. This position is in line with the previous observation, despite the fact that they have the most significant market share in the industry. Two explanations can be given for this. First, many large US company are fabless and therefore relies on foundries that often are foreign. Second, IDMs and foundries, even if their headquarters are based in the US, do not mean that all their manufacturing is also located there (see Appendix 6). The second explanation is also valid for European companies and other companies outside these two regions, even if this trend is less marked. Nevertheless, it is essential to add that even if this trend can explain the figures above, the capacity of each fab is also important, and that could be a parameter that increases this difference or reduces if the more enormous fabs are in the home country.

The question is now, how do the different regions, and especially Europe, come to this position? In the 1990s, the situation was totally different, with significant domination for Europe and the US, counting together for 81%. However, over the years, they lost ground to East Asia

countries, and if nothing changes, the difference should become even more pronounced. This decrease obviously started earlier and continued to develop over the years. One of the first explanations that could come to mind would be that the capacity did not grow since then. This is true and not true. When looking at the US capacity growth¹¹, it has always been positive every ten years. Nevertheless, this growth was below the global one that is where the real problem is that your competitor grows at a higher rate than you. This might be seen as standard in the first years of the 1990s. The US and Europe have such large market share; it is expected that the growth rate is lower for them. However, this is more problematic from the 2000s because the capacity share was much closer, which means that they were about the same manufacturing capacity. Therefore, lower growth means that were going to fall behind. Presently, they still have a lower growth rate despite their main competitors being far ahead. The question is, therefore, why are they unable to turn things around and grow more than their competitors?

Exhibit 13: Global manufacturing capacity by location (%)



Sources: VLSI Research projection; SEMI second-quarter 2020 update; BCG analysis.

Note: All values shown in 8" equivalents; excludes capacity below 5 kwpm or less than 8".

¹Includes Israel, Singapore, and the rest of the world.

Source: Varas et al., 2020

¹¹ The example of the evolution of the US capacity will be use because the figures are given, but the hypothesis is made that the EU capacity had the same problem, while the difference should be even bigger for them.

Varas et al. (2020) provide a reason that led to this situation: the advantageous government policies in Asian countries. These countries have implemented subsidies, tax credits, and favorable government incentives. Compared to Germany and the US, they have applied much higher government incentives (see Appendix 18). These incentives are obviously available for domestic companies to support them et create national champions. However, in many cases, these are also obtainable for multinationals companies.

Looking especially to China, which is forecasted to be the first country by 2030, the incentives mentioned above are offered to multinational firms. However, they often need to agree to share technology with the country. In addition to these incentives, there are additional ones that are not usually in place in other countries. Varas et al. (2020, 9) cite three: “Equipment is leased at preferential rates”, “Firms have access to credit and loans at below-market rates”, and “The state directly invests equity in the domestic company”. Concerning the last one, according to an OECD report (2019a), government support for two companies (SMIC and Tsinghua Unigroup) exceeded 30% of their annual consolidated revenue for the period 2014-2018.

Moreover, Europe and the US also have other disadvantages. These include higher construction and labor cost, including median wage, building, and operating a fab. Furthermore, some countries offer infrastructures around manufacturing sites at no charge.

In conclusion, Europe and the USA are losing their share of global manufacturing capacity for 30 years. The main reason is that Asian countries offer more advantageous incentives, which convinces Western firms to invest there. On the contrary, Asian companies are more willing to stay in their home countries, notably because the incentives are also available for them.

3.3.2. Problems that this implies

The European Commission (n.d., para. 5) has listed four key issues arising from the current situation: “Leading-edge chips have become more difficult and more costly to produce”, “Dependencies”, “Level playing field”, and “Europe’s semiconductor footprint is small”. Not surprisingly, these four issues stand out as the key for Europe. Throughout the analysis, these points came up frequently. While they speak for themselves, it is perhaps worth explaining more precisely what the European Commission means by the third point. Their explanation is: “Geopolitical tensions and the lack of a level playing field harm the competition in this area. The development and fabrication of chips have been increasingly subject to massive subsidies.” (European Commission n.d., para. 5). This explanation means that currently, it is every region for himself to become the number one in this sector, and almost any move is allowed to achieve this goal.

3.4. The different initiatives of Europe

In this section, a look will be given at the different initiatives that Europe has put in place. After, an analysis of them will be made, by giving some positive, negative points and other initiatives that could have been taken.

3.4.1. Europe’s initiatives

As explained before, Europe is behind its main concurrent with only 10% of the market and a growing dependence towards Asia the USA. Europe is aware of it, and in early December 2020, 22 EU member states¹² signed a declaration called *European Initiative on Processors and semiconductor technologies*. Through this agreement, the signatory Members have the will “to

¹² The declaration and list of its signatories is updated as more Member States join. (European Commission 2021d)

bolster electronics embedded systems value chain” with a particular focus “to reinforce the processor and semiconductor ecosystem and to expand industrial presence across the supply chain [...]” (The signatory Member States 2020, 2). The agreement covers two points. First, “Cooperate and engage in efforts to co-invest in semiconductor technologies across the full value chain [...]” (The signatory Member States 2020, 4). Their will of investing across the full value chain means they want to establish advanced design, supply chain, and productions capabilities to produce the leading-edge chip. Second, “Supporting the use of semiconductor technologies in Europe [...]” (The signatory Member States 2020, 4). This agreement will allow the signatories to be more efficient in their investment and research by creating synergies and having a coherent approach (The signatory Member States 2020). The goal presented through the *2030 Digital Compass* plan is to double the market share, i.e. 20%, (Nuttall 2021), but also to produce the 2nm chips, the most advanced chip, both by 2030 (Sterling 2021). To achieve a significant budget should be allocated by Europe, Member States, and private companies. A significant part of the European Recovery and Resilience plans could go to this effect. Microelectronics, and in particular semiconductor have been identified as a key area of this plan, where this €145 billion should go to digital transition over the next 2 to 3 years, which represent 20% of the total budget (The signatory Member States 2020). Part of the different national plans could also go for this purpose.

From a more practical point of view, the basic plan was to join forces with a foreign company to finance the construction of a megafab. The most important companies that have been approached to participate in this project, Intel, TSMC, and Samsung (Baleneri 2020). However, this project is far from being completed. First of all, it will be necessary to convince these companies to invest in Europe, where the market is less attractive. Diplomats and Taiwanese officials have already announced that TSMC would not be interested (EURACTIV.COM and Reuters 2021; Rosemain, Rose, and Chee 2021), even though TSMC has declared that it is not

closed to the idea. However, Intel might be more interested, as its CEO announced in late April this year that he wanted \$9.7 billion (€8 billion) to build a semiconductor plant in Europe (Reuters and Busvine 2021). He said this just before a meeting with the European Commissioner. Nevertheless, several European officials were reluctant to trust foreign companies to build a factory (EURACTIV.COM and Reuters 2021; Rosemain, Rose, and Chee 2021).

Another plan that was in the first instance seen as a complement or replacement of the previous one was to create a European alliance, including notably the continent's major players, namely STMicroelectronics, NXP, Infineon, and ASML (EURACTIV.COM and Reuters 2021; Rosemain, Rose, and Chee 2021). In July 2021, this alliance was officially created under the name *Industrial Alliance for Processors and Semiconductor Technologies* (European Commission 2021e). The two main lines of action are: “The reinforcement of the European electronics design ecosystem” and “The establishment of the necessary manufacturing capacity.” (European Commission 2021e, para. 4). The second point refers to the non-European partner that Europe was looking for to build a megafab. Nevertheless, the goal is not to focus on only one technology but to support the whole sector (Dèbes 2021b). The Members are expected to collaborate across existing and future EU initiatives. Several actors have already joined the alliance. Among them, ASML, IMEC, CEA-Leti, and Soitec. However, some important companies were first missing as STMicroelectronics because the company did not see their strategic interest in the building of the megafab in partnership with a foreign actor. Nevertheless, they finally change their mind and join it (Dèbes 2021c). In the view of the firms that already join it, it is totally expectable that all of the big European companies take part in this alliance in the near future.

3.4.2. US initiatives

On February 24, 2021, U.S. President ordered a 100-days review of the supply chain, including semiconductors (BBC News 2021). In April 2021, during a meeting with executives from 19 major companies in technology but also automotive industries to discuss the shortage of semiconductors (Reuters, Bose, and Nellis 2021a). During this meeting, U.S. President Joe Biden announced an investment of \$50 billion for semiconductor manufacturing and research. This is part of a \$2 trillion infrastructure proposal to rebuild manufacturing in the USA. The objective of this plan announced in March 2021 is to reshape the USA but also counter China's rise and national security threat (Renshaw and Holland 2021). The US president also asked Intel to announce its intention to manufacture chips for car within six to nine months in response to the shortage (Reuters, Bose, and Nellis 2021a). Pat Gelsinger, Intel Chief Executive, confirmed this plan to Reuters, as mentioned earlier. In June 2021, the Senate passed a bill of almost \$250 billion with the objective to strengthen US manufacturing and technology and, to meet China's economic and strategic challenge (Flatley 2021). This has been passed with a majority, showing bipartisanship. It includes \$52 billion to expanding the production of semiconductors for domestic manufacturers (Bloomberg News 2021d; Flatley 2021).

3.4.3. China's initiatives

At the end of 2020, the main goals of the new five-year plan, which will cover the period 2021-2025, had been unveiled but with no specific numbers or targets (Mitchell and Yu 2020). The focus was on "self-reliance" on science and technology and a "strong domestic market", in response to the US sanctions. In March 2021, the plan had to be formally passed during the NPC (Mitchell and Shepherd 2021). Seven key areas have been targeted, among them semiconductors but also notably AI and quantum information (Reuters Staff 2021a). The plan provides for an increase of at least 7% of R&D spending each year until 2025 (Mitchell and

Shepherd 2021). In addition, China is betting on emerging technologies, such as hydrogen vehicles and biotech, to ensure that its chipmakers' companies will be able to compete with the biggest ones (Bloomberg News 2021a). It encompasses the objectives of developing its own software for semiconductor design and its own manufacturing technologies and key materials for third-generation chips.

The government does not only plan R&D rise and semiconductor advancement. It would also build national laboratories for research on quantum information and AI (Reuters Staff 2021a) and innovation centers (Bloomberg News 2021a). It also encourages big technologies companies for open sharing of data (Bloomberg News 2021a; Reuters Staff 2021a).

Different initiatives have been undertaken by Chinese technology companies to develop self-sufficiency in semiconductors. Among these companies, there is ByteDance, Baidu, Alibaba Group, or yet SenseTime (Yang and Munroe 2021). In addition, China already has different companies on the different processes/materials needed to manufacture chips, although they are still technologically far behind (Ting-Fang and Li 2021).

3.4.4. Analysis of European initiatives

3.4.4.1. The positive points

1. The budget. Although there is no precise number about the amount invested, this should be accounted for in billions and at least about the same investment as its competitors. This is important at the view of the projects, namely the megafab and the production of 2nm chips. Therefore, the CAPEX and the R&D will be very high, as it has been observable with the most prominent companies as Intel, Samsung, and TSMC. Therefore, if Europe wants to have a possibility to match these companies and increase their market share, the amount spend needs to follow. In addition, the fact that Europe but also Member State and private companies will

invest allow to believe that the budget could be sufficient and could match the ones from the companies cited before.

2. A non-European partner. Given Europe's backwardness, achieve their 2030 objectives but also catching up with the competitors seems very difficult to stay by themselves. Therefore, having a non-European and global partner will help accelerate their advancement and hope to reach their objectives in time. Alexander & Kirschstein (2021) share this aspect and give two crucial arguments to justify it. First, to move from 14nm to 7nm takes about 3 to 5 years. However, it is delusional to believe that Europe can achieve this that fast on its own. Second, Europe is already late developing 3nm and 2nm chips, leading companies already working on it. These two facts make that without a transfer of technology from a foreign partner, the investment plan will be ineffective.

3. The European alliance. None of the European semiconductor manufacturing companies are among the most important company in the industry. Therefore, they have fewer means than other foreign competitors to develop their products and invest in more advanced technology. In addition, the fact that they are all IDMs means that they need to be present on all parts of the value chain, which increases the need for means. Therefore, unless they change their business model and become Fabless, an alliance will be good for them to share human, financial, and technological resources, especially with the participation of ASML to produce more advanced chips. Nevertheless, despite the official launching of this alliance, having all the important European companies seems a requirement for the alliance to be effective and stay a good initiative.

3.4.4.2. The negative points

1. Manufacturing 2nm chips. On developing 2nm chips, Europe is already behind some other regions that already started working on it and already produced one. Therefore, it will be hard

for them to catch up. In addition, another problem is that if they manufacture 2nm in their new fab, who will they sell them to? There are no companies in Europe that design more advanced chips, and therefore, if the situation stays the same, no company should order that type of node. Thus, Europe should count on foreign actors to buy their chips, which seems unlikely.

2. The megafab. As Kleinhans points out, building a megafab should not be the most effective initiative (Busvine 2021; Fleming, Hollinger, and Hall 2021). As pointed above, there are no big European players in the industry. Therefore, if 2nm are produced there, the demand from European companies will not match the total capacity. Nevertheless, even if less advanced chips are produced, and therefore in line with the European industry, it seems improbable that the megafab runs at full capacity. All this means that they should rely on foreign demand, which seems highly unlikely.

3.4.4.3. What could be other initiatives?

1. Incentives and government policies. One reason that explains the concentration of manufacturing fab in Asian countries is the incentives provided and the favorable government policies. Therefore, if Europe also wants to attract international players on the continent, it could be great to incentivize them. Having some of the giant multinationals on the continent investing in their initiative would be a great thing for Europe regarding funds saved, technology transfer, and rapid manufacturing capacity. The best possibility would be to have a European incentive applicable to the European Union and a national incentive. This combination would allow each country to focus on the segment that is the best for them (R&D, design, manufacturing, OSAT) while having European incentives will enable another range of action, give all the Member State the same basis, and will obviously increase the importance of them.

2. Rebuilding Chip Design industry. Although investing in the design sector has been planned in the agreement signed by 22 Member States, the first initiatives presented seemed to not really

focused on it. However, rebuilding a solid design ecosystem in Europe is required. As Kleinhans points out: “There is no European mobile system-on-a-chip of the type used in smartphones; no EU AI accelerator (the bit of the chip for machine learning) with substantial market share; and no European general-purpose processor, graphic chip or data center processor” (Fleming, Hollinger, and Hall 2021). In addition, on the two last publicly listed Fabless companies, Dialog was sold in February to the Japanese company Renesas Electronics for \$6 billion (Busvine 2021; Kirchfeld and Lanxon 2021). Without a vital design company, producing 2nm chip and fulfilling the demand of the megafab, as explained before, seems impossible. Another reason to focus on this sector is that in the view of TSMC building a fab in the USA to be closer to its customer, having strong companies in Europe could incentivize big foundries to come in Europe. This will therefore match the desire of Europe to have more considerable manufacturing in Europe.

3. Building an ecosystem around semiconductors by investing in other industries in parallel. As seen before, European semiconductor companies are mainly producing DAO because it corresponds to the needs of the crucial industries in Europe. Therefore, if the chip design industry develops itself towards more advanced technologies such as the ones presented above, the industry corresponding needs to be bigger to have a sufficient demand to live. Because once again, hoping for non-European industries to buy European products in the situation seems unlikely. The reasons are first of all that other companies have already an advanced compared to Europe, and it seems very improbable that an electronics manufacturer to make a big contract with a new manufacturer that has possibly everything to prove and because in some sector the brand of semiconductors became one of the most important things. For example, for a customer buying a new computer, the manufacturer and the CPU version and GPU version became more important than the computer manufacturer itself. Nevertheless, some segments of the ICT

industry are not too bad in Europe, such as the ICT infrastructure thanks to Nokia and Ericsson and their 5G equipment.

