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Is Visiting the ESB Website Deteriorating the Air Quality of our Countries? A Statistical Analysis of the Relationship Between Air Pollution Levels and Information & Communication Technologies

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Abstract

Information and communication technology (ICT) is often praised for reducing emissions, however, data centres enabling these technologies have a high energy demand which produces emissions due to CO2-intensive energy production. The purpose of this paper is to investigate whether a relationship between ICT categories and air quality exists and how ICT affects it. This will contribute to a greater understanding of how to mitigate the effect of the rise of new digital technologies.

This paper examines the effects of ICT aspects (Knowledge, Technology, Future Readiness) on air quality in 57 countries by using multilinear regression. The results show that a linear relationship between ICT factors and air quality exists. Technology has a negative effect on air quality, whereas Future Readiness has a positive effect. The effect of Future Readiness on air quality is almost twice as high compared to Technology. A relationship between Knowledge and air quality, as proposed in the literature, could not be proven by the model. It can be concluded that this combination of findings provides some support for the conceptual premise that the net effect of ICT on air quality might be positive and that the share of the total carbon footprint of the ICT sector might have been forecasted too high.

Keywords: Information technology; air quality; energy consumption; sustainability.

1. Introduction

1.1. Is the Internet an Energy Guzzler?

Within one year and with an estimate of over 10.000 monthly page views, the ESB website (www.esb-business-school.de) emits 50.66kg CO_2. The same amount of CO_2 that three trees can absorb in one year (Website Carbon, 2020). This is just an example of a website, but even in 60 seconds, a lot happens on the internet. Based on estimations published by Statista (2019), about 1 million people log in to Facebook. Additionally, 4.5 million videos are being viewed on YouTube and 188 million Emails are being sent every 60 seconds. The internet works through large servers that run 24 hours a day, 365 days a year. Each file, video, Snapchat or WhatsApp must be routed through different servers, searches must be managed and files must be stored. This consumes energy and generates heat (Dayarathna, Wen, & Fan, 2016). The total energy consumption of server farms in Germany was 13.2 billion kilowatt-hours (kWh) in 2017 (+25% compared to 2010) (Hintemann, 2018). In a study commissioned by the German Federal Ministry of Economics and Energy, it is predicted that the energy demand of data centres will rise to 16.4 billion kWh by 2025 (Stobbe et al., 2015). Projected onto the world, data centres could be responsible for one-fifth of global electricity consumption - with correspondingly negative effects on the environment (Lima, 2017).

The energy consumption of data centres and CO_2 emissions are closely connected to the current electricity mix. Energy can be produced by using renewable sources, such as wind or hydropower, or by non-renewable energy sources. These include natural gas and coal which are burned and emit tonnes of CO_2 and other pollutants during the process (EIA, 2020a) which affects the air quality and our health (Ohlström, Lehtinen, Moisio, & Jokiniemi, 2000). In Germany, 46% of the electricity mix in 2019 was renewable (Fraunhofer, 2020). However, because not all servers are located in Germany, the electricity mix varies. In the US, the majority of electricity sources are coal and natural gas; methods of power generation that release relatively large amounts

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of CO_2 (EIA, 2020b). CO_2 in this context belongs to the greenhouse gasses (GHG) and is often used as an umbrella term when analysing its effects as an air pollutant (Bereitschaft & Debbage, 2013; Ramanathan & Feng, 2009).

The Information and Communication Technology (ICT) sector defines the infrastructure needed to enable digital applications and systems (OECD, 2002). Innovative companies such as Google and other cloud services were associated with high hopes to save resources (Schmidt, 2019) and make Information Technologies (IT) greener. Even though the internet consumes an incredible amount of energy, it theoretically saves energy as well. Every search query avoids a trip to the library or a long search in various shops for the best price (Google, 2009). For example, an Email requires neither paper nor delivery by car. But does that also make it more climate-friendly? Not necessarily. Smartphones, computers and the internet also need electricity whose production emits air pollutants.

In terms of energy-saving effects, some studies predict the CO_2 reduction potential of ICT by up to 15% in other sectors (Malmodin & Bergmark, 2015). While economists Hintemann and Hinterholzer (2019) say that in any case, there is no doubt among experts that the internet has long since become a CO_2 slingshot. To date, there has been little agreement on what the actual impact of the ICT sector on CO_2 levels and air quality is.

The rising demand for digital applications indicates that the ICT sector has a pivotal role in mitigating its environmental impacts. Most studies in the field of ICT and sustainability have only focused on the effects of ICT devices on the environment (Andrae & Edler, 2015; Malmodin & Lunden, 2016). Such approaches, however, have failed to address the opposing effects of increased energy demand or saving caused by indirect effects of ICT applications, such as investments and IT integration.

This study aims to analyse the effect of digitalisation on environmental sustainability, more specifically the air quality. A statistical model conducted with a multilinear regression is estimated to show the significant influence of different aspects of the ICT sector (Knowledge, Future Readiness and Technology) on the air quality of different countries. The analysis of the model will provide answers whether a linear relationship between ICT aspects and air quality exists and which aspects, in particular, deteriorate or improve our air quality, based on the assumption that ICT can save, but also demands more energy. Overall, the model investigates how green IT is possible and what this implies for businesses around the globe, also in regard to the global COVID-19 pandemic.

