Is Digitalisation Boosting the Decarbonisation of Industries?

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Abstract

Growth in the industrial sectors plays a key role in global economic growth. However, it also contributes to CO_2 emissions due to the use of fossil fuels. Digitalisation has changed the way companies operate in the market; nevertheless, it is not clear whether digital technologies contribute to environmental sustainability for industries and businesses. From one point of view, modern information and communication technologies (ICTs) are energy efficient and reduce overall electricity consumption. However, the expansion of ICTs and the quantity of systems available are also likely to increase the carbon footprint of industries. Therefore, we quantify the net effects of ICTs on electricity consumption for different industrial sectors, using the latest available data for 14 sectors within 16 countries from 1995 to 2020. We find that investments into ICT capital reduce relative electricity use for all industrial sectors by 7.8% for a 1% increase in ICT capital, and this effect is stronger for manufacturing than services. Furthermore, with technological innovations over the past decades, ICTs show a stronger energy-saving effect in more recent years. Lastly, we analyse cross-country differences in an attempt to shed light on the role of digitalisation in the decarbonisation of Europe, and find that industrial sectors in Germany and the UK benefit the most from the net energy-saving effects of ICTs. These results provide useful insights to industrial sectors, businesses, and policymakers, motivating them to adopt modern digital technologies to reduce their carbon footprint and reach the climate target of net-zero emissions.

1 Introduction

The use of digital technologies in the global industrial sectors has substantially increased since the beginning of the 21st century, with a surge in the use of computing devices, communication equipment, software, smartphones, and the internet. This has revolutionised the industrial sectors and changed the way that companies operate and compete in the market. Although the expansion of the manufacturing and services sectors has a prominent role in the global economic growth, industrial sectors also contribute to about 23% of global greenhouse gas (GHG) emissions (Energy and Climate Intelligence Unit, 2021). These are primarily caused by the burning of fossil fuels, as well as through chemical reactions and leaks from industrial processes, consequently having a significant impact on the environment. The Intergovernmental Panel on Climate Change (2018) recommends that to stay within the climate change target of 1.5°C, GHG emissions are required to reach net-zero by 2050. Thus, the carbon footprint of industries cannot be ignored, and it is important for policymakers worldwide to balance economic growth and sustainability.

To protect the planet and tackle the issue of climate change, the United Nations Sustainable Development Goals (SDGs) were created in 2015, encompassing 17 goals, of which SDG 9 focuses on industry, innovation, and infrastructure, and SDG 13 emphasises on climate action. The use and implementation of modern information and communication technologies (ICTs) can accelerate the advancement towards achieving all of the 17 SDG goals (ITU, 2021). Focusing on sustainable industrialisation, ICTs can increase productivity and foster innovation (ITU, 2017); however, they also represent about 10% of worldwide electricity consumption, consequently having a significant impact on carbon emissions (Gelenbe, 2023). Electricity constitutes an increasingly greater share in businesses' variable costs over the last several decades, rising by about 35% since 1995 (Figure 1).

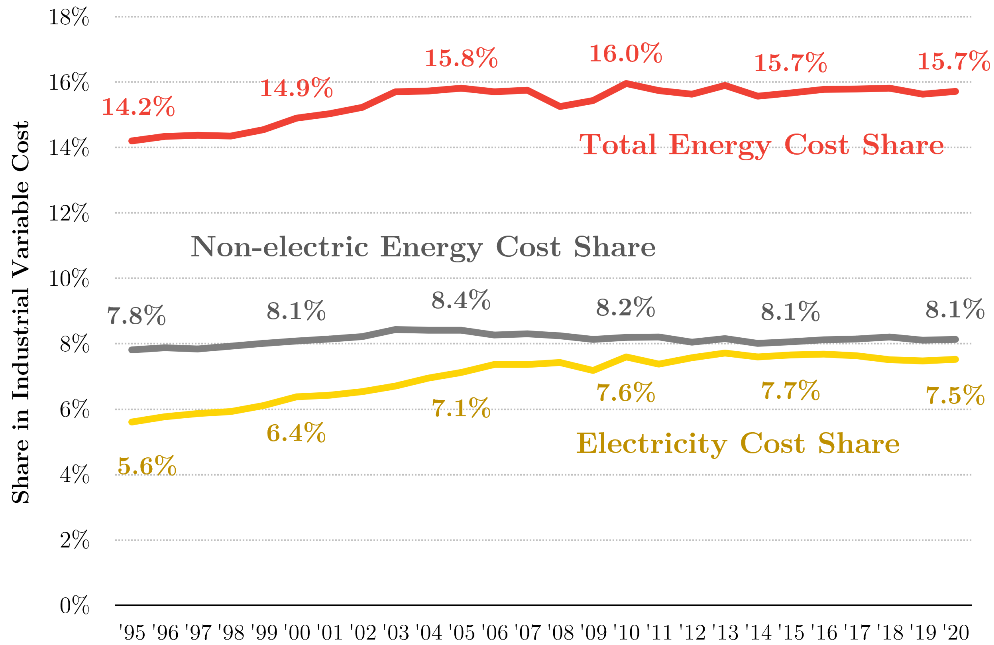

Figure 1: Share of the cost of energy in total industrial variable cost, 1995-2020. Data taken from the IEA (2023a, 2024).