3.5. Main takeaways

- **USA strongly dominate** the market with almost half of the share
- **Asia largely leads the manufacturing step** with more than 60% of the share, and **China accounting for about 50% of this number**
- **Europe has a considerable gap** to catch up compared to the two
- Some of the **reasons** that can explain this gap are:
 - **The important industry in Europe that does not foster** chip firms to **invest in advanced technologies**
 - **The investment** made by Europe was **lower than their competitor**
 - **The manufacturing capacity has been decreasing** over the years, notably due to the **advantageous incentives from Asian countries.**
- **Europe** wants to **reduce its dependency** on other regions and **produce more of the European demand by itself.** **Asia** also intends to **become self-sufficient.**
- Europe set up **several initiatives:**
 - **Alliance with several European stakeholders**
 - **A megafab with a foreign company**
 - **Manufacturing 2nm chips**

4. 5G & 6G

4.1. What is 5G?

In recent years, one topic has become very important in the world of technology, 5G. It is the 5th and latest generation (Ericsson 2021c). Historically, all previous generations have brought significant improvements over the previous ones, which is no exception for 5G. One of the improvements well known by the general public is the speed of download and upload, with the example often given to download a movie in HD in a few seconds (Collela 2017). However, it will allow much more than that and will affect all industries. Among the different horizons that 5G promises to reach, there are autonomous vehicles that can share data to avoid collisions, faster deployment of emergency services or drones that can help in emergency operations; transformation of industries with autonomous production lines based on supply and demand, remote access to robots and vehicles, an increase in the use of IoT in agriculture; and finally more advanced experiences such as immersive virtual meetings and more immersive teaching methods (Ericsson 2021c). However, despite the immense benefits that 5G is expected to bring, the means that will have to be put in place to be able to have it will also be very important, whether it is at the level of deployment, R&D, or new devices to be produced to take advantage of this technology, without forgetting the investments that will have to follow to cover all these costs generated (Wang et al. 2021a; 2021b).

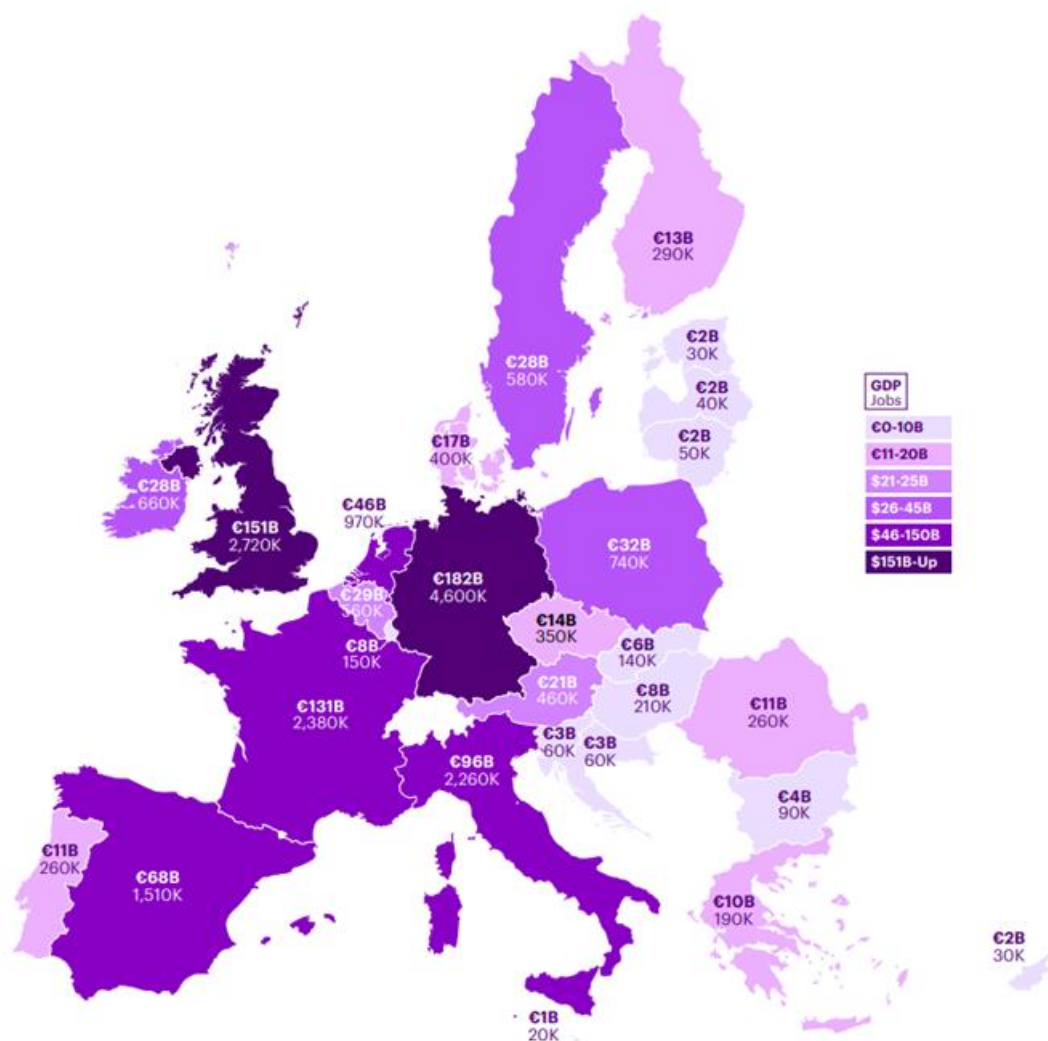
4.2. Industry overview

In this section, an overview of the industry will be given. A focus will be made on the impact of 5G on the European and US economy and a coverage of the most important companies in the industry. The purpose is to have a clear vision of the different actors and to understand better the position and the initiatives of everyone, which will be explained in the following sections.

4.2.1. Impact on the European economy

According to Wang et al. (2021a) estimates, 5G is expected to lead to an additional €2 trillion in gross output growth and add €1 trillion to European PBI and create or transform 20 million jobs in total between 2021 and 2025. Regarding the impact in the ICT industry in relation to the total impact, the report breaks the figures down into three groups: the direct effect on PBI of 5G is forecasted to bring €123.4B, against €58.1B of indirect effect and finally €69.2B of induced effect. However, it will also positively affect other European industries, as they will see their additional revenue, added GDP contributions, or jobs created or transformed.

Exhibit 14: 5G impact on GDP and jobs by country*



*Includes full-time, part-time and temporary jobs; Assumes no labor supply constraints, some of these jobs will be replaced by upward pressure on prevailing wages instead.

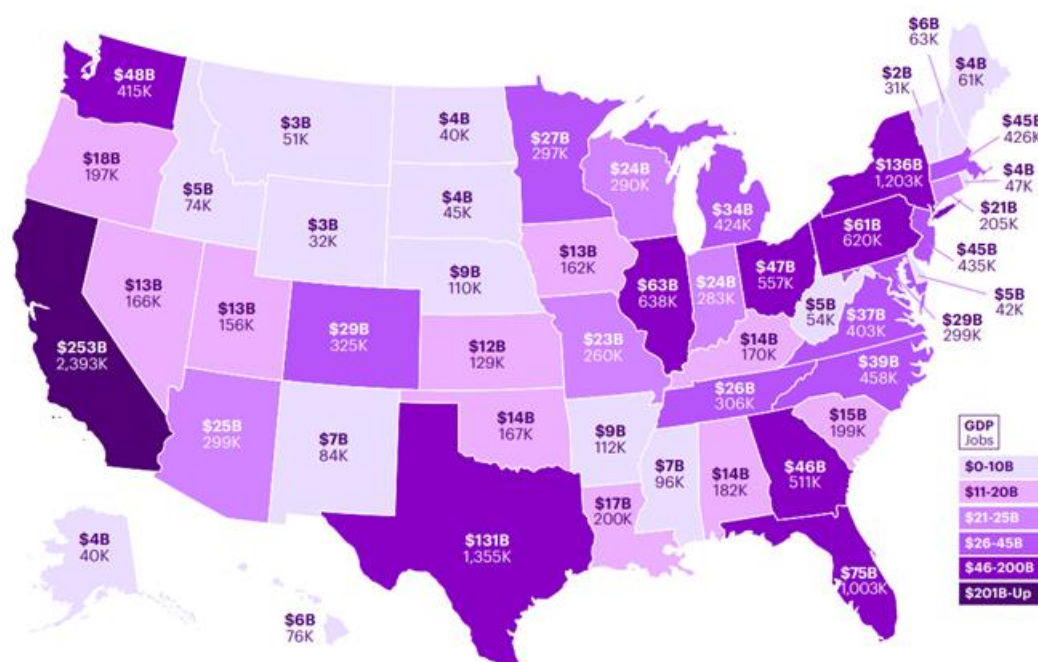
Source: Wang et al., 2021a

However, as mentioned above, 5G will transform some industries profoundly and open new horizons, which can be quantified. Autonomous cars could avoid 70% of rear-end crashes, which would represent €450 million in savings in collision costs. The healthcare industry could save 16% of hospital costs thanks to remote patient monitoring, increasing its overall productivity gains by 20 to 30%. The profits that this new technology will bring affect other parts of these industries and many other industries, such as agriculture and utilities.

4.2.2. Impact on the US economy

For the US, Wang et al. (2021b) forecast \$2.7 trillion in additional gross output growth, an increase of \$1.5 trillion to the US GDP, and 16 million jobs created or transformed. Again, the impact on the ICT industry has been quantified and divided into three groups: the direct effects would account for \$251.3B of the total GDP impact, the indirect impact for \$85.7B, and the induced impact for \$102.1B.

Exhibit 15: 5G impact on GDP and job by state*



*Includes full-time, part-time and temporary jobs; Assumes no labor supply constraints, some of these jobs will be replaced by upward pressure on prevailing wages instead.

Source: Wang et al., 2021b

Duarte Melo et al. (2021) also estimated the impact that 5G will have on the US economy. According to their figures, 5G should contribute between \$1.4T and \$1.7T to the US GDP. This is comparable to the statistics above, except that this estimate is over a decade (until 2030). As for the number of jobs created (and therefore not transformed), the forecast is between 3.8 and 4.6 million jobs. The direct impact would be \$400B to \$500B on US GDP, and the indirect impact would account for the rest, which means \$1T to \$1.2T.

The differences in the numbers show that while a positive impact is certain, the magnitude of the effect is difficult to predict, depending on the factors considered, the timing of the analysis, and the fact that virtually all industries will be affected.

4.2.3. The different companies in the sector

The major players in this industry are separated into two categories: the equipment manufacturers and the communication chips for smartphones manufacturers. There are four large companies in the first category: Huawei, ZTE, Ericsson, and Nokia (Auchard and Nellis 2018). Concerning the second one, Qualcomm, an American brand, is the dominant player on the market. Other brands mainly based in Asia are also in this field: MediaTek, Samsung Electronics, and Huawei (via its subsidiary HiSilicon), the last two of which develop chips for their own devices. In this part, the focus will be on the equipment manufacturers.

4.2.3.1. Nokia

Nokia seemed a player that was going to be very important because the company was present from the beginning of the 5G launches globally, providing equipment for American and South Korean operators (Balenieri 2020). However, by the end of 2020, the Finnish company lost market share, and its revenue was falling (Webb 2020). This situation can be explained by

strategic decisions taken before. In 2015, they acquired the company Alcatel-Lucent SAS for €11 billion. This acquisition was intended to increase the size of the company and the product range, but most importantly, all the operators' needs. The integration was more difficult than expected, which made it fall behind its competitors (Woo 2021a). In addition, they opted for a semiconductor similar to Huawei for the design of their 5G base stations, which allows more flexibility and customization (Webb 2020). However, this makes their products more expensive than the competition and therefore less preferred by telecom operators. Although Nokia has reacted by reorganizing away from offering an end-to-end solution (Balenieri 2020) but also by investing heavily in 5G to regain market share, the company could remain in a problematic solution, since they are behind in the market, they will not be able to invest as much as their competitors with the result that the profits of its mobile network division will decrease sharply (Webb 2020). To change that, they also planned a restructuring with the elimination of between 5,000 and 10,000 jobs, the cost reduction generated by this decision offsetting the investments made (Woo 2021a). These different actions have started to bear fruit because their results in Q1 2021 were better than forecasted and also already planned to raise its full-year outlook (Reuters 2021f). The company could also profit from the issue that its European competitor, Ericsson, knows on the Chinese market.

4.2.3.2. Ericsson

Ericsson was on the opposite path than Nokia. A few years ago, Ericsson had to cut some of its jobs (Balenieri 2020). However, their figures were recently increasing both in sales and results (Balenieri 2020; Mukherjee 2021a). In Q4 2020, the company beat core earnings forecasts, and it even reaches the operating margin level planned for 2022 two years earlier (Mukherjee 2021a). In March 2021, they even surpassed Huawei in cellular equipment sales in large parts

Exhibit 16: Information on companies linked to 5G¹³

<i>Name</i>	<i>Nationality</i>	Revenue in 2020¹⁴ (in billions)	% of patent¹⁵	Market Cap¹⁶ ()	Number of employees
<i>Ericsson</i>	Sweden	SEK 232.39	4.35% (7 th)	SEK 335.063B (Stockholm)	100,824 (as of 31/12/20)
<i>Huawei</i>	China	CNY 891.368 (USD 136.717)	15.39% (1 st)	Private company owned by its employees.	~ 197,000 (as of 2020)
<i>Nokia</i>	Finland	EUR 21.852 (USD 24.959)	9.01% (5 th)	EUR 29.541B (Helsinki)	~ 92 000 (as of 2020)
<i>ZTE</i>	China	CNY 101.451	9.81% (3 rd)	CNY 154.984B (Shenzhen)	73,709 (as of 31/12/20)
<i>Qualcomm</i>	USA	USD 23.531	11.24% (2 nd)	USD 167.666B (Nasdaq)	~ 41,000 (as of 27/09/20)
<i>Samsung Electronics</i>	South Korea	KRW 142,840.934 ¹⁷	9.67% (4 th)	KRW 444.152T (Korea SE)	Not provided
<i>HiSilicon¹⁸</i>	China	CNY 891.368 (USD 136.717)	15.39% (1 st)	Private company owned by its employees.	~ 197,000 (as of 2020)
<i>MediaTek</i>	Taiwan	TWD 322.146	0.7% (20 th)	TWD 1.447T	17,377 (as of 30/04/2021)

Source: Annual reports or financial statements of each company, Bloomberg, IPlytics GmbH cited by Statista

¹³ The first one is about 5G OEMs, the second one is for smartphone communications chips.

¹⁴ As some companies have other business areas, the numbers do not reflect their 5G part, which can lead to very different discrepancies (unless specifically noted). When the conversion to USD was available in the report, it was transcribed in the table. Some companies' fiscal year ends may be different.

¹⁵ There is no distinction between OEMs and chip manufacturers. All requests are taken into account, granted and open.

¹⁶ As of 13/08/2021

¹⁷ Only concerns its semiconductor business. Attention: in the revenues of the consolidated accounts, there is an intercompany elimination not considered here.

¹⁸ The figures shown here are those of Huawei, HiSilicon being one of their subsidiaries.

of the world (Woo 2021b). One of the reasons is that in the countries that decided to ban or restrict Huawei, Ericsson was often chosen by telecom operators to replace it (Balenieri 2020). However, on July 16th, 2021, the news was mitigated for Ericsson. On the one hand, the Swedish company announced a multi-year partnership with Verizon, worth \$8.3 billion, in order to accelerate the deployment of Verizon's 5G network in the US (Ericsson 2021d). On the other hand, it also announced that the company was not expecting anymore the anticipated contracts in China for the second phase of 5G deployment (Mukherjee 2021c). The reason is that Sweden has definitively banned Huawei from its domestic network. The first decision dated from October 2020, when Sweden banned Huawei from supplying 5G equipment to Swedish companies. Huawei sued to reverse the ban and threatened retaliation against Ericsson (Mukherjee 2021b; Woo 2021c). However, the Swedish court upheld this ban in June 2021 (Ahlander and Mukherjee 2021). The decision has been criticized for a long time by the CEO of the company, Borje Ekholm because he feared a possible restriction of free trade by other countries that would hurt Ericsson. Almost all the company's revenue is being made abroad, and the company needs to be in the most technologically advanced market, i.e., the USA and China (Milne and Peel 2021). The Chinese market represented about 10% of the revenue of Ericsson (Ahlander and Mukherjee 2021; Mukherjee 2021c). The sales in China fell by \$290 million (Mukherjee 2021c).

4.2.3.3. Huawei

Back in 2019, Huawei was a very dominant player in the market. They were the IT network market leader, with 27.8% of market share, and on the service providers networks market, with 35.4% (see Appendix 19) (ITCandor 2020). The only segment where they were not the leader, but second, was the enterprise networks, with only 9.5% compared to 56.4% against Cisco. The company was also the first company in the mobile infrastructure market, including 2G, 3G, and

4G, with 31% against 27% and 22% for Ericsson and Nokia, respectively (see Appendix 20) (Téral 2019). The European market was essential for Huawei, 24.3% of their 2018 revenue coming from EMEA, and 40.8% of their network contracts with telephone operators (Duchâtel and Godement 2019). However, Huawei and Chinese vendors were also significant in the European market. In 31 countries analyzed, 15 of them had more than 50% of their 4G RAN equipment supplied by Chinese vendors, including three concerning all their equipment (Strand Consult 2020). Globally, this represented 48% of the total market. On the 5G market, Huawei was forecasted to dominate the market, with about half of the market share (Hart, Snyder, and Fischer 2019). In addition, as of December 2018, this was the company that added the most 5G standard technical contributions, with more than 11,000 (see Appendix 21), at international conferences (Feldman 2019). Presently, Huawei focuses mainly on its home market (Lee 2021).