1.2. Theoretical and practical relevance and structure

This analysis contributes to the existing literature in two ways. First on a theoretical level, as the statistical model classifies which aspects of digitalisation help improve or deteriorate environmental sustainability. And secondly on a practical level, based on the theoretical model it provides concrete steps to prevent digital innovation and improvements from contributing to climate change and deteriorating air quality. This is essential to solve the climate crisis as the ICT infrastructure becomes progressively accessible to more people (GeSI, 2015) and it is hoped that this thesis will contribute to a deeper understanding of the relationship between ICT factors and air pollution.

The first part of the thesis will be a profound literature review introducing two theoretical frameworks to categorise ICT factors. Followed by a derivation of research hypotheses. Secondly, the method, research design and context, data collection including robustness checks will be described. Lastly, after summarizing the data and an in-depth evaluation of the regression results an interpretation and an outlook on further steps of action will be provided to answer the questions whether the ESB website is contributing to the deterioration of our air quality.

2. Literature Review

There is no consensus on ICT's effect on energy consumption and the actual impact on the environment in the literature. While some scholars emphasise the high emission reduction potential (Ericsson, 2020; GeSI, 2012; Malmodin & Bergmark, 2015), some warn about the growing energy and carbon footprint of ICT (Belkhir & Elmeligi, 2018; Van Heddeghem et al., 2014).

A study conducted by Malmodin and Lunden (2016) analysed the carbon footprints of the ICT and the Entertainment & Media (E&M) sector. Illustration 1 indicates that despite an increasing amount of data traffic, the footprints had peaked in 2010 and had deceased since then. The researchers argue that the switch from PCs to smartphones and tablets with lower energy consumption is responsible for the trend change.

Other studies confirm this negative relationship between ICT and energy consumption and found the relationship to be U-shaped with a turning point in 2014 (Han, Wang, Ding, & Han, 2016).

The controversy is fuelled by various scholars claiming that ICT causes a tremendous increase in GHG emissions or electricity demand (Kishita et al., 2016; J. W. Lee & Brahmasrene, 2014). Andrae and Edler (2015) disagree with the previously presented opinions in the literature and predict that ICT "electricity usage could contribute up to 23% of the globally released greenhouse gas emissions in 2030" (p.117). Even though Acharyya (2009) published an update of his 2015 study and the numbers deviate from the previous estimations, he still projects a continuous increase in electricity consumption of the ICT sector. Belkhir and Elmeligi (2018) found that from 2010 to 2020, the contribution of data centres will increase from 33% to 45%. Hence, the energy consumption of data centres is expected to increase rapidly (Illustration 2). This contradicts the findings of the previously introduced studies that increasing data traffic does not affect energy demand.

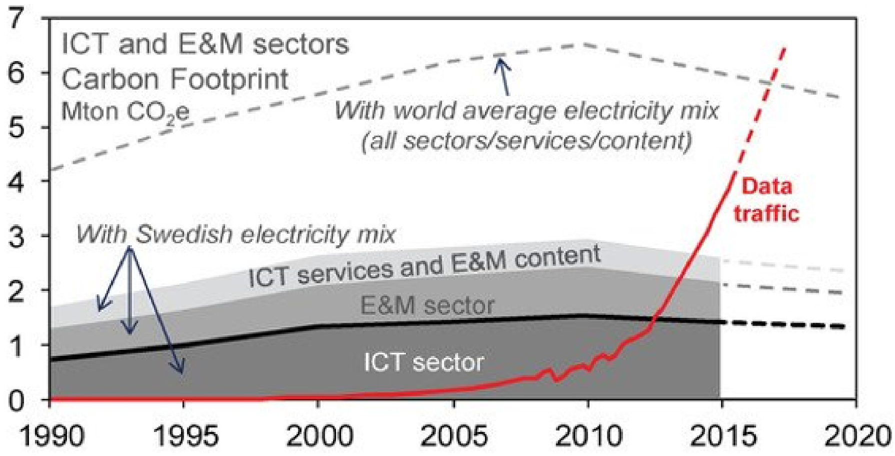

Figure 1: ICT and E&M sector carbon footprint projections in Sweden 1990-2020 (Malmodin & Lunden, 2016)

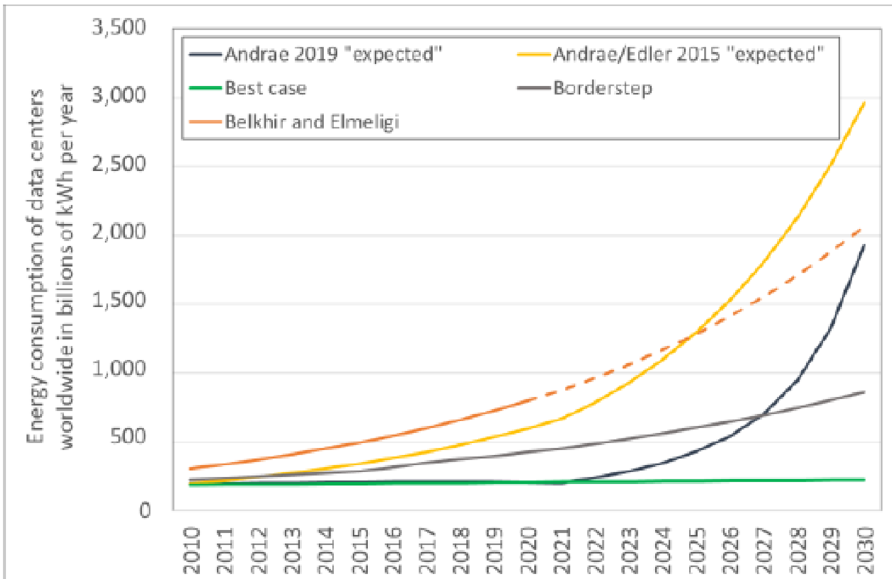

Figure 2: Energy consumption of data centres forecast (Hintemann & Hinterholzer, 2019)