In other words, the expansion of industries and businesses contributes to economic growth; however, it comes at a cost of increasing the industrial carbon footprint. Substantial adoption of digital technologies can help balance this and, therefore, it is crucial to understand the net effect of greater ICT capital investments on industrial energy use. This is particularly important when businesses are committed to environmental sustainability, and it is still not clear whether greater digitalisation results in increased decarbonisation. From one point of view, modern ICTs are more energy efficient and consequently reduce relative demand for energy, contributing to green growth (Taneja and Mandys, 2022). However, with the expansion of ICTs and greater number of systems, the overall carbon footprint is also increasing. The use of ICT capital has increased substantially in the last few decades, increasing over eight-fold since 1995. Consequently, the share of ICT capital in total industry capital rose from only 3.2% in 1995, to over 16% in 2020 (Figure 2). Moreover, there is also a rise in energy intensive digital services where electricity consumption is high, such as data centres and switching rooms (Sorrentino et al., 2016).

Therefore, adoption of ICTs can have an "energy efficiency" effect (reduce relative energy use) or an "energy use" effect (increase relative energy use) (Schulte et al., 2016), and it is still unclear which one of these effects dominate. Previous studies, such as Schulte et al. (2016) and Taneja and Mandys (2022), found that digital technologies have net energy saving effect, whereas other studies, such as Saidi et al. (2017) and Lange et al. (2020) found ICTs to increase energy use. Ultimately, it is an empirical question as to whether ICTs have a positive or a negative net effect on the energy consumption of businesses and the industrial sectors in the current digital era.

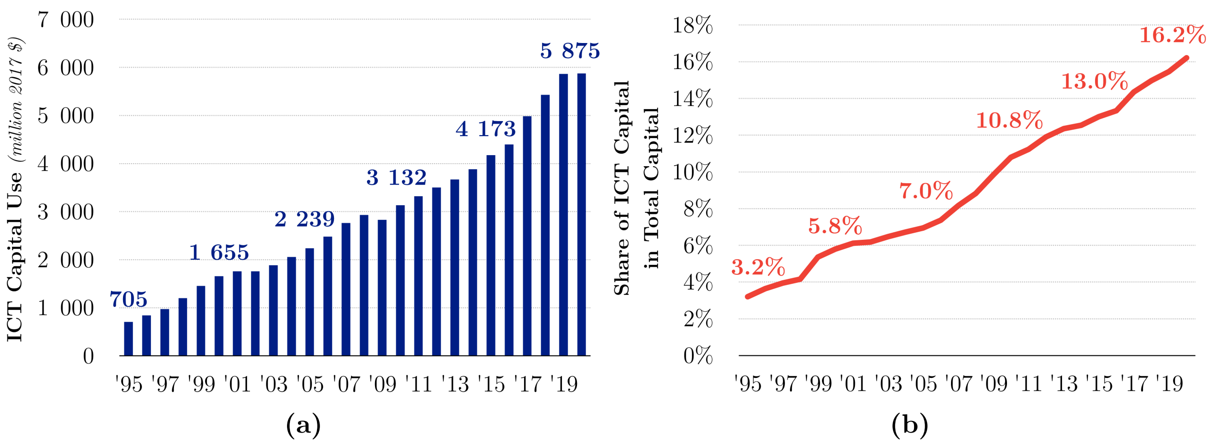

Figure 2: (a) Level of ICT capital use in million 2017 US dollars, and (b) the share of ICT capital in total industry capital, 1995-2020. Data taken from EU KLEMS (Bontadini et al., 2023).

Therefore, using the most up-to-date data, this research provides a significant update on the net effects of ICT adoption on industrial electricity use, for 14 sectors within 16 countries, covering the period of 1995 to 2020. We address the following questions: First, are digital technologies potentially contributing to reducing relative electricity consumption in different industries, consequently boosting decarbonisation of businesses? Second, how are the net energy saving effects of ICTs changing over time for different sectors? And finally, to what extent is digitalisation influencing electricity consumption in a range of countries? To answer these questions, we employ econometric techniques, in particular, we apply the fixed effects ordinary least squares regression on a panel dataset. We then compute the average elasticity of electricity demand with respect to ICT capital using the coefficients generated from the regression, to measure the magnitude of the impact of ICTs on electricity consumption.