4.2.3.4. ZTE

ZTE is the other big Chinese company of 5G equipment. As Huawei, the company was also forecasted to be in the four most prominent companies of 5G equipment. At the end of 2018, ZTE was the fourth company in terms of 2G, 3G, and 4G infrastructure with 11% (see Appendix 20) (Téral 2019). In 2019, they were fifth in the IT network market, with 4.8%, and fourth in the service provider networks market, with 6.8% (see Appendix 19). However, they only had 3,738 5G standard technical contributions as of December 2018, holding seventh place (see Appendix 21). However, as for Huawei, ZTE has been banned from several markets due to national security threats.

4.2.3.5. Samsung

The South Korean company is also present in the 5G equipment market. Thanks to a 6.6 billion deal with Verizon in September 2020, followed by another one with NTT Docomo in March

2021, this has allowed the firm to become the fifth most prominent company in the industry (Lee 2021). Samsung counts on Europe to continue to grow in this sector, as it is visible with their recent deal with Vodafone in Britain (Lee and Mukherjee 2021). Other European companies consider the South Korean company for their 5G network (Lee 2021; Lee and Mukherjee 2021). Samsung is also looking to enter other markets, such as India, Australia, in Southeast Asia, according to Woojune Kim, executive vice president of Samsung's networks business, interviewed by Reuters (Lee 2021).

4.2.3.6. Where is the USA?

When it comes to 5G network equipment, the US is absent from this market. This may seem surprising; however, it is essential to point out that despite their absence in this specific category, they have companies present in several other aspects of 5G and among the largest in the world. In addition, under the Trump administration, a proposal was made by attorney-general William Barr in February 2020 to be present in this market anyway by taking shares in the two European companies, Nokia and Ericsson (Shubber and Stacey 2020). The objective was obviously to promote other companies than Huawei and to consolidate these companies even more. But the US also had an interest in this for itself. It would have allowed them to be sure that they would not be left out of the communication technologies. However, this proposal was quickly abandoned because it was rejected by other representatives and Cisco, which was the American company with the best profile to lead such a bid (Waters 2020).

4.2.4. The ban of Huawei

The transition to 5G has been subject to many concerns, especially about national security. One company of the companies targeted by these concerns is Huawei. This has resulted in the exclusion or the restriction on several markets.

Exhibit 17: Timeline of the ban of Huawei

Date	Event
2011-2012	First suspicions of espionage. The investigation led to no clear evidence.
April 2018	Investigation on possible violation of US sanctions against Iran by Huawei.
August 2018	Ban from the Australian 5G network for national security reasons.
December 2018	Meng Wangzhou, Huawei's Vice Chairman and CFO, was arrested by Canadian police.
May 2019	The US Commerce Department added Huawei and 70 affiliates to the Entity List. U.S. Commerce Department granted Huawei a license to buy US products until August 19, 2019.
January 2020	The European Union allowed member states to restrict or prohibit access to the core parts of their networks to high-risk 5G providers.
May 2020	The US Commerce Department expands the required licenses of semiconductors made abroad with US technology.

Source: Kirton, 2020

The U.S., naming the Chinese company and its counterpart ZTE as threats to national security, has banned its companies from using government funds to buy equipment from these firms (Reuters Staff 2020).

Great Britain had initially just decided to restrict non-essential 5G network allocation before reversing their decision, prohibiting equipment purchase, and removing all equipment from the network before 2027 (Reuters Staff 2020).

Regarding EU member countries, Germany passed a law at the end of 2020, which gives the authorities the power to block a company based on safety concerns, but this does not exclude it from the market at first (Chazan 2020; Thomas 2021).

On the other hand, France did not clearly ban Huawei from its territory but passed a law, commonly called *Anti-Huawei*, which the Constitutional Council validated in February 2021 despite the challenge of SFR and Bouygues Telecom (Euronews and AFP 2021). This law mentions that operators who will buy Huawei 5G equipment will not have the possibility to renew the licenses after their expiration. This is intended to exclude the Chinese company from the French territory gradually. For example, Bouygues Telecom announced that they would have to remove 3,000 Huawei antennas by 2028 (Euronews and AFP 2021).

Finally, Belgium, with Brussels hosting NATO and European institutions, is important for this reason. At the end of June 2020, the choice was to restrict their network access to a maximum of 35% of the total infrastructure for each of the two Chinese companies (Van Leemputten 2020). In addition, some critical areas will be excluded. However, in mid-December 2020, Huawei announced that it was ready to open up the core network code and base stations that would allow the authorities or any other party designated by them to control them (Belga 2020). This seemed to be a last-ditch attempt to participate in 5G. However, it was unlikely because in October 2020, Proximus and Orange, the two largest Belgian operators, had already chosen Nokia and Ericsson for their network (Mukherjee and Binnie 2020).

4.3. The rollout of the 5G

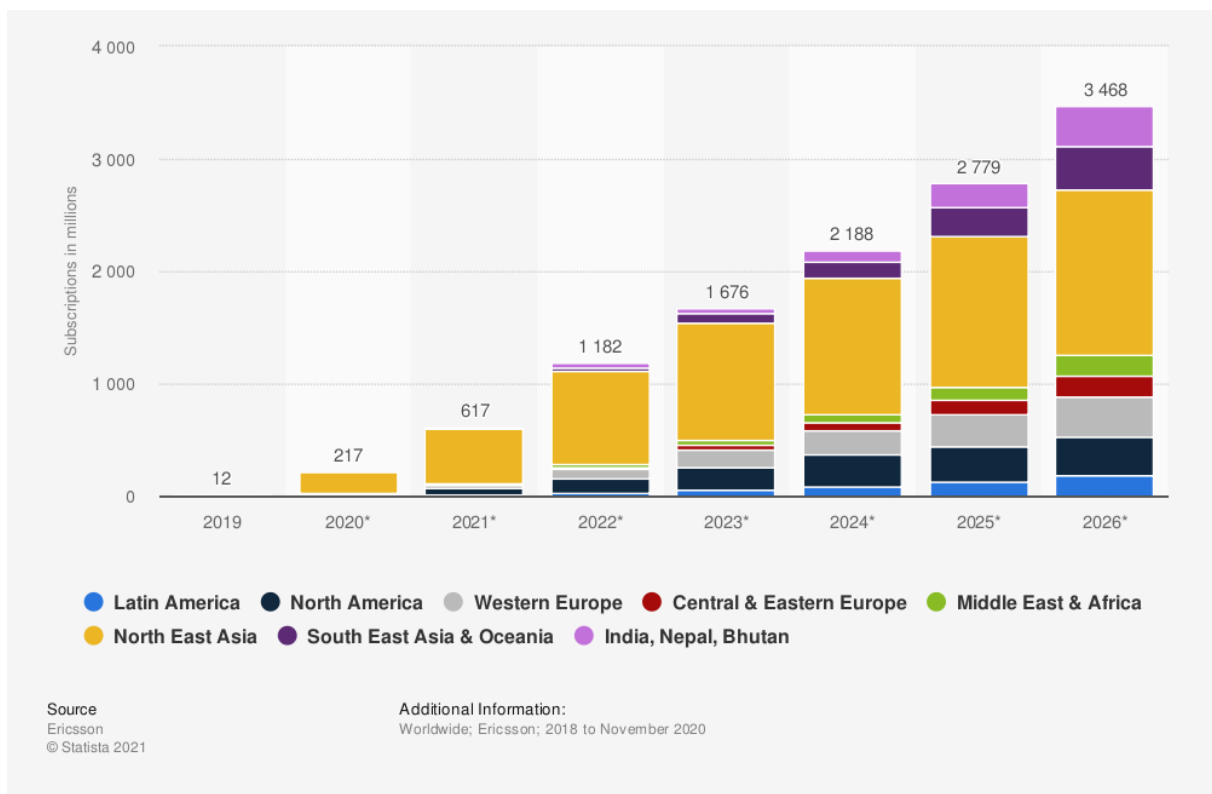
Despite having two companies in the top tier of equipment manufacturers, Europe is behind in the deployment of 5G. The forecast is for a global rollout only in 2030, part of the *Digital Decade* project (European Commission 2021a). According to the current CEO of Ericsson, “Europe is very late. This was already the case for 4G, which may explain why we do not have a European digital champion. The big platforms are almost all American or Chinese, two regions where 4G was deployed first. I fear that this will be repeated with 5G.” (Hivert 2021, para. 2). The CEO of Nokia made the same observation: “Europe is, unfortunately behind” (Mukherjee and Binnie 2020, para. 5). These observations are confirmed in numbers.

China and the US were well ahead in the deployment of 5G in February 2021 (see Appendix 22). Nevertheless, these are absolute numbers. But some interesting information can be taken from them. First of all, Spain is the country with the most cities where 5G is available, where a country like Germany is not even in the top 10. Moreover, looking at the distribution by region (Asia, EMEA & Americas), the reality is a bit different. Asia is 1st with 528 cities, followed by EMEA with 459 towns and the Americas with 349 (VIAVI 2021). This means that China accounts for 64.6% of the total number of cities in its region and the USA for, even more, arriving at 79.9%, whereas it is much more spread out in EMEA, with the largest country (UK) accounting for only 11.8%.

This delay is also reflected in the number of 5G mobile subscriptions. Few people in Europe had one in 2020. According to the chart, there were only 6 million (6 million in Western Europe and 0 million in Eastern Europe) compared to 14 million in North America and significantly 193 million in North-East Asia. This represents just under 90%. In 2021, this gap is predicted to increase with 39 million subscriptions for Europe (36 for Western Europe and 3 for Eastern Europe) against 60 million for North America and 490 million for North-East Asia. However,

the good news is that this gap, although it has increased in absolute terms, will have decreased in relative terms, with North-East Asia accounting for only slightly less than 80%. Nevertheless, this does not allow Europe to be satisfied with this result because Asia has already acquired a significant lead that will enable them to create faster “those new companies that will generate the jobs of the future.” (Hivert 2021, para. 4).

Exhibit 18: Forecast number of mobile 5G subscriptions worldwide by region from 2019 to 2026 (in millions)



Source: Ericsson, 2021a

4.4. The different initiatives of Europe

Here, the focus will be on the different initiatives that Europe has put in place in order to catch up with the other big region, especially the USA and China, in the rollout of 5G. An analysis of the different initiatives will be made, where positive and negative will be given, as well as some initiatives that could have been done.

4.4.1. The initiatives

In 2013, the European Commission launched 5G-PPP to accelerate research and innovation (European Commission 2021b). Public funding of €700 million was attributed to this activity through the Horizon 2020 Programme. Concerning the deployment, they had also taken matters into their own hands early. In 2016, an action plan was set up to ensure that by the end of 2020, all countries had launched 5G services. The plan stipulated a ramp-up afterward to cover all urban areas and major transport routes by 2025. In 2021, they adopted The Digital Compass, with the target that all populated areas would be covered by 2030.

In 2021, they also created a legal and funding entity to coordinate activities between Member State on 5G and 6G (European Commission 2021c). One of the two main activities of the European SNS JU is to boost 5G deployment in Europe, notably under the Connecting Europe Facility Programme. The entity comprises public (European Union represented by the Commission) and private members (The 5G Infrastructure Association). A budget of at least €900 million will be given during the period 2021-2027 to achieve the objectives.

Therefore, the question is what reason can explain this delay taken mainly by Europe and the Americas. Still, according to the CEO of Ericsson, the telecom market does not work in Europe, so they do not invest in 5G because they cannot make their cost of capital, and they have difficulty competing with American and Chinese companies (Milne and Peel 2021). The cause of this malfunction is that no European champions are being as big as the most important telecom operators outside Europe. Consolidation attempts had already been made but were blocked in some countries because of competitiveness. This led some of these companies to lose their profitability compared to their American rivals. The situation in the USA is quite different. Three major players, T-Mobile, Verizon, and AT&T, are trying to provide 5G to their customers as soon as possible, especially against their competitors (Lachapelle 2021). Despite what this race might let us believe, the companies that will build new technologies or improve

existing ones thanks to 5G are the ones that will benefit from this race. Indeed, the sooner the network coverage will be available, the sooner they will start working on introducing them.

4.4.2. Analysis of the European initiatives

4.4.2.1. Positive points

1. Investment: The European Commission has planned an investment of at least €900 million to help the deployment of 5G. This is a good initiative, given that Europe is already behind and needs to accelerate it. In addition, the door is open to increasing this investment, that will maybe be necessary to have a chance to catch up USA and China, or at least not falling more behind. The most important will be how it will be used and how fast the investment will be given.
2. Deadlines are globally respected: According to the 5G Observatory (Pujol et al. 2021a), at the end of December 2020, 24 countries (Members States and the United Kingdom) already launched 5G. The only countries that did not launch it were Cyprus, Lithuania, Malta, and Portugal. This was still the case in March 2021, except for Cyprus (Pujol et al. 2021b). This is globally good news for the EU because it shows that their deadline seems achievable, and therefore, the next step of the deployment has a great chance to be reached in time in most countries.

4.4.2.2. Negative points

1. Deadlines are late: The European deadlines are 2025 to have all important cities and roads covered and 2030 for all populated areas. Although these deadlines are rational given the current situation, this is late compared to other regions and countries, such as the USA and China, that are already well advanced in major cities. In addition, 2030 is also the forecasted for the starting of 6G deployment (as will be explained after), which means that mobile operators will have to finish their investment in 5G and at the same time starting new investment

for 6G, which cost them a lot and could force them to make some negative choices on at least one the two networks.

2. Not all the operators launched 5G commercial service: Although most European countries have launched 5G commercial service, it does not mean that all mobile operators in these countries have launched it. In March 2021, in only 12 countries in the EU-27, all have launched it (Pujol et al. 2021b).

4.4.2.3. What could be done?

1. Consolidation of mobile operator: As seen before, one of the biggest problems of the 5G deployment is that it is not worth it for European mobile operators to invest in it. Therefore, Europe should foster some consolidation of these companies to create European champions. This could and has to be done while keeping EU antitrust laws and protecting customers from a price increase.

4.5. The race for the 6G

From a consumer and most of business perspective, the 5G revolution has only just begun, and it is still far from its full potential, so all the focus is on that. However, this truth is not actual everywhere. For equipment companies and the world's largest economies, they are already looking to 6G, and the race is already on. In the words of Vikrant Gandhi, senior industry director of information and communications technologies at consultancy firm Frost & Sullivan in the U.S.: “Unlike 5G, North America will not let the opportunity for a generational leadership slide by so easily this time” (Zhao, Moritz, and Seal 2021, para. 7). This perspective is more than likely, as this sector is one of the most critical today, and the US has been totally absent from it for 5G equipment while China has taken the lead thanks to Huawei and ZTE. He adds:

“It is likely that the competition for 6G leadership will be fiercer than that for 5G” (Zhao, Moritz, and Seal 2021, para. 7).

Like all generations, 6G will bring new improvements. While it is too early to know what this new technology could get, researchers have an ambitious vision (see Appendix 23) (Zhao, Moritz, and Seal 2021).

This technology is not expected to be available for another decade, around 2030, but research and innovation initiatives have already started, as well as alliances around the world, which will be presented below (Bajpai 2021; Cerulus and Hendel 2021; European Commission 2021b; Zhao, Moritz, and Seal 2021). Nevertheless, there could already be the first battle in only a few years, the one of standards (Cerulus and Hendel 2021). It could occur in the middle of this decade. It will be imperative because the different regions have different visions about the future of the technology and its use (Cerulus and Hendel 2021; Zhao, Moritz, and Seal 2021).