2.1. ICT, GHG emissions and air quality

Whether the ICT sectors saves energy or not, the infrastructure of this sector needs electricity. The global energy mix, however, is still highly dependent on traditional non-renewable energy sources (Smil, 2017). Even though studies argue that the carbon footprint of the ICT sector could be reduced by 80% by switching to renewable energy sources (Ericsson, 2020), GHG emissions caused by the ICT sector still prevail. The increased carbon dioxide mainly is caused by burning fossil fuels and deforestation. Both contribute to air pollution (Feldman et al., 2015). West et al. (2013) argue that air pollutants can be reduced by any endeavours to reduce GHG emissions which benefits our air quality and health. Previous research has established that energy production emits air pollutants, especially $PM_{2.5}$ (Particle matter) (Ohlström et al., 2000).

The net effect theory and the three orders of impact theory are being used to categorize different ICT factors and further investigate the controversy of ICT and its effect on air quality.

2.2. Net effect theory and Hypothesis 1

According to Takase and Murota (2004), ICT can have an income and a substitution effect, which results in an overall net effect on energy consumption levels. The economic growth from increased use of ICT increases energy consumption and is called the income effect. ICT equipment and products require electricity for production and daily operation (Sadorsky, 2012). The substitution effect suggests that ICT has the potential to reduce energy usage because it replaces more energy-intensive and traditional products (Zhou, Zhou, & Wang, 2018). The IT sector, for example, is growing and is less energy-intensive than traditional industries such as manufacturing (Romm, 2002). The effect distinction suggests differentiating effects of various ICT components. A reduction or increase in energy consumption (and the corresponding GHG levels caused by energy production) depends on which trend, the substitution or the income effect, will prevail (Takase & Murota, 2004).

Derived from the previous literature review the first hypothesis states:

H_0: ICT aspects do not influence Air Quality

H_1: ICT aspects do influence Air Quality

Hypothesis 1 serves to verify the general assumption that a relationship between ICT aspects and air quality exists to extend on the prevailing concepts found in the literature. As a first step in the analysis, this validates the context between CO_2 emissions, ICT and their direct air quality impacts.

2.3. Three orders of impact theory – First Order; Hypothesis 2

The three orders of impact theory was introduced by (Berkhout & Hertin, 2001) and further developed by Hilty and Aebischer (2015). In all of the three stages ICT is part of the problem, but also part of the solution regarding the environmental impact. Illustration 3 shows that ICT has direct effects due to its lifecycle. Essentially this is the direct carbon footprint of ICT (Ericsson, 2020) and hence summarized under the term technology. According to Hilty and Aebischer (2015), the direct impacts of ICT are problematic for our environment, as the production and use of devices consume resources and energy (Schickling, 2020). The IMD (2019) defines technology as everything that "enables the development of digital technologies" (p.29), hence the life cycle including capital and the regulatory/technological framework.

According to Statista, the number of internet users worldwide has quadrupled between 2005 and 2019 to 4.121 million users (2020). The causal conclusion would be that more users consume more energy because more devices are needed which leads to an increase in CO_2 emissions. Malmodin and Lundén (2018) found that the emissions per subscription (internet user) decreased from 21.5 to 19kg CO_2 per subscription due to the replacement of old ICT equipment. This indicates that the emissions caused by ICT devices keep rising due to more internet users, despite the small savings. Ericsson (2019) supports this idea by stating that the largest share of carbon emissions are produced by user devices. In a study investigating the optimal equipment replacement cycle of ICT equipment, Chan et al. (2016) reported that the energy consumption and resulting carbon footprint/air pollution, due to rising network life cycle energy demands, could skyrocket if kept unchecked. A big part of the ICT life cycle are high-tech exports. Pan et al. (2017) demonstrate that the bigger the export volume, the higher the CO_2 emissions accordingly. Scholars predict a sharp increase in CO_2 emissions and this trend is driven by the short life cycle of a smartphone (approximately 2 years) and the low recycling efforts (less than 1%) (Belkhir & Elmeligi, 2018).

Indirect effects of the Technology aspect include investment (IMD, 2019). A study conducted in South Korea investigated the effects of ICT investment on electricity consumption (Cho, Lee, & Kim, 2007). The authors concluded that ICT investment contributed to increasing electricity consumption in most of the analysed sectors. This negative correlation was also found between investment and air pollution/CO_2 emission (Acharyya, 2009; Liang, 2008).

As the review of the existing literature largely agrees on the negative direct impacts of ICT (Technology), it leads to the following hypothesis:

H_0: Technology has no negative effect on Air Quality

H_1: Technology has a negative effect on Air Quality

2.4. Three orders of impact theory – Second Order; Hypotheses 3 and 4

The second order of the theory addresses enabling effects such as indirect emission effects from using ICT, positive and negative ones (Ericsson, 2020). Indirect effects refer to the application of ICT services. From an environmental sustainability viewpoint, the enabled effects can be advantageous or disadvantageous.

Unfavourable effects include induction and obsolescence effects. The induction effect describes the situation where ICT increases the usage of other resources. For example, printers demand more paper than typewriters (Mansell & Hwa, 2015). Furthermore, e-commerce can lead – depending on the product type - to more freight transport (Hilty, 2008). Hilty and Aebischer (2015) define the obsolescence effect, as the situation where other resources' useful life is influenced by ICT services or products. This is the case of incompatibility when ICT solutions become obsolete when, for example, software updates do not support the hardware anymore or when "smart" tags make it more difficult for bottles or cardboard to be recycled (Wäger, Eugster, Hilty, & Som, 2005).