2 Literature Review

The literature suggests that there are mixed results found when analysing the impact of digital technologies on industrial energy use. Evidence of a negative association between different types of ICTs and energy use can be found in Taneja and Mandys (2022), examining 13 countries and 28 industrial sectors from 1995 to 2007. The authors confirmed that investments into computing devices and communication equipment can reduce energy use, resulting in greater energy efficiency. Similarly, Schulte et al. (2016) also confirmed a negative relationship between ICTs and total energy demand, when analysing 10 OECD countries, and found that both computing and communication devices also have a negative association with total energy demand. In a separate study, Bernstein and Madlener (2010) focused on manufacturing industries of 8 European countries from 1991 to 2005, and found that communication technologies showed an electricity-saving effect; however, the influence of computing and software was not clear cut.

On the other hand, studies have also found a positive effect of ICT capital on overall energy use. For example, Sadorsky (2012) analysed 19 emerging economies covering the period of 1993 to 2008 and found that ICTs, as measured by internet connection, mobile phones, and PCs, increase electricity consumption. Similar results were also found by Salahuddin and Alam (2016), suggesting that both mobile phones and internet increase electricity consumption. Furthermore, exploring a large range of countries, Saidi et al. (2017) also found ICTs to have a positive relationship with electricity consumption when examining 67 countries from 1990 to 2012, similarly to Lange et al. (2020). Some studies found a mixed effect of ICTs on energy consumption, where less developed countries did not experience a net energy saving effect of ICTs (Arshad et al., 2020).

Previous studies have also focused on one specific country to understand the effect of digitalisation on energy demand of industries and businesses. For example, Collard et al. (2005) studied the French services sector from 1986 to 1998 and concluded that while greater investments into communication equipment reduce energy consumption, computing equipment and software increases it. In a Malaysian study conducted by Solarin et al. (2021) covering the period from 1990 to 2015, evidence of a positive impact of ICTs on electricity consumption was found. Similarly, Ishida (2015) confirmed a moderate reduction in energy consumption due to ICTs in Japan from 1980 to 2010.

In summary, while numerous studies have analysed the impact of digital technologies on energy use, there is evidence of mixed results found in the academic literature. Therefore, it is not clear whether investments in ICT capital contribute to reducing the carbon footprint of industries or cause hindrance to environmental sustainability. In order to help businesses and policymakers, it is important to understand the role of digitalisation in addressing the targets of net-zero emissions. Furthermore, given the ongoing improvements in machinery, i.e., rise in smart technologies and growth of artificial intelligence (AI), it is becoming crucial to have a more recent dataset, which can reflect new developments and evaluate the net impact of modern technologies on energy use. Notice that previous works have used relatively outdated datasets, which are, therefore, not able to capture the current situation of the manufacturing and services sectors. Therefore, we use the most recent and updated dataset, covering the period of 1995-2020 to explore these net effects.

3 Data

To evaluate the overall impact of digital technologies on industrial energy consumption, we construct a dataset by combining information from four specific sources: 1. EU KLEMS & INTANprod Data, 2. Groningen Growth and Development Centre (GGDC) Productivity Level Database, 3. International Energy Agency (IEA) Energy Prices Data, and 4. IEA Extended World Energy Balances. More specifically:

1. **EU KLEMS & INTANprod Data** *(2023 release)*: We construct the use of ICT capital (includes computing equipment, communication devices, and software), non-ICT capital (e.g., transport equipment, machinery, buildings), factor prices (labour wages and total labour cost), and output. These are calculated separately for different countries, sectors, and years (Bontadini et al., 2023).
2. **GGDC Productivity Level Database** *(2023 release)*: This dataset is used for collecting the purchasing power parity (PPP) data for different sectors and countries. PPP values are unique for each sector within each country, and allow us to transform key variables to real-terms and a common currency, i.e., real 2017 US dollars (Inklaar et al., 2023).
3. **IEA Energy Prices Data** *(2023 release)*: We collect the prices of different energy products for different countries over time from the IEA Energy Prices and Taxes Statistics available on the OECD website. This includes industrial prices for e.g., electricity, coal, gas, oil, petroleum products, etc. (IEA, 2023a).
4. **IEA Extended World Energy Balances** *(2024 release)*: The data on industry energy consumption for different sectors and countries over time is taken from the IEA Extended World Energy Balances also available on the OECD website. This includes very detailed energy consumption of e.g., different types of renewable energies, various petroleum products, coal types, etc. (IEA, 2024).