4.5.1. The different initiatives

4.5.1.1. Europe’s initiatives

In Europe, several projects are already launched under the 5G-PPP and have received funding from the European Union's Horizon 2020 research and innovation program (European Commission 2021b). There are nine which are worth €60 million. The most important project is the *Hexa-X*, the flagship initiative, which aims to develop a first 6G system concept. This project is a partnership of 25 organizations with as coordinator (overall lead) Nokia (Hexa-X n.d.). Among the other members there are Ericsson (technical manager), Atos, Intel, Orange, or Siemens. Various universities are also involved in this project. The eight other projects will explore the 6G complementary technologies to the ninth (European Commission 2021b). They all started on January 1, 2021, and most of them will last 36 months. In addition to this, as explained before, the European Commission adopted the SNS JU (European Commission

2021b). The goal is to “Fostering Europe's technology sovereignty in 6G” with notably an investment of at least €900 million between 2021 and 2027 (European Commission 2021c).

Through its digital decade, the EU has put 6G among the areas of possible international partnerships (European Commission 2021a). The EU hopes to promote its people-centric digital strategy through these partnerships and encourage alignment or convergence with EU standards.

4.5.1.2. US initiatives

In the USA, an alliance was also launched at the initiative of ATIS in October 2020, called *Next G Alliance*, which has the stated “that will advance North American mobile technology leadership in 6G and beyond over the next decade” (ATIS 2020, para. 1). Among the founding companies and members, there are telecom operators like AT&T, T-Mobile, and Verizon, hardware companies like Apple, Dell, Intel, Qualcomm, HP, etc. or software companies like Facebook, Google, Microsoft, etc. In addition to these American companies, other global technology giants are present, such as Ericsson, Nokia, Samsung, MediaTek but not Huawei or ZTE. ATIS has identified three strategic actions on which they will focus:

- “1. Develop a 6G national roadmap that addresses the changing competitive landscape and positions North America as the global leader in R&D, standardization, manufacturing, and adoption of Next G technologies.
2. Align the North American technology industry on a core set of priorities that will steer leadership for 6G and beyond to influence government policies and funding.
3. Identify and define the early steps and strategies that will facilitate and lead to rapid commercialization of Next G technologies across new markets and business sectors and promote widescale adoption, both domestically and globally.” (ATIS 2020, para. 3).

4.5.1.3. China's initiatives

Huawei has already been working on 6G since at least 2019 (Bajpai 2021). Indeed, they were working on 5G and 6G at the same time. However, they are still in the early stages and are focusing on fundamental theories about 6G. Nevertheless, they are, for the moment all alone, and are looking to create an alliance to work on 6G, like what can be seen in other regions or even its competitor in the same country, ZTE. ZTE, together with China Unicom, in May 2020, entered into a long-term agreement to work on 6G.

In addition to companies initiatives, China has also launched several projects, including a national working group to work on 6G R&D, but also a general expert group to promote the development of 6G (Bajpai 2021). But this was not the main initiative. Indeed, another one has been much talked about. In November 2020, China sent 12 satellites into orbit with, for the first time, a satellite for test terahertz signal transmission.

4.5.1.4. Other countries' initiatives

South Korea, which is among the most advanced countries in the world, and having notably launched 5G first (Bembaron 2019), have also started their preparation for the next generation. The government announced in August 2020 a 5-year investment plan beginning in 2021 of ₩200 trillion (Bajpai 2021). The goal is to secure the basic 6G technology. But Samsung, too, has taken matters into their own hands. They want to bring the connection to every part of our lives. For this, Samsung Research founded its Advanced Communications Research Center in mid-2019. A partnership has also been created between Samsung Electronics, LG Electronics, and SK Telecom (Zhao, Moritz, and Seal 2021).

According to several news reports cited by Bajpai (2021), in Japan, another prominent technology country, the government has decided to allocate ¥50 billion to research and develop

6G. In addition, a new alliance has been formed between this time Sony, NTT, and Intel, which have created a global platform to work on the next generation (Zhao, Moritz, and Seal 2021).

4.5.2. Analysis of the initiatives

As the initiatives are still at a starting point, this is difficult to see what initiative is positive or negative. However, some facts can already be highlighted. China seems to be in the leading position for the moment, notably with the launch of the satellite for testing signal transmission. However, the race for 6G is not a sprint but a marathon (the forecasted availability is 2030, although around 2025, some battles for the standards could occur). With this vision, Western initiatives seem more ready for this. Among the most advanced globally, many technology companies of several nationalities are cooperating to advance on the 6G research and innovation rapidly. At the same time, Chinese network equipment is not in such a good position. Huawei has not teamed up yet, and ZTE has found only one partner, but it is another Chinese company and will not profit from international advancement. Nevertheless, the fact that many companies from different nationalities are present in this cooperation could be problematic at the moment. Each company will surely want to protect their interest and those of their country/region, leading to inevitable tensions and could slow down the advancements of these alliances.

4.6. Main takeaways

4.6.1. 5G

- **2 European companies** are among the **global top 4 5G equipment manufacturers**: Ericsson and Nokia
- The two firms took profit from **US sanctions and the different bans towards Huawei and ZTE**
- **Europe is late in the deployment of 5G** compared to China and the USA

- **Investment is planned to accelerate the deployment** on the continent
- **The total deployment** is expected for **2030**

4.6.2. 6G

- **The race for 6G already started**
- **Europe created Hexa-X**, an **alliance including Nokia** (Overall lead), **Ericsson** (Technical manager), and **other stakeholders from Europe and the USA**
- **The USA started the Next G alliance** with many of the **most leading ICT companies** from the **USA, Europe, and Asia**
- **China launched a satellite** to try terahertz signal transmission. However, **Huawei did not find a partner** to work on 6G; **ZTE partner up with a Chinese mobile operator**
- **South Korea and Japan also started some initiatives**

5.Conclusion

As seen before, the ICT industry is ahead of many changes that could shift the domination for the different regions and private companies. The past and present have already been described and analyzed in the previous chapters. In this section, an analysis of the potential future will be given, based on the different information highlighted throughout the document. The objective is to provide first the main strengths and weaknesses from Europe, the USA, and China for their different objectives in this industry. Then, the crucial features that could impact the most the success of their initiative will be discussed. Finally, a prospect of where Europe, the USA, and China in 2030 will be done focusing on the semiconductors, 5G/6G, and the whole ICT industry.

5.1. The relation between regions

First of all, a point that concerns all the different regions will be crucial in the future of this industry, notably, the relation between the different regions. In this part, several scenarios will be given about how the different relations between Europe, the USA, and China could evolve and what implications they could have.

1. All regions battle for themselves and the cooperation between region are almost or totally stopped. Therefore, Europe will find itself alone. It would be the worst scenario for them because they will be technologically behind in the long term. Indeed, their current lag in many sectors of the ICT industry will be a massive problem in this case. They will need to catch up with the present more advanced technologically region while others will already work and develop the next generation. It will be almost impossible to get out of this circle alone because there are no big companies, except for the 5G infrastructure, the investment is lower, and they have less technological property than their counterparts.

On the contrary, the USA could be in a not too bad situation and even more. Many of the biggest ICT companies are American, their investment in R&D is enormous, and they have a lot of

technology property. The last point has notably been seen with the ban of the use of US technology by Huawei. However, the USA should solve some problems such as capacity manufacturing and their absence in some segments. Nevertheless, these two problems could be overtaken. For the first one, the example of semiconductors can be used. Although there is only one American foundry in the top 5 for many American Fabless companies (and IDM) in the top 10, this is still a strong basis for them to increase. In addition, Intel has announced the starting of a foundry activity, which will also increase this capacity. It will still need a massive investment in CAPEX to cover all the American demand. For the second point, this is the situation in 5G. It could also occur in some new technology such as IoT and Robotics, two very important and among the most disruptive innovation, where Asia has the lead currently. Nevertheless, with their tremendous amount in R&D, this difference could be catch up while keeping their advantage in the other segment.

China would be in the middle of the two. They would be behind the US because of a technology lag, notably in the traditional technologies. However, contrary to Europe, they already have many manufacturing fab and technology companies among the most important in the world. Even though they are still mainly using US technology or buying US products, it should be a question of time, some years, to develop their solution and become self-sufficient. This is not a new quest, but the US sanctions have undoubtedly accelerated and slow it. It accelerates because if they do not find solutions quickly, they will lose market share, and many companies will suffer from this. However, it also slows it because they will not be able to continue to grow while at the same time developing their technologies. Therefore, they will have to use old technologies first to finally arrive at the current technology level.

2. Complete cooperation between Europe and the USA, China being alone. This would obviously be a better position for Europe and the USA because it means more resources to use for both of them. Europe could take profit from technology share to learn and improve from

this. In addition, this could be an excellent way to foster the construction of fabs, R&D, or design centers on the European ground by US companies. If this happened, they could also do like some Asian countries and develop the infrastructure around a technological center. This would allow European companies to grow thanks to US technology and Europe to become an advanced technology region again on the world map, by mainly catching up on several parts at the same time while not spending too much.

For the USA, it would represent an essential ally while not being too dangerous to challenge their current lead in the short/medium term. Furthermore, plants being one of their problems could allow them to construct some on the European territory while asking for some funds from the European Union and the Member States. Although it would not be on their territory, it would help them indirectly increase their lead and gain some share compared to Asian countries. They would also have closer links with some important companies, such as Ericsson and Nokia, two 5G infrastructure equipment companies that should keep their important place for 6G. In contrast, the US does not have this type of company at the top, although some US firms can achieve it for 6G equipment, the race for 5G being already finished for new competitors.

China will not be in the best position. Although it will not change a lot in their quest presented in the previous scenario, they will see Europe having the possibility to quickly catch them up on several segments and even overtake them depending on how easily they will be able to use US technologies. Nevertheless, thanks to the importance of its internal market, they would have the possibility to keep their independence for some years while not losing too much in the short term. Their long-term position will depend on their ability to find allies or not and how important they and their market are.

The question is, how likely are these scenarios possible? In reality, not so much, and the real scenario should be between the two. Because of the different recent events, i.e., Huawei ban

and 6G collaboration, the US and Europe are not close to China, and there are few chances to see this change. Cooperation between the two regions is necessary if they want to keep a specific form of domination. However, it would be delusional to think that the two will fully collaborate and see them as true allies. They will obviously defend their own interest first, even if it could be at the cost of the other. Therefore, they should see the other one more like a useful help, and the relations would hang on a thread. However, this collaboration is more important for Europe than the opposite, and if one searches to take too much profit from the other, the repercussion could be really different. If it is Europe, the US could stop it and continue alone, while it is less likely to see Europe be able to have this liberty vis-à-vis the US. Nevertheless, Europe must pass by this step as that they cannot achieve their objectives only independently. It seems to be known as they are looking for a foreign partner to construct a semiconductor megafab and created an alliance with many non-European companies for 6G.

The critical point in the medium/long term is, will Europe be able to make themselves indispensable for the USA? Not competing with the first time but giving the desire to US companies to invest in Europe. Therefore, this follows the path that Asian countries used years ago to become an essential region in manufacturing. However, the means used could be different. As mentioned earlier, European Union and European countries should use some kind of incentives to be attractive. These incentives could take many various forms. Therefore, analyzing the European and national laws is necessary to see what each stakeholder could do. Another analysis will be to see what the giant companies are looking for to install some of their activities in Europe.

Three other scenarios could have been considered, but it seems almost impossible. These are a rapprochement between Europe and China or the USA and China and full cooperation between the three regions. There is no real reason to believe about it for the reasons explained just above.

Another important point is obviously to know what other countries, such as South Korea, Japan, United Kingdom, will do in the future. This is imaginable to see them close to mainly the USA in a role comparable to Europe. However, thanks to its size, Europe should have a better potential for implementation and less likely to become a competitor in the short-term, contrary to South Korea, for example.

5.2. Europe

5.2.1. Strengths and weaknesses

5.2.1.1. Strengths

1. Strong basis to work on. Despite their lag in many segments of the industry, Europe still has some crucial assets to build on. Whether it is in R&D or manufacturing, Europe has some non-negligible basis that could lead the train of the European digital revolution. This makes a big difference because they do not have to construct everything from scratch but rebuild it and/or improve it.
2. Economy comparable. No European countries have a size, economy, or importance comparable to the USA or China. However, with the 27 Member States that composed Europe, this difference is less pronounced. This is a real force because, on the contrary of some countries have to rely almost only on foreign countries. To illustrate this, a comparison between Samsung and Ericsson could be made¹⁹. Both of them are making most of their profits in other countries than in their home. However, thanks to the European Union, Ericsson should always have access to this market. At the same time, Samsung must hope that no tension or dispute occurs between South Korea and other countries that would prevent them from entering a market.

¹⁹ The two companies are different on many points, and mainly on their products although both of them are present in 5G equipment. Here, the purpose is just to give an illustration of the difference in opportunity.

5.2.1.2. Weaknesses

1. Technology lag. As it has been shown earlier, they have a lag in technology. This lag is more than just producing less advanced technology. This has repercussions on many other industries because they cannot be developed as fast as in the different regions. This means that Europe is in a vicious circle where there is less revenue, which means less investment for innovation and, therefore, less revenue. Without a reversal of the situation, this will continue to grow in the wrong way.
2. Several Member States. Although it is also a force, having that many countries under the same flag mean many countries with different politics, culture, economies, and essential subject. Therefore, they do not all have the same vision on how to deal with several questions. It is so more challenging to have only one position on the different initiatives to take on the contrary of the other region that can directly decide for all the country.
3. Other industries. The industries the most developed in Europe are not the ones that ask for the most advanced technologies. This does not give any incentives to invest and design it because to sell it after. They will need to prove that the products are at least as good as those around for years and have contracts with foreign companies that already have partners.

5.2.2. The most crucial points

5.2.2.1. The relation between the Member States in the European Union

This is a strength and a weakness of Europe, which could decide the future place of Europe in this industry. If all the countries, or at least a majority, cannot stand as one and follow the same objective, it could have a huge negative impact. However, a sign that shows the opposite rather is the *European Initiative on Processors and semiconductor technologies* with 22 Member States that signed it, for example. Nevertheless, it is still a minor action given the fact that this is only an agreement to try to have a better position with no obligation of doing anything.

Therefore, it seems normal that most countries have signed it because semiconductors are a vital sector presently. In addition, all countries want to defend their interest, and not being in this alliance at an early stage could be damaging for them if, in the end, it finishes well. At the same time, they could leave more or less quickly or at least not be too implicated if they finally think it is not a positive idea. Furthermore, each country has a better relationship with other countries (European or not) that obviously play a role in the decision that could be taken. For example, in 2018-2019, the Trump administration put under pressure and lobbied their Netherlands counterpart in an effort to convince them to block export licenses to Chinese customers that ASML had, and this worked (Alper, Sterling, and Nellis 2020). It was at the beginning of the US sanctions against China. It gives an example of a significant relationship between the Netherlands and the USA.

With the descriptive and analysis part made in this master thesis, it is impossible to give a precise answer of how the situation could evolve. A deeper analysis of each country's politics but also of the current and future trends of the politics should be done to see where they agree and where they are not. Therefore, with that analysis, it would be possible to give a better framework of Europe's work to catch up with other regions.

5.2.2.2. The budget

This is an important subject because it will condition the success, the importance, and the rapidity of an initiative that a stakeholder can undertake. This is an essential subject for Europe because, when looking at the current spending in the ICT industry, they are far behind in almost all sectors. This is problematic, especially in the new technologies that will be very important and disruptive for many more industries than just the ICT. In addition, of the necessity of investing for future innovation, Europe needs to finance its initiative to catch up in traditional sectors. No definitive or precise amount has been announced to finance the initiatives on the

sectors that have been addressed earlier. However, this seems pretty good with the information already available, namely €145 billion to digital transition. This will allow them to at least cover the cost of their initiatives, even if this will remain too low to catch up rapidly. It has indeed to be split into various actions for different sectors and be really lower. In addition, due to the lag of Europe being in innovation but also infrastructure/capacity, this will be divided by two while it is less the case for the USA and China.

5.2.2.3. The reconstruction of the European ICT industry

Europe will need to reconstruct many segments of this industry. This is a necessary step to be a big competitive region again but also to be attractive for the biggest players. This has to take two different paths. Firstly, if they want to produce and sell the most advanced technologies, an important part will need to be done outside Europe. Therefore, they will need to prove to electronic companies as well as customers that their products and all the manufacturing process are reliable and are competitive against the already well-established players. This means in terms of rapidity, price, logistics, shipping,... Secondly, if Europe manages to rebuild large players in different segments and add some incentives, no matter the type, it could relaunch the interest in Europe, and non-European related companies could decide to establish some infrastructure there, as it can be seen with TSMC in the USA. Nevertheless, in both cases, time will also be needed because all this is not feasible in some months, and it will surely take several years to arrive at that level.