Substitution and optimization effects are expected to reduce the environmental impact of ICT (Illustration 3). Any replacement of physical elements by ICT is summarized under the term substitution effect. During the COVID-19 pandemic, videoconferences replaced business travel. Due to the substitution effect, resources can be saved which can have a positive impact on the environment (Yi & Thomas, 2007). Internet retailing and e-commerce - despite the negative effects due to induction effects - is also part of the substitution effect and is found to reduce consequent CO_2 emissions (Weber, Koomey, & Matthews, 2010). Another aspect of substitution is the robots' distribution (IMD, 2019). In an analysis of the air pollutants of robotic tractors, the scholars concluded that the robotic tractors could be responsible for a 50% reduction in emissions in a best-case scenario (Gonzalez-de Soto, Emmi, Benavides, Garcia, & Gonzalez-de Santos, 2016). Especially, robotic applications are projected to reduce greenhouse gas emissions (Harris, 2019).

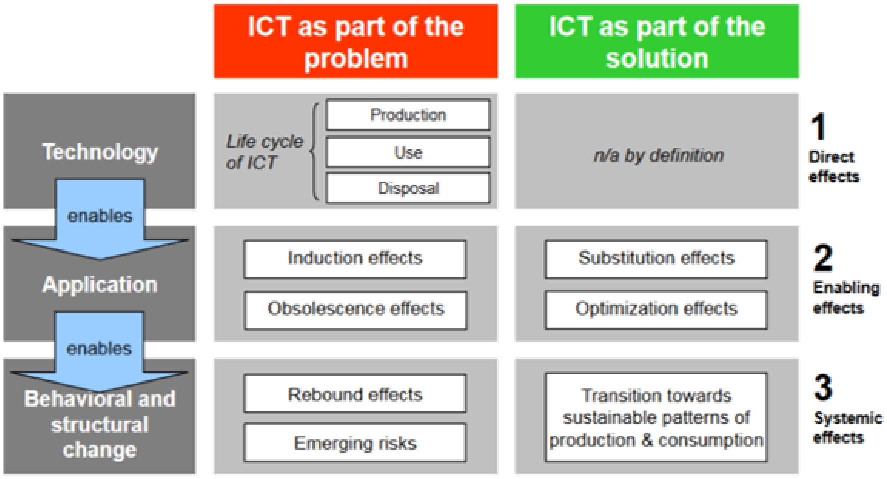

Figure 3: Three orders of impact grid (Hilty & Aebischer, 2015)

The optimisation effect is defined as the usage reduction of other resources because of ICT applications, for example, smart homes can save energy, hence, increase energy-efficiency (Jahn et al., 2010). This effect is also closely linked to smartphone and tablet possession because the usage of them can reduce the carbon footprint of the ICT sector (Malmodin & Lunden, 2016). Other analyses showed, however, that emissions due to smartphones will continually rise and will make up 11% of total ICT emissions by 2020 (Belkhir & Elmeligi, 2018). Not only houses can be optimized by ICT, but also governmental processes which is called eGovernment. This refers to the increased use of modern IT technologies and electronic media for government and administrative processes (BMI, 2020). Online participation can benefit climate change adaption by improving the efficiency of decision-making (Bojovic, Bonzanigo, Giupponi, & Maziotis, 2015).

Other studies working with the model concluded that the enabling effects of ICT (2. Order) are more significant than technological impacts and have a positive effect on the environment (Erdmann, Hilty, Goodman, & Arnfalk, 2004).

In the following the second order will be called "Future Readiness" to define the "Level of a country's preparedness to exploit digital transformation" (IMD, 2019) and match the terminology of the data used. This includes adaptive attitudes, business agility and IT integration.

The literature indicates that the positive effects of Future Readiness on air quality and emissions outweigh the negative effects. This suggests the following hypotheses:

H_0: Future Readiness has a no positive impact on Air Quality

H_1: Future Readiness has a positive impact on Air Quality

H_0: Future Readiness has not a bigger impact on Air Quality than Technology

H_1: Future Readiness has a bigger impact on Air Quality than Technology

The statistical analysis will show whether positive effects of ICT might outweigh the negative ones and contributes to better air quality.

2.5. Three orders of impact theory – Third Order

The second order enables behavioural and structural changes (third order) which can promote more sustainability. However, rebound effects and emerging risks can diminish these desirable patterns. The (Umweltbundesamt, 2019b) defines the rebound effect as impacts where efficiency increase oftentimes reduces costs, which can in turn ramp up consumption, thus partly cancelling out the original savings. SMARTer2030 quantified the rebound effect at 1.4 gigatons CO_2 in 2030 (GeSI, 2015). Scholars note that rebound effects are often not considered when calculating the carbon footprint of the ICT sector causing misleading results (Pohl, Hilty, & Finkbeiner, 2019). Since these effects are long-term reactions and linked to behavioural changes, this study will refrain from deriving a hypothesis based on the third order.