The above data sources are combined to create a balanced panel dataset containing all key variables. This final dataset is used for the empirical analysis and comprises of 16 countries, i.e., Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Netherlands, Portugal, Slovakia, Spain, Sweden, UK and USA. We include 14 separate industrial sectors in our analysis, namely: agriculture, forestry, and fishing; mining and quarrying; food and tobacco (manufacturing); textile and leather (manufacturing); wood, paper, and printing (manufacturing), chemical and petrochemical (manufacturing); non-metallic minerals (manufacturing); iron, steel, and non-ferrous metals (manufacturing); machinery (manufacturing); transport equipment (manufacturing); other manufacturing; construction; transport; and commerce and public services. The time period of the study is from 1995 to 2020.

4 Methodology

Following Schulte et al. (2016) and Taneja and Mandys (2022), we use the short run restricted variable cost function with capital as a quasi-fixed factor (Brown and Christensen, 1980). The industry variable cost combines the cost of energy (electricity in our case), and the cost of labour:

$$VC = P_E E + P_L L \tag{1}$$

Above, VC is the variable cost, P_E is the price of electricity, E is electricity use, P_L is the price of labour, and L is labour use. The variable cost function can be approximated using a translog cost function, using the values of energy prices, labour prices, ICT capital, non-ICT capital, and output. Applying the translog cost function, we can calculate the share of electricity in variable cost using the following regression function:

$$S_E = \beta_0 + \beta_1 \ln\left(\frac{P_E}{P_L}\right) + \beta_2 \ln\left(\frac{P_{NE}}{P_L}\right) + \beta_3 \ln\left(\frac{K_{ICT}}{Y}\right) + \beta_4 \ln\left(\frac{K_N}{Y}\right) + \beta_5 \ln Y + \delta t \tag{2}$$

In Equation 2, S_E is share of electricity in variable cost, P_E is price of electricity, P_{NE} is price of non-electric energy, P_L is price of labour, K_{ICT} and K_N is ICT and non-ICT capital use respectively, Y is output in terms of value added, and t captures time. In order to estimate the above regression function, we use the fixed effects ordinary least squares technique.

This allows us to calculate the value of interest - the percentage change in electricity use after an increase in ICT capital (i.e., an elasticity). The calculation of the elasticity uses the coefficient β_3 from Equation 2, and the total shares of electricity (S_E) and ICT capital (S_{ICT}) in variable cost:

$$\varepsilon_{K_{ICT}}(E) = \frac{\beta_3}{S_E} - S_{ICT} \tag{3}$$

The value of $\varepsilon_{K_{ICT}}(E)$ then represents the percentage change in electricity use after a 1% increase in ICT capital.

5 Results

5.1 Impact of ICTs on Electricity Use in Industrial Sectors

Over the last several decades, the use of ICT capital by businesses and industries has been increasing substantially (Figure 3). While in 1995, ICT capital constituted about 3% of total industry capital, this increased to over 16% by 2020. This rise was particularly prominent in both the services and the manufacturing sectors, although the increase slowed down in the manufacturing sector after the 2008 financial crisis.

Similarly, ICTs have been increasingly adopted by all major economies since 1995. The leaders in this sense are USA and France, approaching a share of ICT capital in total capital of 20%. On the other hand, Germany and UK have been particularly slow in digitalisation, with UK businesses' ICT capital representing only about 3.5% of their total capital.

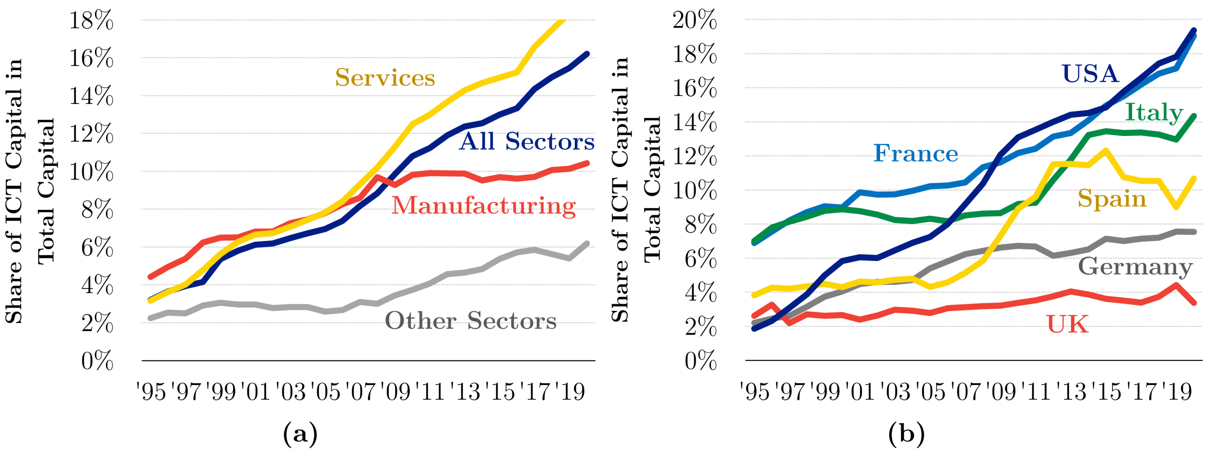

Figure 3: (a) Share of ICT capital in total industry capital across sectors, and (b) across major economies, 1995-2020 (authors' own calculations).