5.2.3. In 2030, what is the position that Europe could expect?

Starting with semiconductors, the probability for them to have 20% of the market share seems pretty unlikely. The first reason that can be highlighted is that a megafab will not be enough to reach that goal in time. Furthermore, for the moment, this is still in the phase of discussion, to

know who will take part in the project, in the European stakeholders but also the foreign ones. In addition, after having found all the partners ready for this project, other discussions will need to be done, notably about the repartition of the investment, and given the number of potential stakeholders, this step could last for a long time. Finally, once all the discussions are done, the construction will surely take several years. Therefore, a possible deadline should be around half of the decade. If this is indeed the case, it will surely be late for Europe to be on time to produce 2nm chips. With the first one already produced by IBM, it could be planned a massive production in the next few years. Therefore, the most prominent existing foundries and the future ones (Intel) will already be manufacturing them and have contracts with design companies. Thus, when Europe will finally produces, most of the demand will most likely already be fulfilled. In addition, as it will be a new entity, they will need to prove everything, in terms of quality, rapidity of production,... Nevertheless, the current shortage showed that demand is increasing, although it has some other causes, and the European megafab could take advantage of that if more capacity is needed. This possibly is to really unsure because, notably Intel, TSMC, and Samsung, it will increase their capacity, and it will be reached before Europe. Concerning 5G, the deployment should continue and be finished in 2030 in most of Europe. However, despite the investment from Europe notably, they will surely not catch up with their current lag compared to the USA and China. Nevertheless, the biggest problem resulting from this situation is the lag that other industries will take compared to other big regions. On the 6G, there are positive signs that Europe, mainly Ericsson and Nokia, could and should keep an essential part of the equipment. In addition, to the alliance to develop 6G, many countries have changed from Huawei/ZTE to Nokia/Ericsson. When the question of which equipment manufacturer for 6G will occur, it will be less costly for mobile operators to continue with the manufacturer of the 5G network than changing (once again for some of them) to another one, no matter the company. The only point that could play in disfavor of the European is if they are

late for the battle of standards and patent or to produce it. Nevertheless, with the already announced investment from Europe and the different alliances with some of the biggest ICT companies in the world, this is very difficult to believe.

Globally, the situation should not be really better for Europe in 2030 considering the whole industry. In the best case, the different initiatives will allow them to stabilize the situation and not to have lost more ground or even gain a bit in some areas. But it will be most likely the opposite, due notably to the new technologies, where the current spending will certainly not allow them to have access as quickly as the USA and/or Asia.

5.2.4. Is Europe burning some steps?

Europe wants to return to the top, reduce its dependency and be again an important technological region. That is great and important for the future. However, the objective and the deadline to achieve seems big given their situation. Gaining 10% of the market share of a semiconductor industry that big while the other region also wants to gain market share and become, at least, self-sufficient in only ten years seems pretty impossible. Even for the USA, despite their huge lead in many segments, it would be a considerable challenge. Several executives are not convinced about these initiatives on the semiconductors, arguing that the European Commission has not learned from the previous failure, such as a campaign launched in 2013, with the same global objective to increase market share (Fleming, Hollinger, and Hall 2021). In the first time, market share is not the most important thing to work on because even if they arrive to gain some, the most important will be to keep it and continue to grow this. However, in Europe, this will not be the case, as no company nor industry is developed enough to follow the level from the other region. The need to rebuild before developing is a necessary step. And for this, new ICT technologies could be a good opportunity. This is indeed meaning a whole new market where everything is to construct, as well as the companies that will

dominate it. Therefore, Europe can focus on one or two most disruptive segments, such as IoT or Robotics, while continuing to invest and attract foreign stakeholders in other sectors. This could be a more sustainable way for them. The two new technologies are not chosen by hazard, but this is where Asia, including China, invests the most and the USA the less. In the views of the current relationship between them and the USA, they could be the choice, maybe forced as it is the case for the 5G equipment, for the American companies.

5.3. The USA

5.3.1. Strengths and weaknesses

5.3.1.1. Strengths

Strong leadership. As already mentioned earlier, the USA dominates many ICT segments thanks to their giant tech companies. This makes them a key player for all companies that are related to their business no matter the industry, but that also means they are always at the forefront of technology. That means that many technologies have been developed by the Americans, and therefore they have certain control over them. This circle makes it very difficult for new companies to make a place and really compete with them.

R&D spending. The USA is the region that invested the most in R&D. This is an important point because that means that they should always be one step ahead of their competitors from innovation in many sectors and therefore have a technology lead and control. Having this advantage also means that they should always be at the forefront when standards need to be determined for new technologies and can therefore design them as they want and imagine.

5.3.1.2. Weakness:

Manufacturing capacity. The US capacity is lower than in many other regions. In addition, many American headquartered firms moved outside the USA or outsourced their demand. The

country needs to rely on foreign manufacturing to fulfill the whole demand from their companies, and this could become an issue in the future. If a problem occurs, U.S. companies could find themselves without components to meet their demand²⁰.

Some segments to fill: Despite their lead, sometimes huge in some segments, some others are completely or partially let down by the US, such as the 5G equipment. This is also visible in their spending compared to other regions, especially Asia. Obviously, the USA cannot be at the top, neither spending more than everyone else in all the segments but in some of them, which seems more important, this could be detrimental if they need to rely on foreign supply.

5.3.2. The most crucial points

5.3.2.1. Their ability to consolidate their position

The US position is presently put under pressure and will even be in danger in the future years. Several regions are setting up actions to either catching up or gaining market share. Nevertheless, during the time that these regions will take to achieve it, the USA can, for their part, use their resource in other actions to strengthen their advantage and make it even more sustainable. For this, initiatives from private stakeholders as well as public ones will be necessary. With the current way of investing, one possible room for action will be to increase their technology advantage by innovating a lot and released new technologies first. For example, with the Europe and China objectives on semiconductors, US domination will decrease as their market share will follow the same path if both of the regions reach their target. However, as IBM was the first to produce a 2nm chip, and they partnered up with Intel, this should give them a first-mover advantage to gain the market.

²⁰ Different from a shortage situation

5.3.2.2. Their ability to compensate for their missing parts

It will also be important to compensate sustainably for their segments where they are more vulnerable. This can take several forms. Firstly, building strong segments and companies that will be able to compete with the current leader. However, this option will be costly, and the possibility to achieve it quickly and to keep it in the long term seems difficult, although not impossible. Secondly, they could consolidate their link with a few foreign companies where they are sure they will not have any problem in the future, especially from a political point of view. This will ensure them to always be supplied with the components they need, and they do not have to produce by themselves. Nevertheless, this is still potentially risky because they could finally find themselves without any possibility if a problem of any type occurs. A final possibility would be to merge or acquire some companies within the segments they need the most. This could be the most sustainable and sure option as they will directly learn the technology, and they will have a brand already with customers on the market. However, this could be relatively costly, especially if they target some of the biggest ones. Nevertheless, this is the option that seemed to have been chosen by the USA, as two examples showed earlier can prove, the acquisition attempt of Arm by Nvidia and the failed proposal of acquiring one of the two European 5G equipment.

5.3.3. In 2030, what is the position that the US could expect?

In the semiconductor segment, this is difficult not to expect the USA to stay at the top. Their position allows believing that their leaders and, therefore, their revenue should stay about the same. Therefore, US companies should continue to invest at least as much as presently, which is bigger than most of the other firms and therefore should not see their advantage disappear in 2030. Furthermore, the manufacturing capacity will undoubtedly increase, notably due to the investment from Intel and TSMC on their territory, but other investments, such as Intel

Foundries, could arrive and increase, even more, their market share. In addition to this increase, they will also surely come back at the top of the manufacturing of the most advanced technologies, namely the 2nm chips, with the association between Intel and IBM.

On the 5G, in 2021, the deployment is well advanced and should continue on this path in the future years. Even if they need to rely on non-American suppliers to supply them, this seems not to be a huge issue, as the deal between Verizon and Ericsson showed. The US should also be in a good position to come on top of the utilization and take the most profit from it, with all the leading companies they already have, through many industries, and the higher R&D spending in general. On the 6G, the future seems to smile more to the US than to the others. Presently, they have created the biggest global alliance, and it is under their direction. The only questions are, will it work due to the number of different companies and nationalities present, and will a US company be able to manufacture 6G equipment, or will American mobile operators need to count once again on European products?

For the whole ICT industry, with the current spending, notably on certain of the new technologies, the US should be in a good position. They invested in all of them and should be able to develop these technologies in the near future. The only question is when it is going to be and most importantly, compared to the others. Because if they come out first, they will be able to catch a major part of the market, while if they are only second or even later, they will need to catch up a huge delay which will ask many resources. The situation on the traditional ICT technologies should not change a lot, although the dispute between the USA and China notably should redistribute the regional market share.

5.4. China

5.4.1. Strengths and weaknesses

5.4.1.1. Strengths

1. Big market. The importance of their internal market is an important asset for China. Firstly, for foreign industries, it is really important to be present and have a market share there. Not being in can heavily hurt the companies concerned compared to others having access. The situation of Ericsson is a good example of this. Secondly, this allows Chinese companies to grow and be accounted among the biggest global ones before trying to expand worldwide. In addition, some of the companies that are currently under US sanctions could help them to survive while developing their own technology.
2. Technology basis. Thanks to the technology transfer done in the framework of their advantageous incentives, they have been able to acquire knowledge rapidly, more than other countries, and therefore fill the gap with notably the USA. This is important because, in their quest to become autonomous in many segments, such as semiconductors, it will accelerate it.
3. Some big players. Despite many industries being dominated by US companies, China has some big ones. The first one in the ICT industry is obviously Huawei, which had been among the leader in many segments: such as mobile equipment and smartphone, even though the situation is more difficult presently due to the US sanctions notably. Other companies are also important such as Lenovo (personal computer), Xiaomi, vivo, and OPPO (smartphone); Huawei and ZTE (5G equipment).

5.4.1.2. Weaknesses

1. Bad relationship with the US and Europe: While a few years ago, this would have been a threat, presently, the situation made it a weakness. This is negatively impacting China for the

moment because they have less access to certain important markets but also to some advanced technologies.

2. Technology lag. Despite a good technology basis, China still relying a lot on American technology. This means that to be self-sufficient, they will need to invest mainly in R&D to catch up with the USA. This process will take several before arriving at a comparable level to the US one.

5.4.2. The most crucial points

5.4.2.1. Speed to close the technology gap

Despite having several companies among the giant tech firms, China still has a technological gap with the US mainly, as this has been seen with the US sanctions against notably Huawei, which has to use old technology, in the first instance. Therefore, they will have to close this gap before having the possibility to really run by themselves. To achieve that, this will obviously go through the investment in R&D that will need to increase but also in terms of talents, centers, and contracts. First, the talents are obviously necessary because they are the ones that will innovate and find new technologies and solutions. Taiwan has said at the end of March that China was poaching talent from the island in order to boost their semiconductor self-sufficiency (Reuters Staff 2021b). Secondly, big R&D centers will help this initiative because it will allow researchers to focus on one topic while having a dedicated space to work faster and better. Finally, they will need to make contacts with the most different actors possible to allow them to be supplied and to have buyers of their products. This will obviously be needed from Chinese firms, but foreign should also be needed to reach other markets than their internal.

5.4.2.2. Their expansion to other markets

Another important point for Chinese technology is, are they going to have access to other markets, and especially European and American ones? Their internal market can allow Chinese companies to survive and even more thanks to its size, but if they want to overtake the biggest companies in the world in the long term, they need to reach the other ones and to establish themselves in the long term. Although not all companies and not all products have been banned from these markets, the current situation makes this difficult to believe that full access for everything will be provided, especially if the products are mainly or totally done with Chinese components. Several scenarios could be imaginable, making all the products with Chinese components and potentially renouncing to the other markets (the opposite and therefore renouncing to the Chinese market is another scenario but seems impossible) or using both components depending on the final market.

5.4.3. In 2030, what is the position that China could expect?

For China, it can be expected, notably with the R&D investment announced, that they will arrive at the correct level of chip manufacturing, advanced enough compared to the future level, and self-sufficient. They could start competing with the biggest actors on the design and foundries segments. It is actually difficult to imagine this occurs before as China does not only need to develop more advanced but also all the equipment around. In addition, it seems pretty unlikely to see their technology on some markets such as American and European ones, even if it does not mean that no other market than their internal one will accept it. Therefore, at that moment, they will surely stay behind the biggest players but closer than before.

On the 5G, the deployment should continue as of now, and they should not really slow down with their two national champions, Huawei and ZTE. As for the USA, the battle will be on the use that 5G will enable and which one will make the most profit of it. The question for China

is, will they be able to take profit at least at the same pace as other regions without the US technology? On the 6G, if the situation does not change, namely they do not find a non-Chinese partner to develop 6G, they will surely be later than the rest of the world, although this is expecting to arrive around the same period. Another question is about Huawei and ZTE and how the different sanctions will affect them. They lose market share and revenue. Therefore, the investment allocated to the development of 6G, should decrease and unless an intervention for the State, it will almost condemn them.

For the whole traditional ICT industry, they will certainly start being fully autonomous and, therefore, will be able to rely on themselves to grow. The growth will obviously be related to the international political situation and the evolution over the years. Concerning the new technologies, the question is will they be able to release them first? This could be difficult due obviously to US sanctions against some Chinese companies but also because they are investing less in R&D than their US counterpart, and therefore, it could be more difficult for them to follow the rhythm of innovation in the near future.

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Appendices

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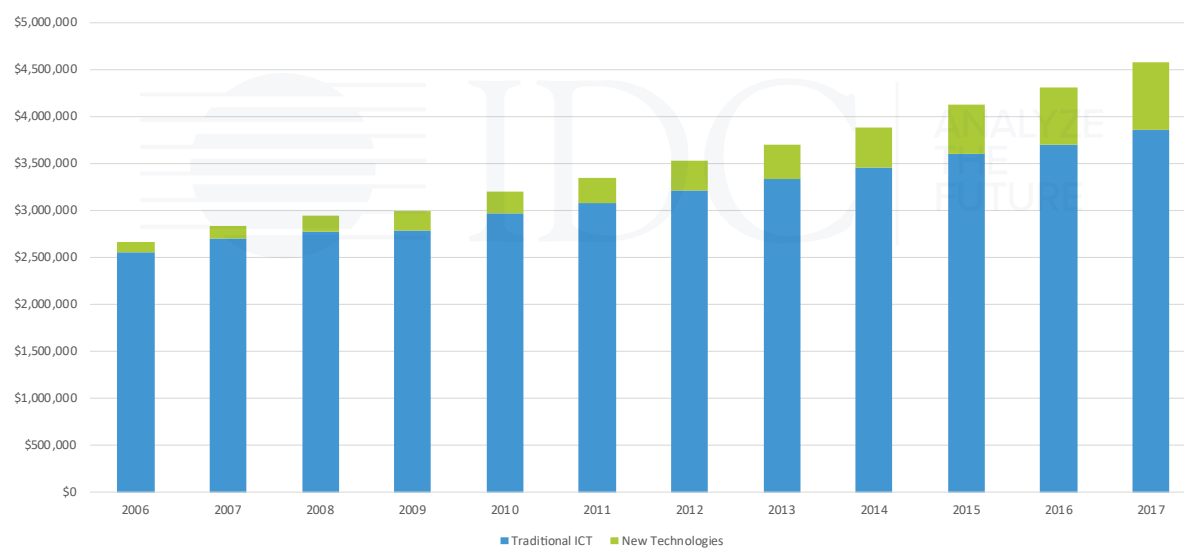
Appendix 20: 2G/3G/LTE mobile infrastructure market share 2018

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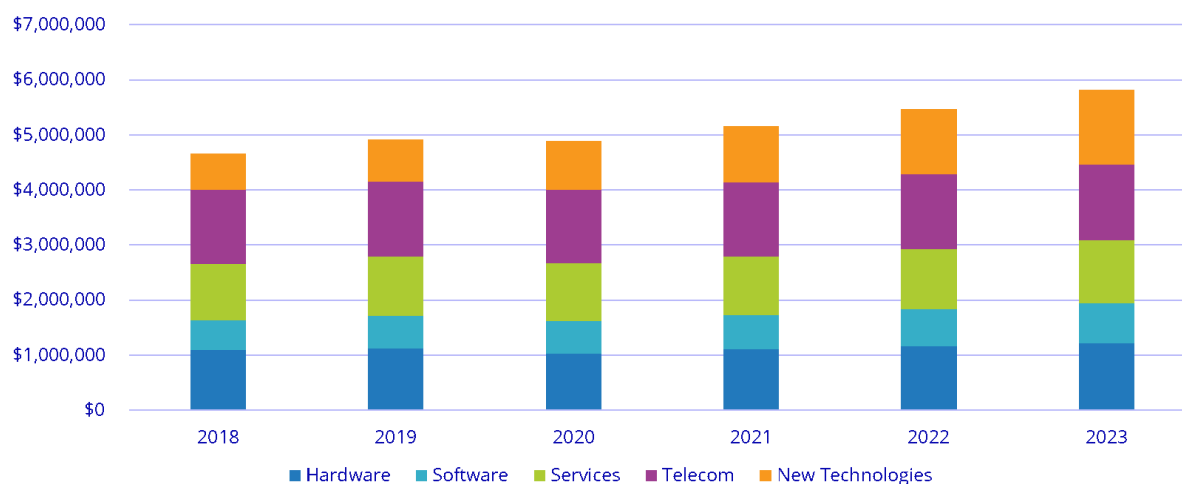
Appendix 23: The G Factors: How different generations of wireless networks compare with each other