2.6. Knowledge and Hypothesis 5

A large and growing body of literature has investigated the effects of knowledge on the environment. This is an important indirect aspect both theories are missing. In this context, it is defined as "Know-how necessary to discover, understand and build new technologies" (IMD, 2019, p.29). Developed nations are often described as knowledge economies because their economic system is based on intellectual capital (Powell & Snellman, 2004). According to the World Bank (World Bank, 2007), access to ICT infrastructures represents a fundamental pillar of the definition. Human capital, such as education, contributes to the development and improvement of ICT structures. A Portuguese study found a negative relationship between education and energy intensity, hence, more education reduces environmental impacts (Sequeira & Santos, 2018). Other studies come to the same conclusion while analysing the relationship between R&D and carbon emissions (K. H. Lee & Min, 2015) or air pollution (Cole, Elliott, & Shimamoto, 2005).

The existing literature is mainly characterized by positive effects associated with knowledge on air pollution which leads to the following hypothesis:

H_0: Knowledge has no positive impact on Air Quality

H_1: Knowledge has a positive impact on Air Quality

This hypothesis will show whether empirical effects suggested in the literature can be proven by a statistical model.

3. Method

3.1. Research design

The central hypothesis stated in Section 2 regarding the relationship between ICT aspects and air quality was tested by using a multilinear regression. Previous studies have based their research on top-down and bottom-up modelling approaches (Malmodin, Bergmark, & Lundén, 2013; Malmodin & Lunden, 2016). The benefits of a multi linear regression are the ability to quantify relative influences and to determine outliers (Weedmark, 2018). A multiple regression analysis studies the simultaneous effects that various independent variables have on one dependent variable (Cochran, 2014). It is assumed that the multiple regression model takes the following form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \epsilon$$

y is a linear function of $x_1, x_2, \ldots x_n$ plus the error term ϵ. The dependent variable (y) and independent variables ($x_1, x_2, \ldots x_n$) represent the observed data, whereas the multiple linear regression algorithm computes the values of the intercept (β_0) and coefficients ($\beta_1, \beta_2, \ldots$). This modelling minimizes the residual or error (ϵ) in the model. To calculate the predicted values y_i the observed values ($x_1, x_2, \ldots$) are multiplied with their corresponding coefficients ($\beta_1, \beta_2, \ldots$) and the intercept β_0 is added. The difference between the observed value of y_i and the predicted value $\hat{y}_i$ is defined as the error term (Boslaugh, 2013).

3.2. Data

The multiple regression used for all hypotheses is based on the Environmental Performance Index (EPI) 2018 and the IMD World Digital Competitiveness Ranking (WDC) 2019.

The EPI is a data-driven index that uses 32 performance indicators across 11 issue categories of 180 countries developed by two US-American universities (Yale/New Haven and Columbia/New York) on behalf of the Davos World Economic Forum (Wendling et al., 2018a). It targets environmental health and the vitality of the ecosystem. For this study the Air Quality issue category was chosen as a dependent variable which measures direct impacts of air pollution on human health (Wendling et al., 2018a). This category makes up 26% of the complete index (Appendix A.2). The indicators of this category include $PM_{2.5}$ (Particulate Matter) exposure, household solid fuels and $PM_{2.5}$ Exceedance of WHO guidelines (Wendling et al., 2018b). $PM_{2.5}$ describes particulate matter whose diameter is smaller than 2.5 μm (Zheng et al., 2005). Particulate matter is not only emitted directly (primary particles) but also forms of precursors (including sulphur dioxide, nitrogen oxide and ammonia) in the atmosphere (secondary particles) (Umweltbundesamt, 2019a). The component "household solid fuels" measures the impact of exposure to indoor air pollution caused by household use of solid fuels (Wendling et al., 2018b). The EPI was chosen because previous research has established that energy production contributes to the global $PM_{2.5}$ levels (Ohlström et al., 2000). The score data (0-100) was chosen. The final sample used included 57 countries (N = 57) and as a whole had a relatively high Air Quality (M = 79.39, SD = 15.43, 95% CI [75.30, 83.48]) (Appendix C.1).

In 2008 the German Environment Agency criticised the EPI because they found the significance of the country ranking for Germany was particularly low due to clear methodological shortcomings of the index (Kraemer & Peichert, 2008). However, the index was published every other year since 2006 and improvements of data validation were implemented as the variables used were adapted and data generation improved (Wendling et al., 2018b).

The WDC "ranks the extent to which countries adopt and explore digital technologies" (IMD, 2019, p.28) in the areas of Knowledge, Technology and Future Readiness. These three categories include 51 criteria (Appendix A.1). Knowledge is defined as the "know-how necessary to discover, understand and build new technologies" (p.29) and it includes the sub-factors scientific concentration, training/education and talent. The WDC interprets Technology as the infrastructure needed to run digital technologies such as regulatory framework, capital and technological framework. Lastly, Future Readiness is the "level of country preparedness" (p.29) in terms of digital innovations which included adaptive attitudes, business agility and IT integration. The yearly published ranking is computed by comprising hard data (statistics) and survey data (opinions, panels) of 63 countries worldwide. Knowledge, Technology and Future Readiness are the independent variables used for the regression. The score data (0-100) was chosen. The descriptive statistics show that the mean score for Knowledge was 67.70 ($SD = 13.83$, 95% CI [64.03, 71.34]), for Technology it was 68.77 ($SD = 14.14$, 95% CI [65.02, 72.53]), and for Future Readiness it was 68.21 ($SD = 15.62$, 95% CI [64.07, 72.36]) (Appendix C.1). This indicates that the countries performed on average better in the categories Technology and Future Readiness.

Both indexes were chosen because of the continuity of the data collection over several years and their profound methodological approach.

The data evaluation described in the following was performed with the statistics programme SPSS (Statistical Package for the Social Sciences) Version 25 and significance levels were set to 5%. To ensure the traceability of the results all outputs were documented in the Appendix.