Figure 4 shows the average elasticities of electricity demand with respect to ICTs, by industrial sectors from 1995 to 2020, for 14 sectors within 16 countries. Our results indicate that the average elasticity of electricity demand with respect to ICTs for all sectors is -0.078, suggesting that a 1% increase in ICT capital reduces electricity demand by 7.8%. This implies that digital technologies have the potential of reducing electricity use for all sectors.

Splitting the sectors into manufacturing and services, we find evidence of a slightly stronger negative effect for manufacturing than services, although both sectors confirm that ICTs are associated with a reduction in electricity demand. Furthermore, we combine industries that are not included in manufacturing or services into "other sectors", and this includes agriculture, forestry, and fishing; mining and quarrying; construction; and transport. We find that an increase in ICTs by 1% results in a considerable reduction of electricity demand by 10.7% for industries categorised in the other sectors.

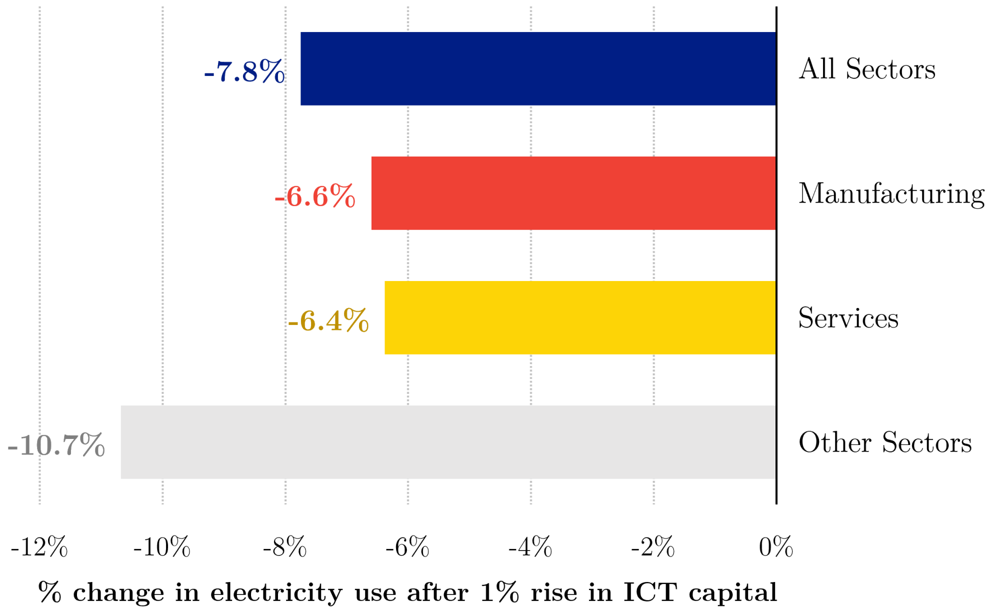

Figure 4: Average elasticities of electricity demand - change in electricity use after a 1% increase in ICT capital (authors' own calculations).

Thus, industrial sectors are likely to benefit from investments in digital technologies, available machinery, and equipment, to reduce their overall electricity consumption. In an attempt to address climate change, companies are increasingly thinking about reducing their carbon footprint, and digital technologies are proving their energy-saving potential. Digitalisation can help businesses conserve resources, reduce waste, and save energy, for example, by using digital resources, such as blockchain, instead of paper. Automating different processes can result in improved operational efficiency, minimising human error, and consequently increasing productivity and improving profitability. Therefore, industrial sectors should invest in digital transformation, in order for businesses to remain competitive, and at the same time, achieve sustainability.

Our empirical analysis confirms that digital technologies have the potential to reduce industrial electricity use. Motivated by these results, we calculate the net effects of ICTs on the demand for electricity for each of these sectors separately. This can provide an understanding of which industries are likely to be more sustainable due to greater digitalisation (Figure 5).

ICTs contribute to the largest reduction in electricity demand in the manufacturing sector. The use of ICTs shows a negative effect on electricity consumption in manufacturing of machinery, food, textiles, chemicals, and other manufacturing. Production represents a significant part of the economies of many countries, and manufacturing relies on large amounts of energy use, contributing considerably to CO_2 emissions. However, the growth of new ICTs, such as AI, cloud computing, and machine learning, can solve some of the challenges faced by the manufacturing sector in becoming more energy efficient (Financial Times, 2020).