Appendix 1: Worldwide ICT spending

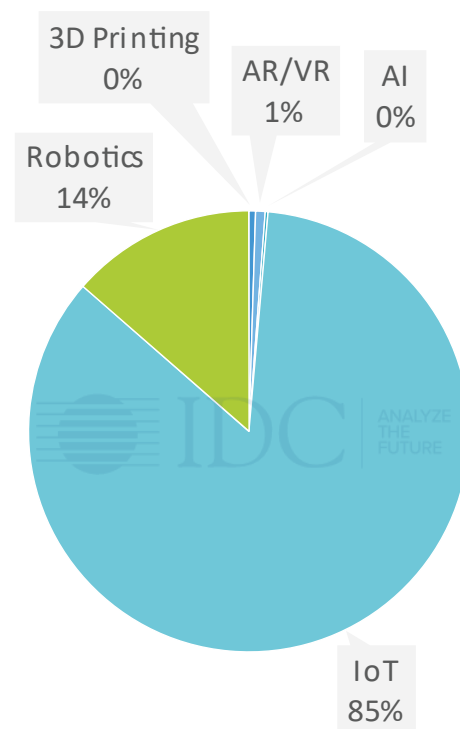


Source: IDC. (n.d.-a). *Global ICT spending—2007—2017 (\$3.8T in 2017)*. IDC. Retrieved July 15, 2021, from <https://www.idc.com/promo/global-ict-spending>

Appendix 2: Worldwide ICT Spending 2018-2023 (\$Million, Constant Currency)

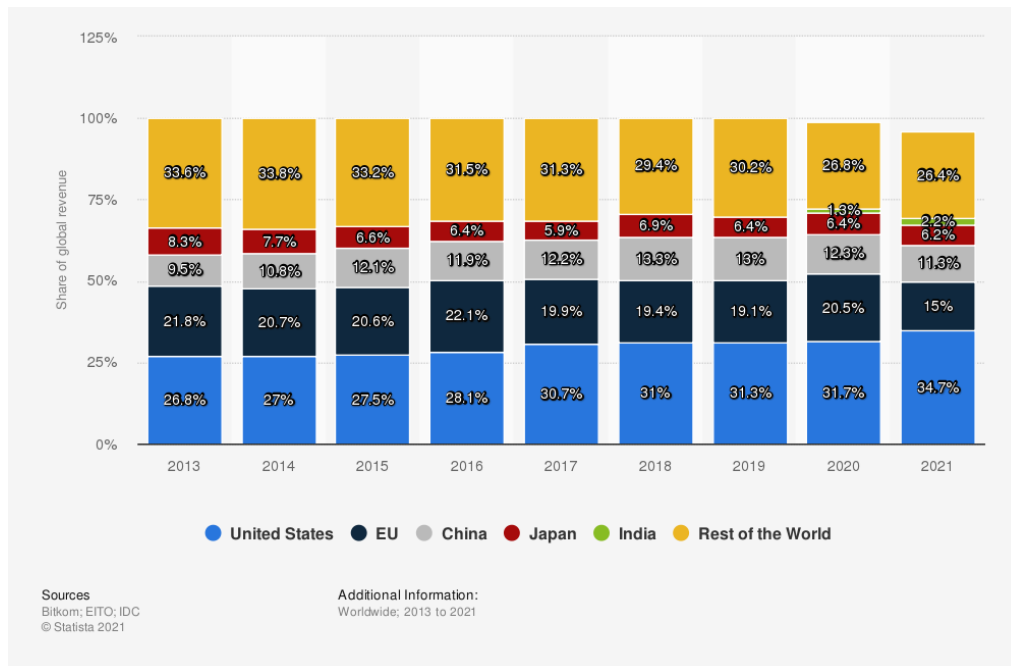


Source: IDC. (n.d.-b). *Global ICT spending—Forecast 2020 – 2023*. IDC. Retrieved July 13, 2021, from <https://www.idc.com/promo/global-ict-spending/forecast>

Appendix 3: Worldwide spending in New Technologies 2017

Source: IDC. (n.d.-a). *Global ICT spending—2007—2017 (\$3.8T in 2017)*. IDC. Retrieved July 15, 2021, from <https://www.idc.com/promo/global-ict-spending>

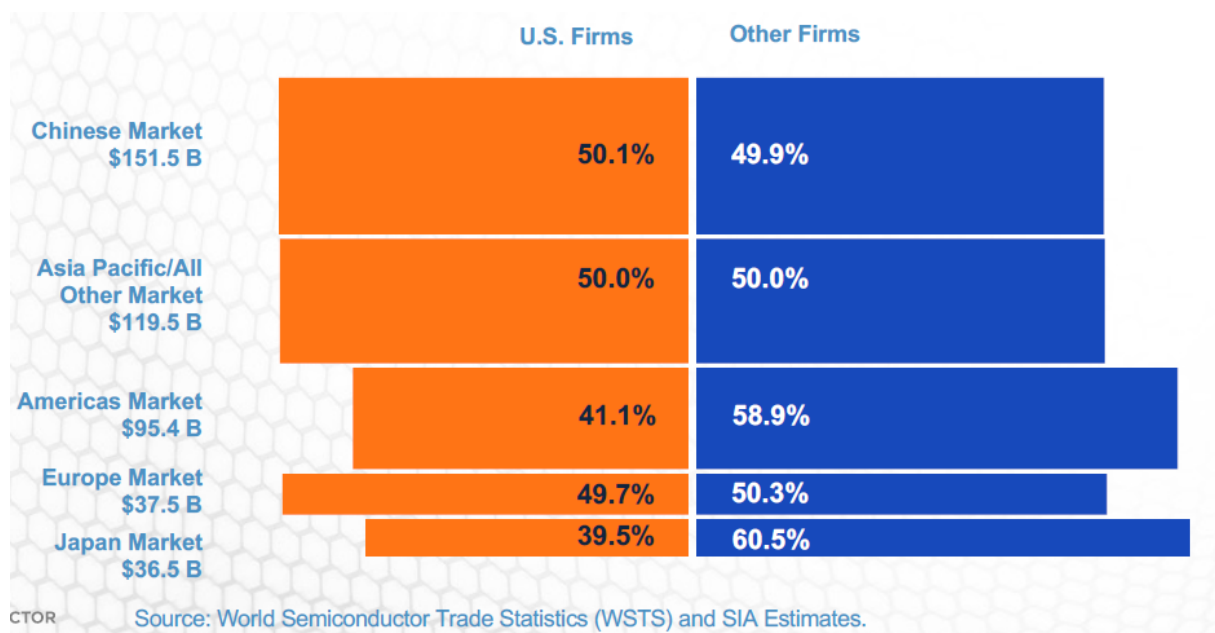
Appendix 4: Global market share of the information and communication technology (ICT) market from 2013 to 2021, by country/region



Source: Bitkom. (2021). *Global market share of the information and communication technology (ICT) market from 2013 to 2021, by country/region* [Graph]. Statista.

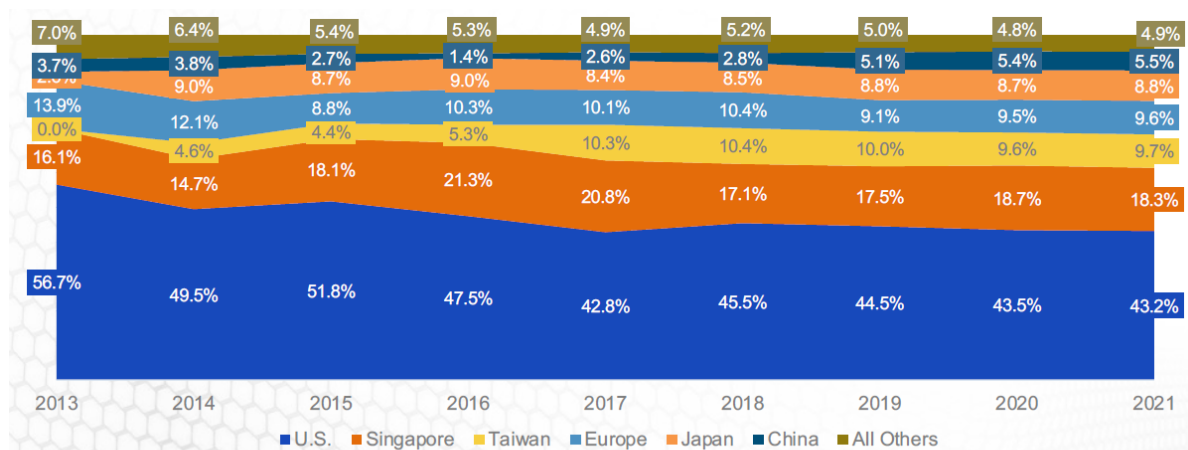
<https://www.statista.com/statistics/263801/global-market-share-held-by-selected-countries-in-the-ict-market/>

Appendix 5: Share of US-based semiconductor companies in major regional semiconductor markets



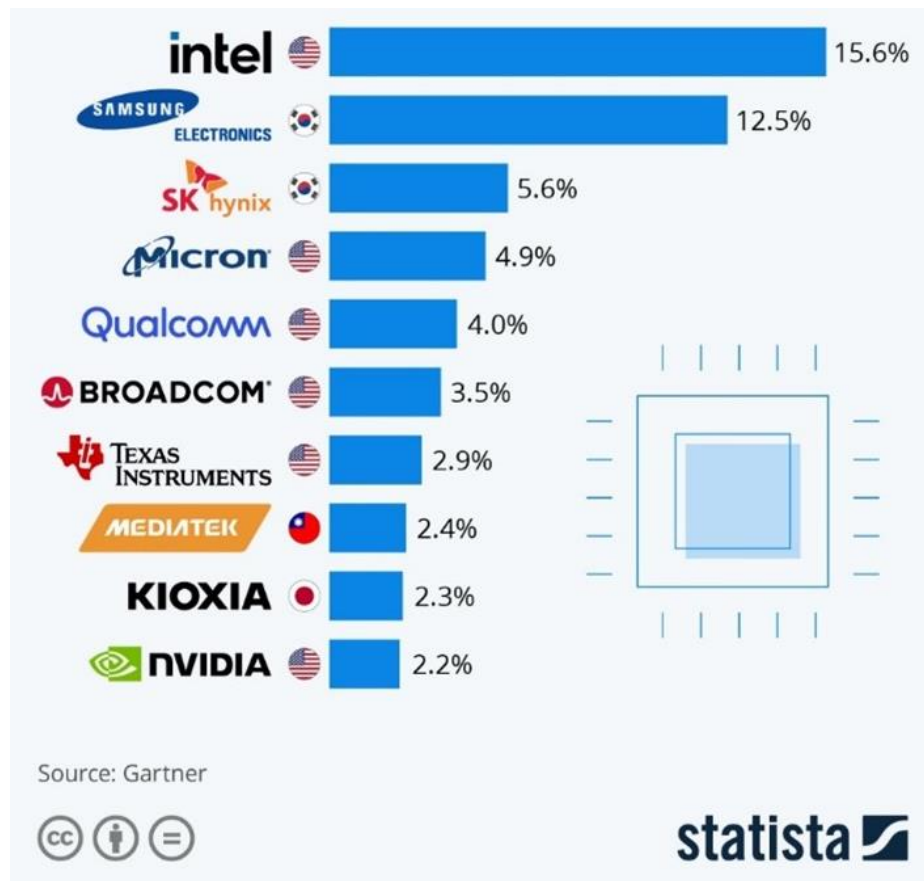
Source: Semiconductor Industry Association. (2021a). *2021 factbook*. <https://www.semiconductors.org/wp-content/uploads/2021/05/2021-SIA-Factbook-FINAL1.pdf>

Appendix 6: Share of capacity of US-based companies in the world



Source: Semiconductor Industry Association. (2021a). *2021 factbook*. <https://www.semiconductors.org/wp-content/uploads/2021/05/2021-SIA-Factbook-FINAL1.pdf>

Appendix 7: Market shares of the world's biggest semiconductor producers in 2020



Source: Buchholz, K. (2021). *Intel and Samsung lead global semiconductor production* [Digital image]. Statista.

<https://www.statista.com/chart/24485/biggest-semiconductor-producers/>

Appendix 8: Top 35 global semiconductor companies, by revenue in 2019

	Company	Country	Business model (major technology segment)	2019 revenue
#1	Intel	U.S.	IDM (NAND, CPUs, GPUs)	\$65.8B
#2	Samsung Electronics	South Korea	IDM (NAND, DRAM)	\$52.2B
#3	TSMC	Taiwan	Contract foundry	\$35.8B
#4	SK Hynix	South Korea	IDM (NAND, DRAM)	\$22.4B
#5	Micron	U.S.	IDM (NAND, DRAM)	\$20B
#6	AMAT (Applied Materials) (*1)	U.S.	SME	\$17.2B
#7	Broadcom	U.S.	Fabless (SoCs)	\$15.3B
#8	ASE Technology Holding (*SPIL included)	Taiwan	OSAT	\$13.8B
#9	Qualcomm	U.S.	Fabless (CPUs)	\$13.5B
#10	Texas Instruments	U.S.	IDM (analog, automotive, SoCs, FPGA)	\$13.2B
#11	ASML Holding	Netherlands	SME (extreme ultra violet lithography)	\$13.2B
#12	Nvidia	U.S.	Fabless (GPUs and SoCs)	\$10.9B
#13	TEL (Tokyo Electron) (*2)	Japan	SME	\$10.4B
#14	Lam Research (*3)	U.S.	SME	\$10B
#15	Sony (*2)	Japan	IDM (CMOS image sensors)	\$9.8B
#16	STMicroelectronics	France, Italy	IDM (analog, automotive, SoCs, sensors)	\$9B
#17	Infineon Technologies (*4)	Germany	IDM (analog, automotive, sensors)	\$8.9B
#18	Kioxia Holdings	Japan	IDM (NAND)	\$8.8B
#19	NXP Semiconductors	Netherlands	IDM (analog, automotive, SoCs, sensors)	\$8.7B
#20	MediaTek	Taiwan	Fabless (CPUs)	\$8.2B
#21	Western Digital/ SanDisk (*5)	U.S.	IDM (NAND)	\$7.8B
#22	HiSilicon	China	Fabless (SoCs)	\$7.4B
#23	AMD (Advanced Micro Devices)	U.S.	Fabless (CPUs, GPUs)	\$6.7B
#24	Renesas Electronics	Japan	IDM (analog, automotive, CPUs, sensors)	\$6.6B
#25	Analog Devices (*6)	U.S.	IDM (analog, SoCs, sensors)	\$5.9B
#26	KLA-Tencor (*3)	U.S.	SME	\$5.8B
#27	ON Semiconductor	U.S.	IDM (analog, automotive)	\$5.5B
#28	Microchip Technology	U.S.	IDM (analog, automotive, SoCs, sensors)	\$5.3B
#29	Synopsys (*6)	U.S.	EDA	\$3.4B
#30	JCET Group	China	OSAT	\$3.3B
#31	Xilinx (*7)	U.S.	Fabless (FPGA, SoCs)	\$3.2B
#32	SMIC	China	Contract foundry	\$3.1B
#33	Cadence Design Systems	U.S.	EDA	\$2.3B
#34	Tsinghua Unigroup	China	IDM (memory and other IC)	\$2.2B
#35	ARM (*2)	UK	IP blocks	\$1.9B

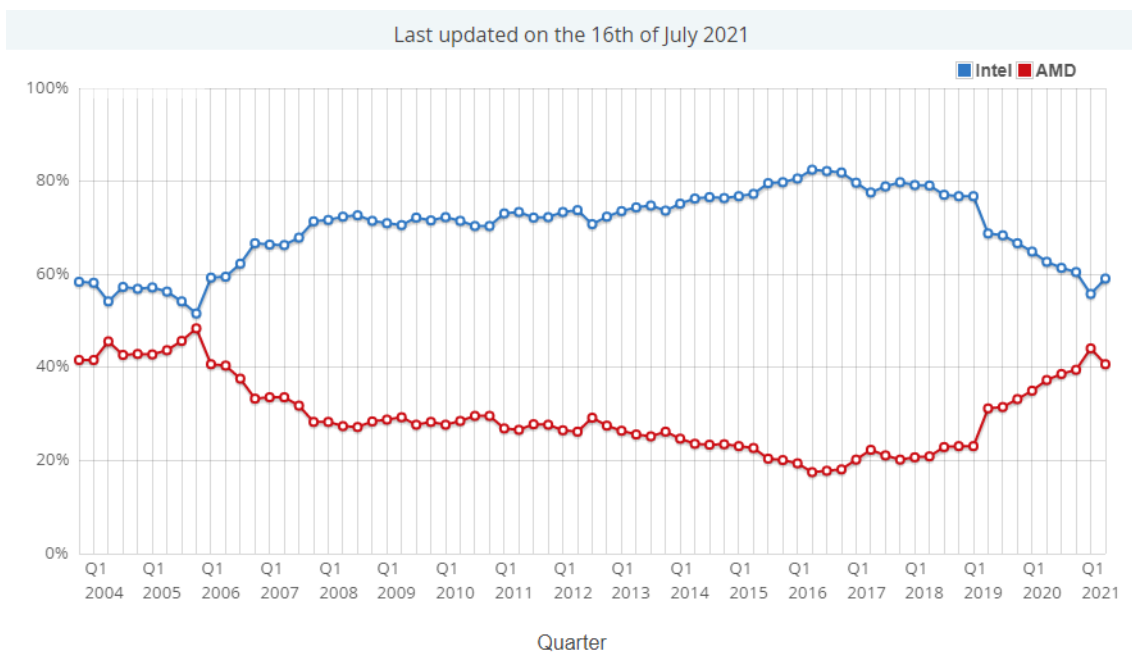
(*1) Fiscal year ended October 2019; (*2) fiscal year ended March 2020; (*3) fiscal year ended June 2020; (*4) fiscal year ended September 2019; (*5) fiscal year ended July 2020; (*6) fiscal year ended November 2019; (*7) fiscal year ended April 2020.