3.3. Robustness check

To determine whether the model is robust and matches important prerequisite assumptions of multiple regressions, the following aspects were investigated.

3.3.1. Linearity

The individual Q-Q-Plots meet the assumption of linearity (Appendix B.1.3, B.2.3, B.3.2, B.4.2). The partial regression plots also indicate that Air Quality and Technology have a negative linear relationship, whereas Air Quality and Future Readiness/Knowledge have a positive linear relationship (Appendix C.7). Additionally, the linearity assumption is proven because the values follow the least-squares fit line in the P-P-diagram (Appendix C.5).

3.3.2. Normally distributed

The histogram of standardized residuals indicates that the data is normally distributed (Appendix C.4). The normal P-P plots of standardized residuals contained approximately normally distributed errors, which is indicated by the points being close to the line (Appendix C.5).

3.3.3. Independence of errors

The data met the assumption of independent errors (Durbin-Watson value = 1.989) (Appendix C.3). The assumption of non-existing auto-correlation of the residuals is upheld as long as the value is close to 2 (Field, 2018).

3.3.4. Multicollinearity

Tests to see if the final model meet the assumption of collinearity indicated that multicollinearity was not present (Technology, Tolerance = .229, VIF = 4.374; Future Readiness, Tolerance = .229, VIF = 4.374) (Appendix C.3).

3.3.5. Misspecification

To control whether nonlinear combinations of the independent variables influence the dependent variable, a Ramsey Reset Test was conducted (Ramsey, 1969). The variable RAM2 is not significant and ($t(56)$ = -1.308, p = .196) misspecifications can be eliminated (Appendix C.10).

3.3.6. Endogeneity and measurement error

A common mistake in the empirical specification is to forget about possible endogeneity (Kennedy, 2011). In this research, it is unlikely but cannot be ruled out completely. Both indices conduct their research regularly. Therefore, the measurement error is expected to be low, but cannot be eliminated 100%.

3.3.7. Heteroskedasticity

The standardized residuals shown in the scatterplot are scattered uniformly and randomly around zero which indicates homoscedasticity (Appendix C.6). Besides that, a Breusch-Pagan test was conducted which led to the acceptance of H_0, stating the homogeneity of variance (Appendix C.9).

3.3.8. Non-zero variances

The data also met the assumption of non-zero variances (Air quality, Variance = 237.875; Technology, Variance = 200.076; Knowledge, Variance = 191.234; Future Readiness, Variance = 243.895) (Appendix C.1).

3.3.9. Causality

The model claims that Knowledge, Technology and Future Readiness have an impact on Air Quality. This is a causal relationship derived from existing literature: More energy consumption by the ICT sector causes more CO_2 emissions due to electricity production or energy savings effects reduce the CO_2 emissions. A conclusion that Air Quality impacts ICT aspects does not seem likely.

3.3.10. Outliers

India, China and Venezuela were identified as outliers by boxplots (Appendix B.1.1, B.3.3). South Korea and South Africa were excluded from the sample to smooth out the model as indicated by an analysis of the standardized residuals. The sample size then included 57 countries.

3.3.11. Sample robustness

The robustness of the model was checked by conducting a regression with 80% of the original sample. The model is still significant and all assumptions can be upheld (Appendix D).

No breach of the assumptions was identified, therefore, the interpretation of the results of the multiple linear regression is considered trustworthy under these aspects. The results are presented in the following section.

4. Results

A multiple regression was carried out to investigate whether Technology, Future Readiness and Knowledge could significantly impact a country's Air Quality. Results of the multiple linear regression indicated that there was a collective significant effect between the variables Technology, Knowledge, Future Readiness ($F(3, 53) = 17.729$, $p < .001$, $R^2 = .501$) (Appendix C.2). While Technology ($t(56) = -3.544$, $p < .001$) and Future Readiness ($t(56) = 5.003$, $p < .000$) contributed significantly to the model, Knowledge did not ($t(56) = .980$, $p = .331$). Knowledge appeared to be a non-significant variable. Using the enter method and excluding Knowledge it was found that Technology and Future Readiness explain 47.3% of the variance of Air Quality ($F(2, 54) = 26.132$, $p = .000$, $R^2 = .492$, $R^2_{Adjusted} = .473$)

(Appendix C.3). This adjustment only has small effects on the remaining variables: Technology ($t(56)$ = -3.434, $p <$ .001) and Future Readiness ($t(56) = 6.058$, $p < .000$). Interestingly, the $R^2_{Adjusted}$ decreases after the variable Knowledge was removed and the F statistic of both tests is significant despite the non-significant t-test of Knowledge. The final predictive model can be summarized as follows:

Air Quality = 48.84 – 0.76*Technology + 1.214*Future Readiness

The coefficient of Technology is negative, indicating that countries with higher technological impacts have on average lower Air Quality. While Future Readiness has a positive coefficient, which means that the higher the future readiness of a country is the better its Air Quality. Looking at the standardized coefficients beta shows the absolute impact of the variables on the model (Technology: $\beta = -.697$; $p < .001$; Future Readiness $\beta = 1.229$; $p = .000$) (Appendix C.3). Hence, the influence of Future Readiness on Air Quality is almost twice as high as that of Technology in absolute terms.

5. Discussion of the results

The regression aimed to analyse the impact of various ICT factors on air quality. In this section, all the statistical results from the multilinear regression outlined in Section 4 are being discussed and examined in detail. The effects of the variables on the level of air quality are being explained, and various implications for business, also taking note of the COVID-19 pandemic, are being introduced.