Apart from manufacturing, digital technologies are also benefiting the commerce and public services sectors in becoming greener. Our results show that a 1% increase in ICTs can lead to a 6.4% reduction in electricity demand in the services sector. The use of AI is being promoted in public services as means of saving time, as well as reducing administrative costs, through remote working, chatbot delivery services, and increased use of online facilities, i.e., e-health or e-schooling (Unison, 2021).

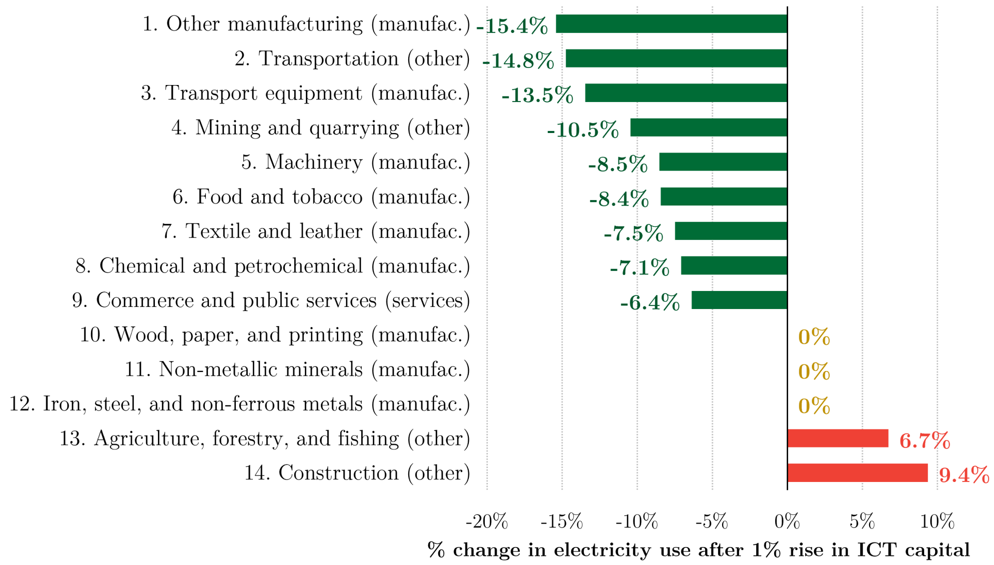

Figure 5: Average elasticities of electricity demand across sectors - change in electricity use after a 1% increase in ICT capital (authors' own calculations).

Furthermore, digital technologies also have the potential to reduce electricity consumption in the transport sector. We find that a 1% increase in ICT capital reduces electricity use by 14.8%. The Transport sector is known to be the largest source of CO_2 emissions globally; however, modern technologies can help reduce these, through electrification of transport modes and the expansion of alternative fuel vehicles (KPMG, 2020). Similarly, ICTs contribute towards energy savings in the mining and quarrying sector. Advanced machinery, such as robotic drilling, drones, or remote-controlled excavators, can increase productivity levels, reduce the risk of accidents, as well as help companies increase their operational efficiency (Identec Solutions, 2023).

Our results show that ICTs are likely to increase electricity use in the construction sector. The building sector, which includes construction, is responsible for 30% of the energy consumption worldwide (IEA, 2023b). Thus, while advanced technologies are likely to contribute to energy savings, the energy requirement of the more numerous devices may offset the relative energy saving potential in this sector. More specifically, the construction sector uses high-powered equipment and energy-intensive processes, such as heating, ventilation, and air conditioning (HVAC) systems, which increase electricity use. Similar effect to the construction sector can also be seen in the agriculture, forestry, and fishing sectors. Business should therefore perform regular energy efficiency audits, in order to reduce their energy consumption and costs (Yü Energy, 2023).

In summary, industries within the manufacturing sector are shown to benefit from digital technologies, due to their contribution towards lower electricity consumption and CO_2

emissions. Achieving sustainability in the manufacturing sector is a challenge (Financial Times, 2020), however, scaling up the use of digital technologies can be one of the solutions for manufacturing companies and businesses. The manufacturing industry can significantly gain from the new advancements made in AI, robotics, blockchain technology, and data analytics, to improve their revenues and, at the same time, reduce their carbon footprint. Similarly, ICTs contribute towards electricity savings in the services sector, suggesting that adoption of digital technologies can enhance the quality of services provided, while fostering sustainability through efficient electricity usage.

5.2 Impact of ICTs on Electricity Use in Sectors Over Time

In the current digital era, we are seeing technological innovation growing at a fast pace. Different businesses rely on different types of technology for their operation; for example, the banking sector was mostly a customer-facing business, but this has changed over the years with the rise in internet banking facilities, and the use of AI in more administrative tasks (Forward Role, 2023). Similarly, the automotive industry is also using increasingly more technology in cars, such as AI, improved GPS, and safety systems.