SOURCE: Institut Montaigne, Gartner

Source: Cerulus, L. (2021, January 14). *Experts urge Europe to up its game on microchips*. POLITICO.

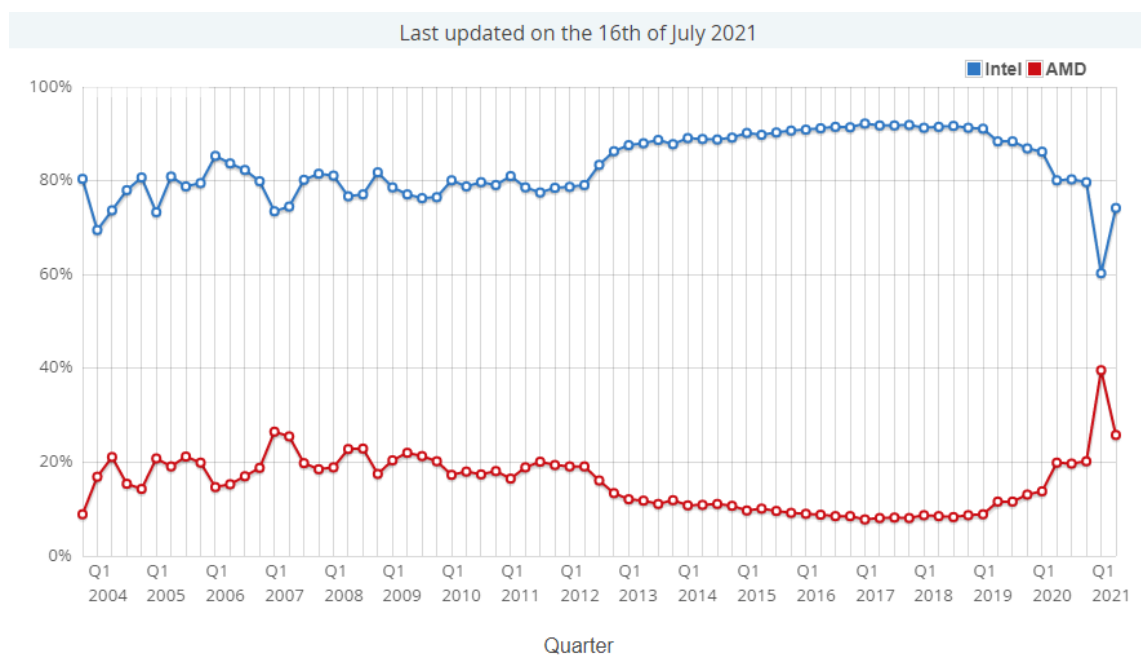
<https://www.politico.eu/article/europe-microchip-technology-autonomy-production-china-semiconductors/>

Appendix 9: AMD vs Intel Market Share (All CPUs)



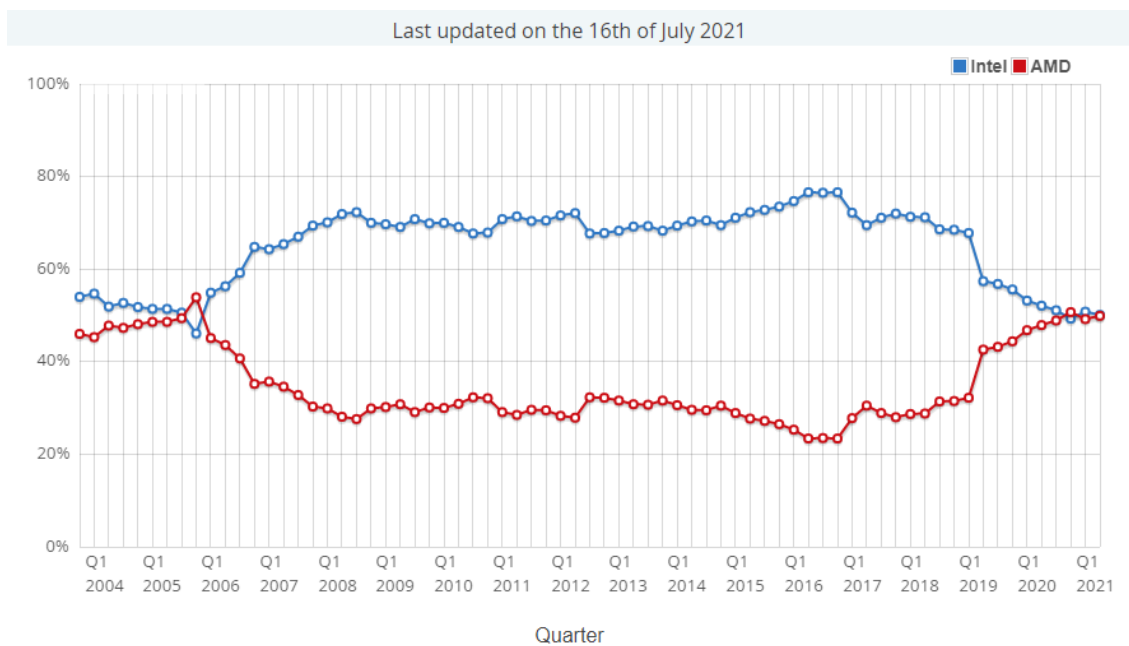
Source: PassMark (CPU Benchmark). (n.d.). *AMD vs Intel market share*. CPU Benchmarks. Retrieved July 16, 2021, from https://www.cpubenchmark.net/market_share.html

Appendix 10: AMD vs Intel Market Share (Laptop Market Share)



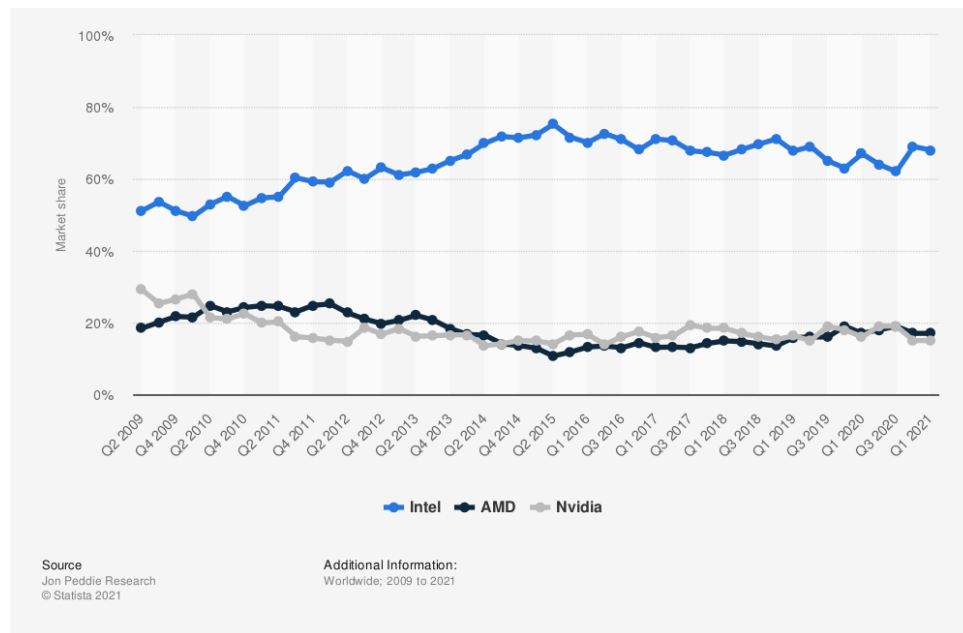
Source: PassMark (CPU Benchmark). (n.d.). *AMD vs Intel market share*. CPU Benchmarks. Retrieved July 16, 2021, from https://www.cpubenchmark.net/market_share.html

Appendix 11: AMD vs Intel Market Share (Desktop Market Share)



Source: PassMark (CPU Benchmark). (n.d.). *AMD vs Intel market share*. CPU Benchmarks. Retrieved July 16, 2021, from https://www.cpubenchmark.net/market_share.html

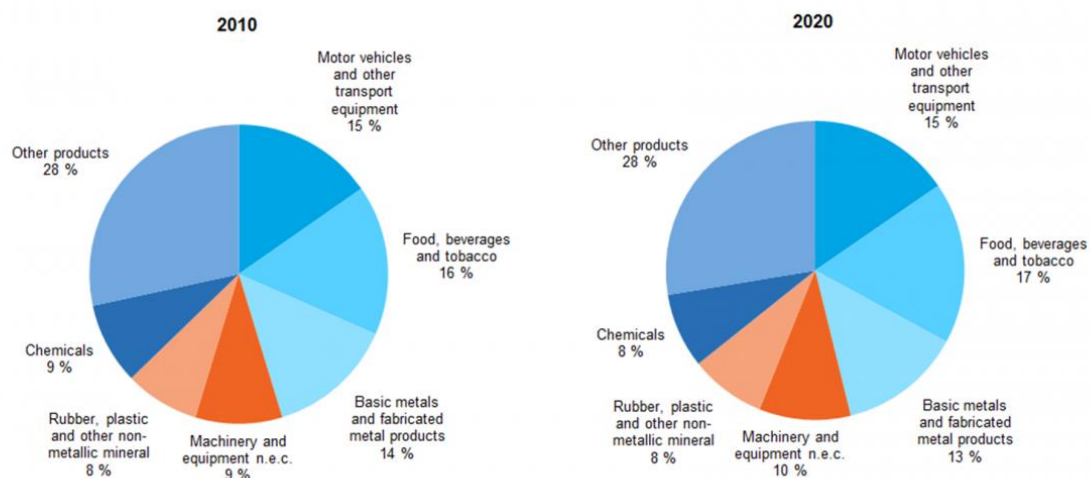
Appendix 12: PC graphics processing unit (GPU) shipment share worldwide from 2nd quarter 2009 to 1st quarter 2021, by vendor



Source: Jon Peddie Research. (2021). *PC graphics processing unit (GPU) shipment share worldwide from 2nd quarter 2009 to 1st quarter 2021, by vendor* [Graph]. Statista.

<https://www.statista.com/statistics/735904/worldwide-x86-intel-amd-market-share/>

Appendix 13: Value of sold production by group of manufacturing activity, EU, 2010 and 2020 (% share of total sold production)



Note: EU-27 except Cyprus, Luxembourg, Malta

Other products: Wood and paper, and printing; Furniture, other manufacturing and installation of machinery and equipment; Electrical equipment; Computer, electronic and optical products; Textiles, wearing apparel and leather; Pharmaceutical products; Mining

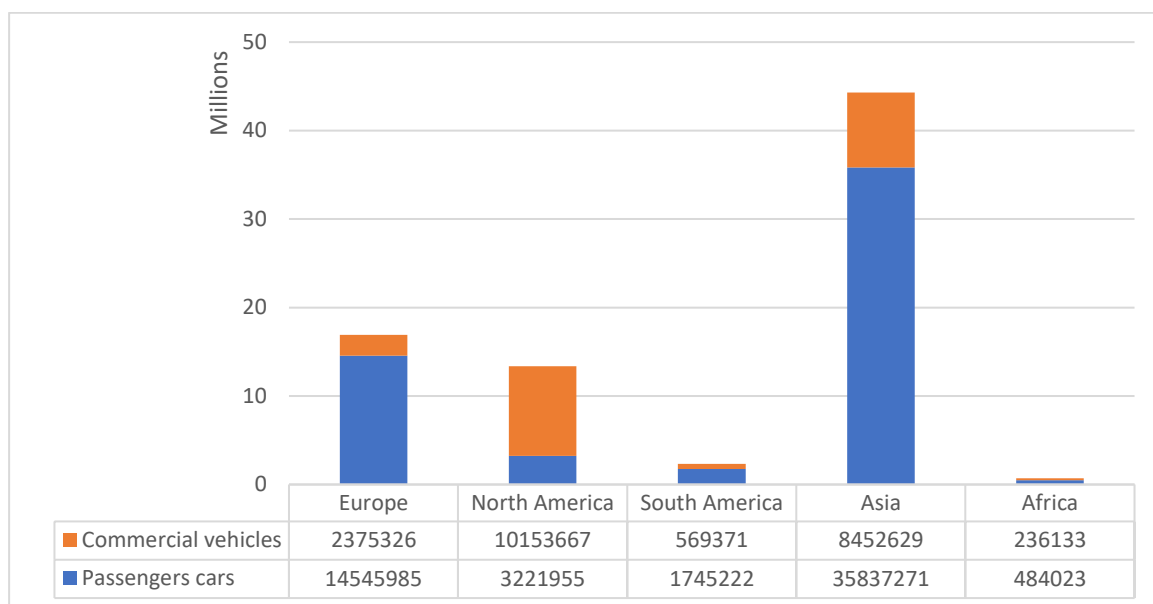
Source: Eurostat (online data code: DS-066341)

eurostat 

Source: eurostat. (2021, July 14). *Industrial production statistics*. Eurostat.

https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Industrial_production_statistics

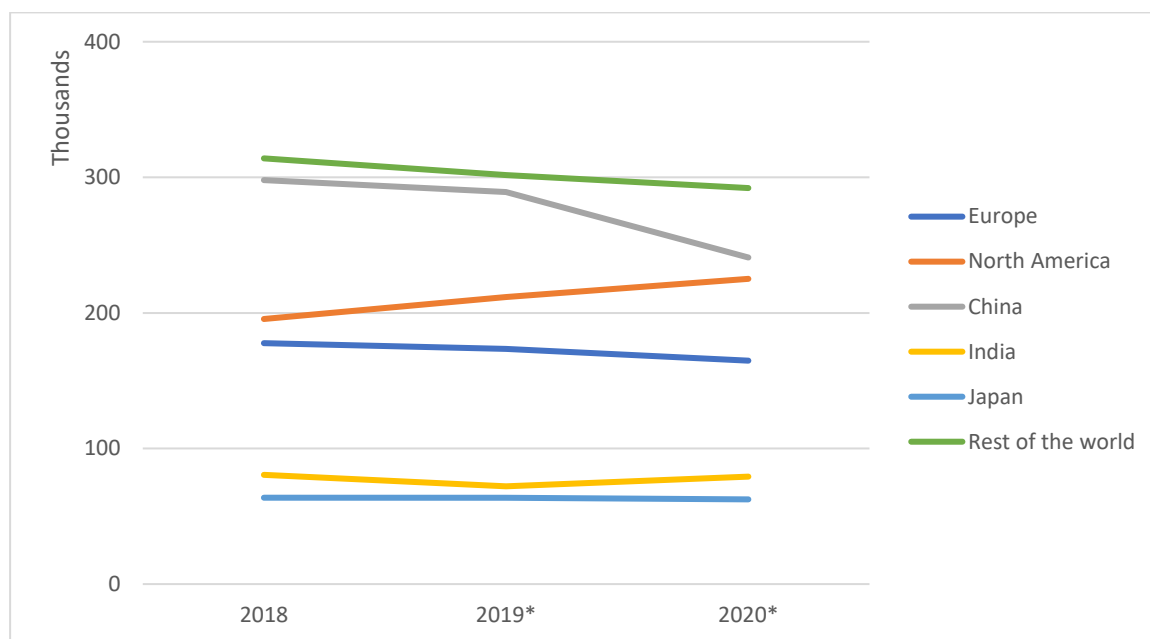
Appendix 14: 2020 Production of cars (Units)