In line with Hypothesis 1 that ICT aspects do influence Air Quality, H_0 is rejected and H_1 accepted, at least for the variables Technology and Future Readiness. An impact of Knowledge on Air Quality could not be shown. These results support previous research into this area which links ICT usage to an income and substitution effect (Takase & Murota, 2004). This confirms the general assumption of the environmental impact of ICT, in both positive and negative ways, as proposed in the literature and proves the net effect theory.

In accordance with the present results, previous studies have demonstrated that every internet user causes CO_2 emissions. Even though these could be reduced by replacing old ICT equipment it might explain the negative effect of the variable Technology on Air Quality found in the regression analysis (Hypothesis 2). The findings are also consistent with them of Pan (2015) and Chan et al. (2016) that Technology has a negative effect on Air Quality and H_0 is rejected in favour of H_1. Agreeing with the present results, previous studies have demonstrated that investments in the ICT sector have a negative impact on air pollution, more CO_2 emissions and cause an increase in energy consumption (Acharyya, 2009; Liang, 2008). The negative impact of Technology on Air Quality might be explained by the fact that user devices account for the majority of the ICT carbon footprint (Ericsson, 2019). The rising amount of internet users (Statista, 2020) might cause an increase in ICT carbon emissions. Overall, these results correspond with existing evidence of the negative impacts of the life cycle of Technology on the environment found in the literature (Belkhir & Elmeligi, 2018).

The regression model indicates that Future Readiness impacts Air Quality positively (Hypothesis 3). This builds on existing evidence of Malmodin and Lunden (2016) who argue that the overall carbon emissions of the ICT sectors had peaked in 2010 despite rising data traffic. A possible explanation for these results may be the increasing efficiency of new devices. Internet retailing is a factor of the Future Readiness variable and the literature disagrees on the effect of e-commerce on the environment. The results, however, are in agreement with those arguing that the net effect of the induction and substitution effect caused by online retailing has a positive environmental impact (Weber et al., 2010).

These results further corroborate the idea that the impact of the substitution and optimisation effect is substantially greater than those of the induction and obsolescence effect. This interpretation is in accord with previous studies indicating that enabling effects of ICT and the subsequent environmental impacts are more substantial than those of the direct effects of ICT (Technology) (Erdmann et al., 2004; Hilty et al., 2006). Consequently, H_0 of Hypothesis 4 is rejected in favour of H_1.

These results should be considered when discussing the net effect of ICT emissions on air quality. Future Readiness has a positive impact on Air Quality and this impact is almost twice as high compared to the negative impact caused by Technology. This combination of findings provides some support for the conceptual premise that the net effect of ICT on air quality might be positive. This finding, while preliminary, suggests that the overall carbon footprint of the ICT sector is significantly smaller than previously forecasted. This interpretation further supports the idea of Malmodin and Lundén (2018) who come to a similar conclusion and various studies which emphasize the emission reduction potential enabled by ICT (Ericsson, 2020; GeSI, 2015). This result may be explained by the fact that Internet of Things subscriptions are growing (Ericsson, 2019) and energy-intensive devices are becoming more efficient (Malmodin & Lundén, 2018).

The regression analysis has been unable to demonstrate an effect of Knowledge on Air Quality (Hypothesis 5), H_0 is being accepted, and therefore the results contradict the claims of K. H. Lee and Min (2015) that Knowledge has a positive impact on air pollution and CO_2 emissions, hence air quality (Cole et al., 2005). Due to the broad definition of the variable, it is difficult to investigate what exactly is causing this deviation. This provides new insights into the relationship between Knowledge factors and Air Quality. While previous research found a causal effect, these results demonstrate that the relationship might be not as significant as once anticipated.

A possible explanation for the decrease in $R^2{}_{adjusted}$ after the exclusion of the variable Knowledge might be that if the number of predictors increases, R^2 is artificially increased, since it also increases by the inclusion of insignificant regressors and thus never becomes smaller (Field, 2018). The significance of the F statistic despite non-significant t-tests could be attributed to a correlation problem (see limitations) (Archdeacon, 1994).

This statistical output contributes a clearer understanding of how digitalisation can mitigate the effects of environmental delegation partly caused by rising CO_2 emissions.

5.1. Theoretical and practical implications

5.1.1. Business implications

Increased visibility of environmental impacts of business practises and environmental degradation caused societal concerns and forced managers to find new ways of decreasing the environmental externalities of their corporations (Porter & Reinhardt, 2007). The theoretical findings of the regression imply that businesses need to invest more in their future readiness, while making the life cycle of their ICT applications more efficient. This includes embracing their business agility and IT integration.

Referring back to the findings of the model, business agility as part of the Future Readiness variable plays a significant role in mitigating the environmental impacts of businesses. It refers to a certain degree of flexibility of a company by reacting quickly to marketplace changes and customers demand (Tsourveloudis & Valavanis, 2002). IT integrations included using ICT-enabled conferencing tools and benefitting from an IT network to make operations run more efficiently.

The overall implication for businesses is that they should switch to renewable energy sources for their overall supply chain (Greenpeace, 2017). In compliance with the Paris Agreement, the ICT industry commits to reduce its GHG emissions by 45% from 2020 to 2030. The Secretary General of the International Telecommunication Union (ITU), an agency specialized on ICT of the united nations, calls this agreement a "guidance on the pathway towards net zero emissions for the ICT industry" (ITU, 2020). Microsoft, for example, announced in early 2020 that their goal is to be carbon negative by 2030. Steps to reach that goal include investing in carbon reduction and removal technology and empower customers to deploy more digital technologies (Smith, 2020).