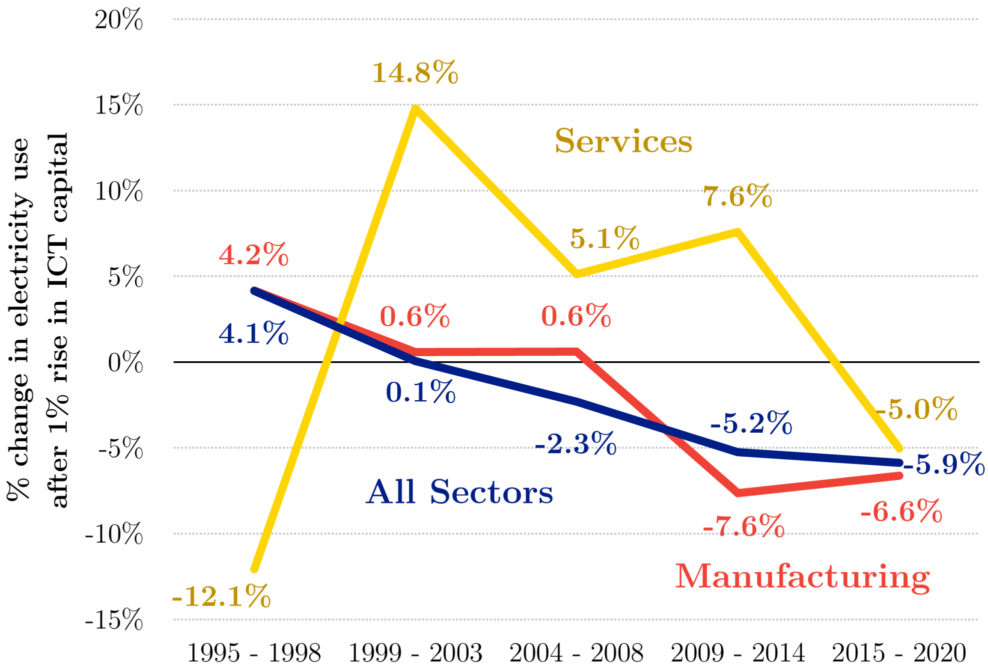

Figure 6: Average elasticities of electricity demand across sectors, over time - change in electricity use after a 1% increase in ICT capital (authors' own calculations).

Given the growth in the use of technologies in industrial sectors over the years, we report the emerging patterns in the net impact of ICTs on electricity use from 1995 to 2020, for manufacturing, services, and all sectors combined (Figure 6). Focusing on all sectors, we find a downward trend, suggesting a potentially stronger contribution of ICTs in lowering electricity use in more recent years, compared to earlier time periods. The impact of digital technologies on electricity use also shows a similar downward trend for both the manufacturing and service sectors, resulting in more sustainable businesses. As firms across various sectors increasingly integrate technological advancements into their operation, our results underscore the potential of ICTs to reduce electricity consumption and create a more efficient and environmentally conscious industrial landscape.

5.3 Impact of ICTs on Electricity Use in European Countries

According to a report by the European Investment Bank (EIB, 2020), European firms have fallen behind in the uptake of digital technologies compared to the USA, especially within the construction sector. However, Netherlands, Czech Republic, and Finland have the highest level of digitalisation in Europe (EIB, 2020). Moreover, the different level of economic development of each country and their focus on different economic sectors is likely to contribute to the varying ICT effects on electricity demand. Thus, it is interesting to analyse the cross-country differences to understand the role of digitalisation in the decarbonisation of European countries.