Source: OICA

Appendix 15: Worldwide sales and sales forecasts of construction equipment, 2017-2022

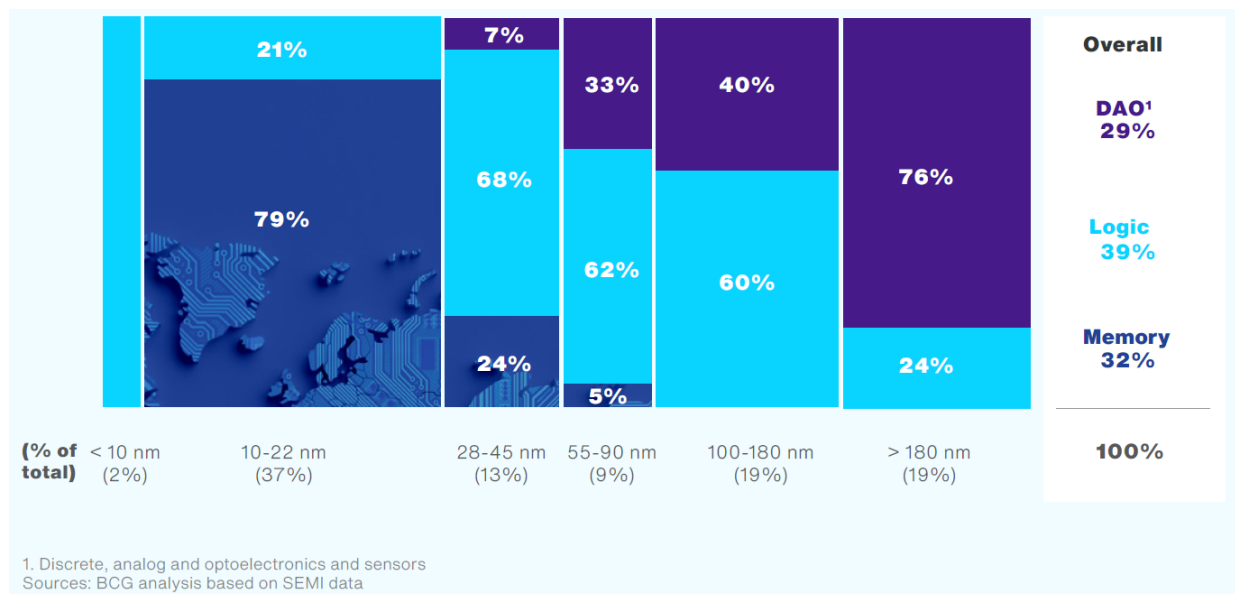
(Units)



*Forecasted in 2019

Source: Off-Highway Research

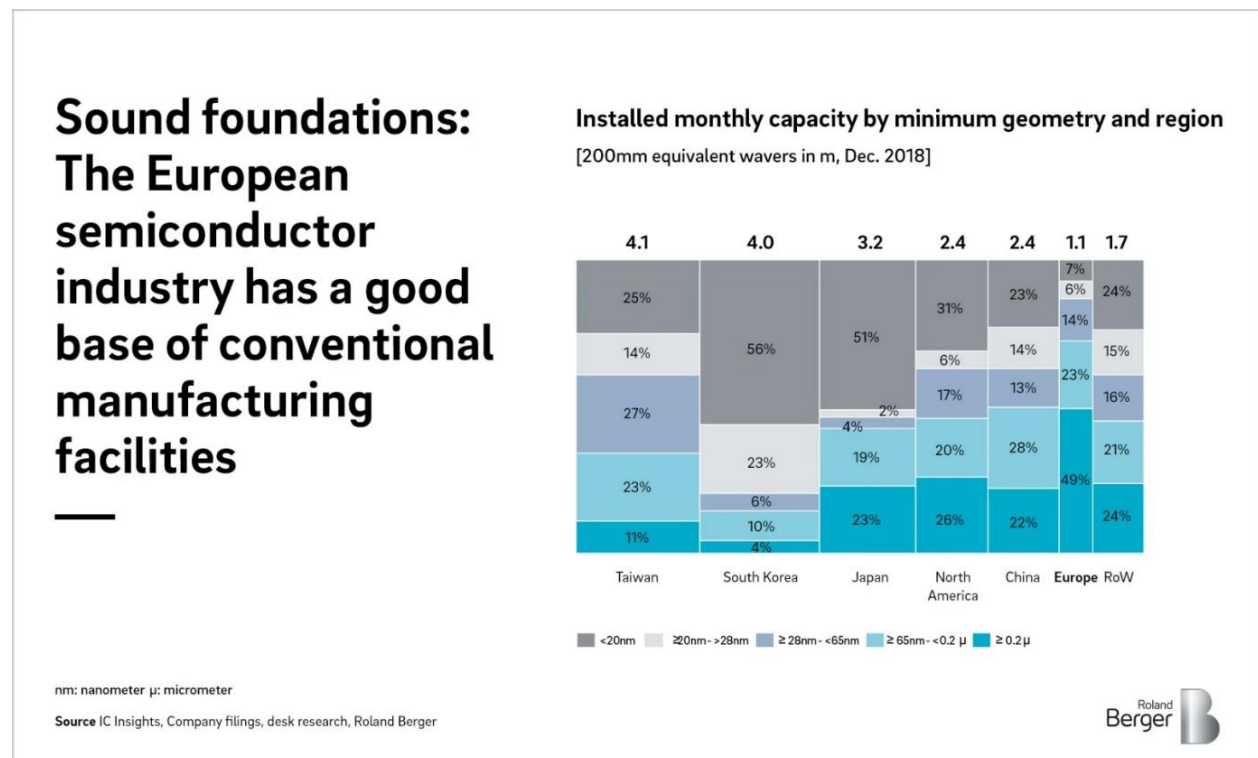
Appendix 16: Global manufacturing capacity by node and semiconductor type, 2019 (% of 8” equivalent wafers per month)



Source: Varas, A., Varadarajan, R., Goodrich, J., & Yinug, F. (2021). *Strengthening the global semiconductor supply chain in an uncertain era*. Boston Consulting Group & Semiconductor Industry Association.

https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf

Appendix 17: Installed monthly capacity by minimum geometry and region



Source: Alexander, M., & Kirschstein, T. (2021, February 12). *A path to success for the EU semiconductor industry*. Roland Berger. <https://www.rolandberger.com/en/Insights/Publications/A-path-to-success-for-the-EU-semiconductor-industry.html>

Appendix 18: Comparison of government incentives across locations

	US ¹ (%)	Japan (%)	S. Korea (%)	Taiwan (%)	Singapore (%)	Asia avg. ² (%)	China ³ (%)	Germany (%)	Israel (%)
Capex reductions									
Land	50	75	100	50	100	85	100	100	75
Construction and facilities	10	10	45	45	25	33	65	35	45
Equipment	6	10	20	25	30	20	35	5	30
Opex reductions									
Labor and benefits	5	5	5	5	15	7	33	7	5
Tax reductions⁴									
Corporate tax	—	—	60	—	35	30	75	—	74
State tax	100	—	—	—	—	—	—	—	—
Property tax	100	100	100	—	—	60	—	—	—
Overall	10–15	~15	25–30	25–30	25–30	~25	30–40	10–15	~30

Source: BCG analysis.

Note: Incentives are on the first ten years of operation. All countries also include a 100% reduction on equipment-import costs and a 5% R&D write-off and deferral; not exhaustive.

¹ Based on a best-case scenario with current incentives and recent agreements.

² Excluding China.

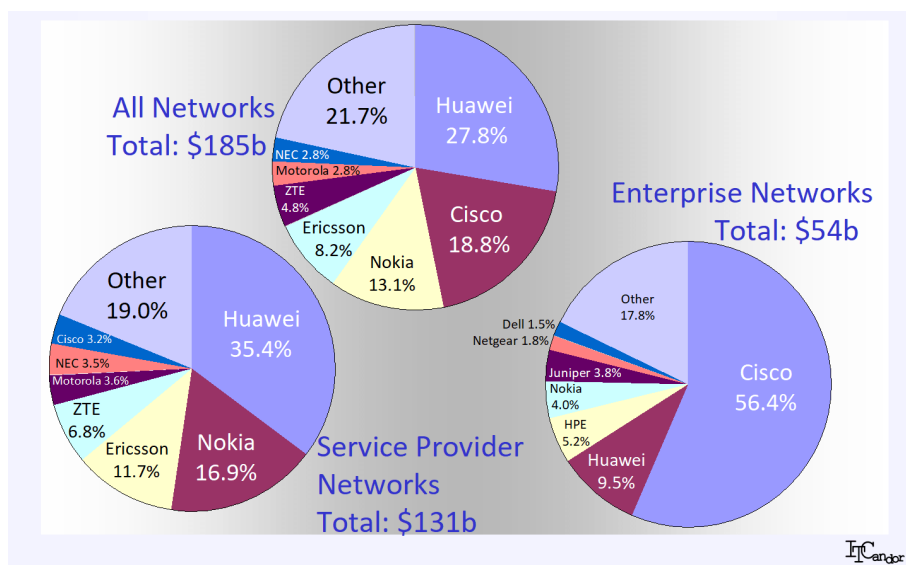
³ Mainland China.

⁴ The effective tax rate is considered separately from generally available incentives and is based on current statutes.

Source: Varas, A., Varadarajan, R., Goodrich, J., & Yinug, F. (2020). *Government incentives and US*

competitiveness in semiconductor manufacturing. Boston Consulting Group & Semiconductor Industry Association. <https://www.semiconductors.org/wp-content/uploads/2020/09/Government-Incentives-and-US-Competitiveness-in-Semiconductor-Manufacturing-Sep-2020.pdf>

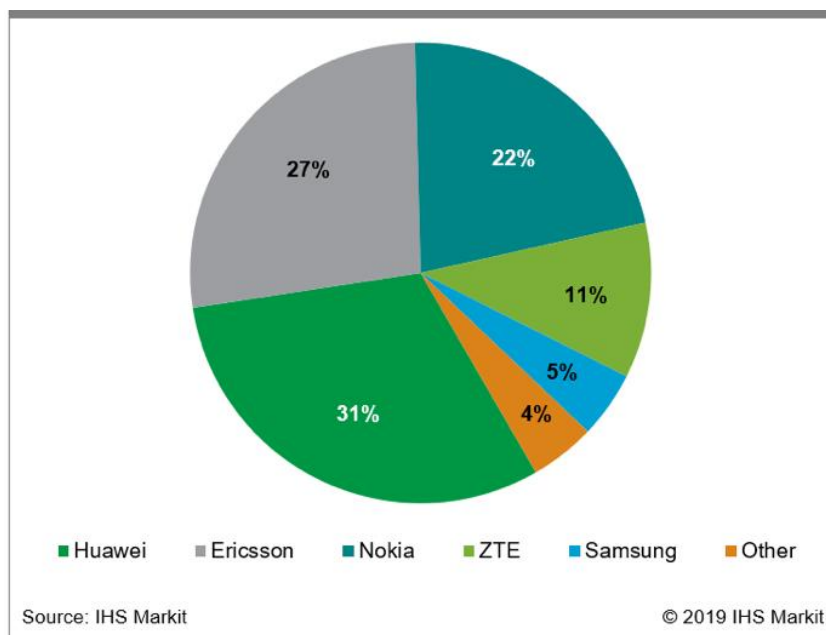
Appendix 19: Network market shares (\$US billion) all, service provider, enterprise - 2019



Source: ITCandor. (2020, March 30). *Networks – \$185b, 2.1b ports shipped in 2019*. ITCandor.

<https://www.itcandor.com/network-2019/>

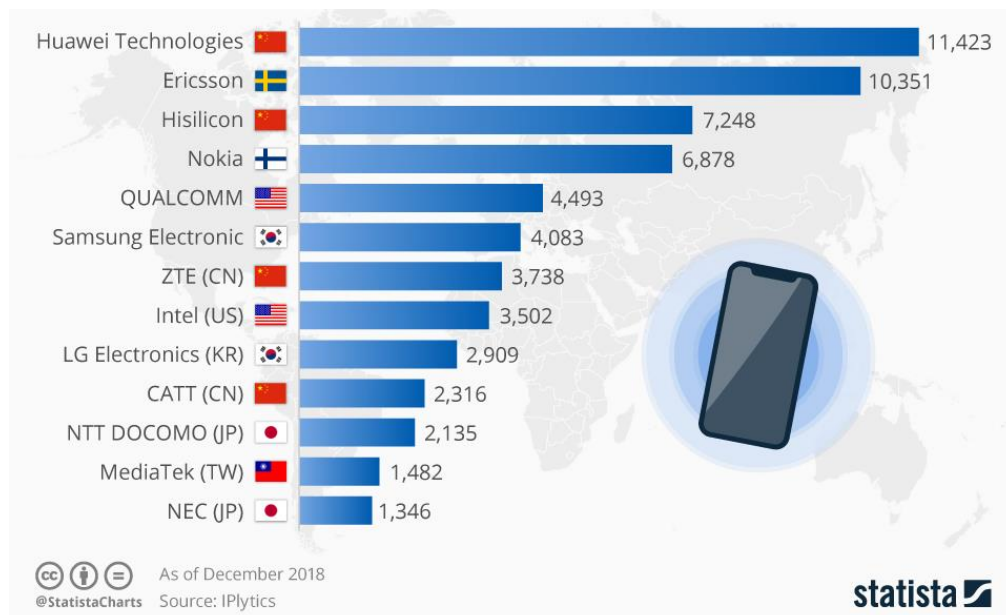
Appendix 20: 2G/3G/LTE mobile infrastructure market share 2018



Source: Téral, S. (2019, April 3). *IHS Markit: Huawei led global 4G LTE infrastructure market which totalled \$22.9B in 2018; China CAPEX bottoms out*. Technology Blog.

<https://techblog.comsoc.org/2019/04/03/huawei-led-global-4g-lte-infrastructure-market-which-totalled-22-9b-in-2018/>

Appendix 21: Who is leading the race to develop 5G? Number of 5G standard technical contributions by company worldwide



Source: Feldman, S. (2019). *Huawei is leading the race to develop 5G* [Digital image]. Statista.

<https://www.statista.com/chart/17536/mobile-network-standards/>

Appendix 22: The top 10 countries: 5G leaderboard



Source: VIAVI. (2021). *The state of 5G deployments surge despite global pandemic*. VIAVISION.

<https://www.viavisolutions.com/es-es/literature/state-5g-deployments-2021-posters-en.pdf>

Appendix 23: The G Factors: How different generations of wireless networks compare with each other

Generation	Peak Download Speed	Lowest Latency	Use Cases
3G	42 Mbps	58 milliseconds	Internet-connected phones; multimedia messaging
4G	300 Mbps	36 milliseconds	Smartphone; media streaming; video conferencing
5G	10,000 Mbps (10 Gbps)	1 millisecond	High-definition streaming; autonomous cars; Internet of Things
6G	1 million Mbps (1 Tbps)	0.1 millisecond	Holographic imaging; flying cars; Internet of Everything, including connected bodies and brains

Source: Bloomberg

Bloomberg

Source: Zhao, S., Moritz, S., & Seal, T. (2021, February 8). Forget 5G, the U.S. and China are already fighting for 6G dominance. *Bloomberg.Com*. <https://www.bloomberg.com/news/features/2021-02-08/forget-5g-the-u-s-and-china-are-already-fighting-for-6g-dominance>