Businesses not in the ICT sector need to join these efforts. Institutions, such as ESB Business School also need to be aware of their carbon footprint caused by various online tools, such as their website, should set sustainability goals and consider green hosting (Website Carbon, 2020). Other measures could include energy transparency, renewable energy commitment, energy efficiency & mitigation, renewable procurement and advocacy (Greenpeace, 2017).

Mitigating the environmental impact of companies can benefit their financial performance due to cost savings caused by increased efficiency. Although researchers disagree on how severe the effect is, most agree on the causal link between going "green" and better financial performance (Clarkson, Li, Richardson, & Vasvari, 2011; Riillo, 2017).

5.1.2. COVID-19

During the global COVID-19 pandemic streaming providers saw a spike in new memberships (Schuler, 2020) and a majority of the working force started working from home using online meeting tools (Bary, 2020). Here the substitution effect becomes visible. The DE-CIX, one of the largest internet exchange points worldwide, recorded an all-time high and broke a data traffic world record during the pandemic (DE-CIX, 2020). As indicated in the literature review, it is debated whether the energy demand of data centres increases with rising data traffic (Belkhir & Elmeligi, 2018; Malmodin & Lunden, 2016). The film Birdbox, for example, was viewed over 80 million times which leads according to a British study to an equivalent of 66.133.333kg CO_2 (SaveOnEnergy, 2019). On the other side, video conferences replaced business travel and air traffic was at a standstill. Some early studies identified a reduction of 26% CO_2 emissions worldwide (Le Quéré et al., 2020), others argue that it is not possible to draw conclusions about the net effect of these opposing influences and the health-relevant air pollution caused by the pandemic (Umweltbundesamt, 2020). Nevertheless, the COVID-19 pandemic demonstrates how important it is to integrate more renewable energy sources into the system. The rising demand for online applications during the global pandemic revealed the problems of rising emissions contributed by conventional energy sources used to keep the system running (GeSI, 2015). Mitigating the energy consumption of the net also includes making data centres even more efficient (Ivanova, 2020). The economic consequences of the coronavirus pandemic made the already abandoned climate targets for 2020 still achievable (Zeit, 2020). The question is whether these savings are only temporary (Le Quéré et al., 2020).

5.2. Limitations and future research

Nonetheless, the results and implications presented should be considered in light of some limitations. First, the similarity of the independent variables increases multicollinearity effects (Daoud, 2017). The distinction between closely related ICT aspects combined with substitution and income effects both found in individual aspects can cause the standard error to increase and can lead to a biased model. Second, the data used summarised many aspects under one variable which makes it difficult to fully analyse the effects of individual factors. Both indexes used data of different years which could interfere with the practicability of the model. And lastly, the overall causality of the study could be confirmed, however causalities within the variables do not always line up with the overall assumption. For example, credit rating is part of the Technology variable, and scholars have found a significant impact of climate risk on the country credit rating (Mathiesen, 2018). This refers back to the previous limitation of more distinguishable data.

Future research should include a clear differentiation between different ICT aspects. The results of various studies use different research approaches and designs which makes it difficult to compare the effects. As many forecasts made predictions for the year 2020, considerably more work will need to be done to determine what the actual environmental impact of the ICT sector in 2020 was, also focusing on the implications of the COVID-19 pandemic.

6. Conclusion

The present study was designed to determine the effect of ICT factors on air quality. Multiple regression analysis revealed that a significant linear relationship between ICT factors and air quality exists and that the different factors have different impacts on air quality.

One of the more significant findings to emerge from this study is that technical aspects such as the usage of ICT devices have a negative impact on Air Quality, whereas Future Readiness which includes online retailing has a positive effect on Air Quality. In absolute terms, the effect of Future Readiness is twice as high as the effect of Technology on Air Quality. Furthermore, the results of this study indicate that factors such as R&D and other forms of education summarized as Knowledge do not significantly influence Air Quality. Taken together, these findings suggest a role for Future Readiness in promoting Air Quality, hence, environmental sustainability.

These findings have significant implications for the understanding of how the whole IT sector can become greener. This includes making devices become more efficient and making the life cycle of technologies more sustainable, but also investing in the adoption of technologies to exploit digital transformation.

The relevance of the analysis is clearly supported by the current findings. The global COVID-19 pandemic and increasing environmental degradation cause a new approach to the usage of ICT and the study shows that digital technologies offer solutions to some of the corresponding problems. The implications showed that the emissions caused by the ICT sector are closely related to CO_2-emitting energy sources. A reasonable approach includes investing in renewable energies to reduce the carbon footprint of the ICT sector further.

The findings from this study make several contributions to the current literature. First, they provide a statistical model to support an impact analysis of ICT elements on the environment. Second, they indicate a positive net effect of ICT on the air quality and third, show that the carbon footprint might be forecasted too high in the past and calls for further research to quantify the net effect of ICTs. Lastly, the approach of this study differs from others, as it combines different factors of ICT and builds an impact model to define the direct and indirect effects of ICT on the environment, rather than analysing solely the direct effect of individual devices.

In conclusion, to answer the question raised in the introduction: Yes, the ESB Website is partly deteriorating our air quality, but switching to green hosting would help the ESB to emit 9% less CO_2 (Website Carbon, 2020). Besides that, data centres will become more efficient and the effect can be offset by the energy-saving potential of ICT in other areas of the university or by the planting of three trees.

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