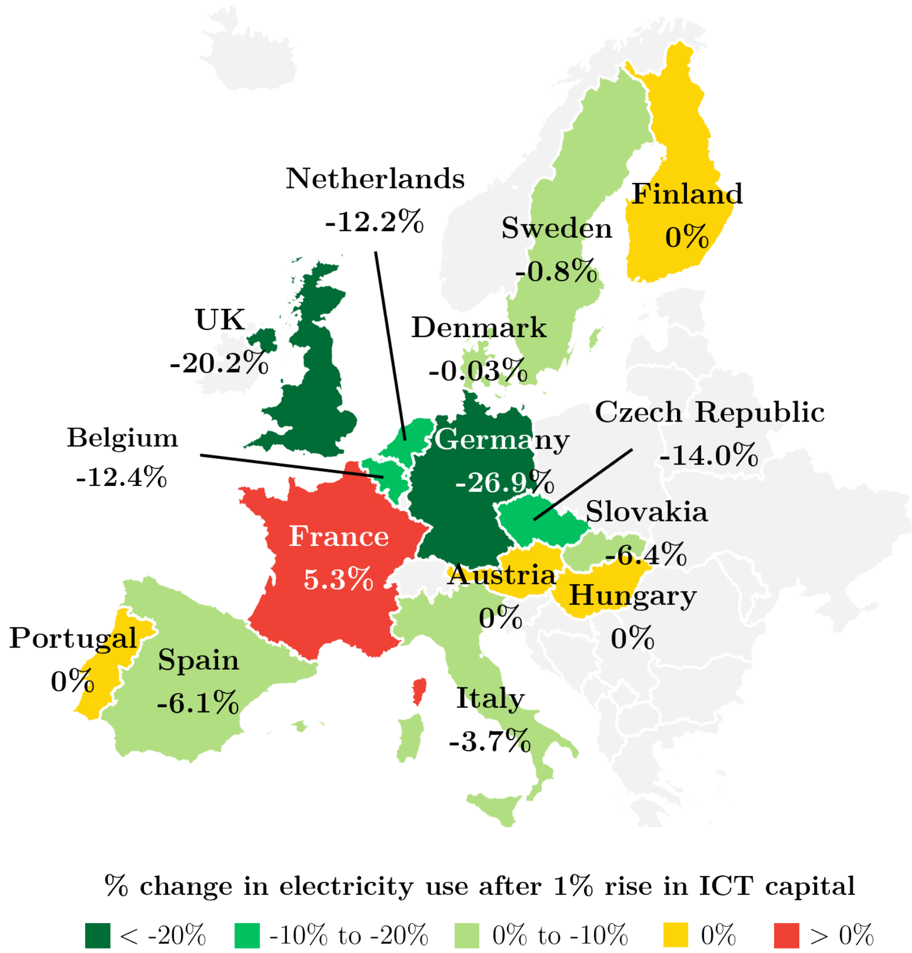

Figure 7: Average elasticities of electricity demand across countries - change in electricity use after a 1% increase in ICT capital (authors' own calculations).

From Figure 7, a 1% increase in ICT capital reduces electricity demand the most in Germany, by almost 27%, followed by the UK (20%). Furthermore, ICTs can significantly reduce electricity use in Netherlands and Belgium. Central European countries, such as Czech Republic and Slovakia, also experience a reduction in electricity consumption attributed to greater ICT investments. On the other hand, France is the only European country with a positive impact of 5.3%, suggesting that ICTs increase energy demand. Furthermore, digital technologies have a much smaller negative influence on energy demand in Denmark and Sweden, while moderate reductions can be seen in Italy and Spain.

Given the strong net energy-saving effects of ICTs, companies and businesses within the EU should invest more in digital technologies, to tackle the issue of climate change.

6 Conclusion

Understanding the association between digital technologies and electricity consumption is crucial, as it sheds light on the profound impact of digitalisation on advancing environmental sustainability efforts. The industrial sectors are the main drivers of economic growth; however, they also use fossil fuels that produce GHG emissions. The net effects of greater ICT investments on energy use are still unclear, i.e., whether digitalisation increases or decreases the overall energy consumption of businesses. Thus, we quantify the net effects of ICTs on electricity consumption for different industrial sectors, using the latest available data for 14 sectors within 16 countries from 1995 to 2020.

We find that digitalisation boosts decarbonisation of industrial sectors, and this effect is stronger for manufacturing than services. The ongoing improvements in technology seen today, i.e., the rise in smart technologies, AI, machine learning, robotics, etc., are associated with a reduction in overall electricity use, particularly in the more recent years. We also showcased that greater digitalisation supports European decarbonisation efforts, revealing that industrial sectors in Germany and the UK reap the greatest benefits from the net energy-saving effects of ICTs. Therefore, businesses can benefit from digital transformation by achieving operational efficiency and improved productivity, as well as reducing their carbon footprint to help the environment.

While there are significant benefits of digitalisation for businesses, new technologies can be costly. Therefore, businesses can take small steps and invest in new technologies more conservatively, and get a return on investment early on (Digital Directions, 2024). Businesses can use the environmental, social, and governance (ESG) criteria, and monitor their performance to evaluate the impact of adopting ICTs on sustainability and stakeholder engagement. Furthermore, while digital technologies come with a risk of data breaches as more businesses use cloud-based storage systems, such risks can be managed and prevented by improving business cyber security.

A few limitations of our study were identified. Although we use the latest available data on ICTs, it would be interesting to see the effects of different types of technologies, such as AI, robotics, etc. on the overall industrial electricity use. Furthermore, a more detailed disaggregation of the industrial sector data would allow researchers to provide specific recommendations for each sector. Therefore, future work in this area can look into collecting a more detailed dataset to analyse the effects of a range of emerging technologies on industrial energy use.

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