The Impact of 5G on Future Data Center's Carbon Dioxide Emissions

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ABSTRACT

5G enables engineers to invent new devices and solve societal problems in a wide variety of fields. These devices increase the already growing worldwide data flow. To compensate for this demand for fast networking, data centers have to be improved. By combining existing studies and technology predictions a reasoned system dynamics model is designed to prepare the needed electricity infrastructure and use the existing power grid, efficiently. It is filled with data from various studies and estimates future Co2 emissions. This raises awareness of the correlation between internet usage and climate pollution.

Keywords

Data Center, 5G, Energy Consumption, Co2 Emission, Carbon Dioxide, IoT, Server Farm

1. INTRODUCTION

Global internet traffic is expected to reach 4.2 trillion gigabytes per year in 2022 [10], which is three times as much as in 2015 [22]. This exponential growth of data traffic is influenced by the newest generation of network connectivity, 5G, which enables new technologies and application fields [10]. Most of this traffic is managed by data centers.

The data center's energy consumption is divided between multiple components. Apart from lights, office space and the cooling system, an uninterruptible power supply is used for servers, storage devices, and network equipment. A typical server has these power-consuming parts, ordered descending by their peak power consumption [12]:

- CPU
- Memory
- Disks
- Peripheral slots
- Motherboard
- Fan
- Power supply losses

In 2018 data centers already covered nearly 1% of the global final electricity demand. In the growing climate change awareness, the CO2 emission of electricity generation significantly contributes to recent discussions. 13 Gt of CO2 was emitted for electricity generation in 2018. That is 38% of the total energy-related CO2 emissions of that year [17].

This paper provides an overview of the impact of 5G on the data center's energy consumption and the caused carbon dioxide emissions based on a modular system dynamics model.
It answers the central research question: "How will future data center's carbon dioxide emissions evolve, considering the deployment of 5G?"

1.1 Structure of the Paper

First, previous research in the field of data center energy consumption and 5G gets presented. After that, the methodology used in this research is explained. This is followed by the results section, which includes the gathered data, an explanation of the system dynamics model, followed by the made observations and the discussion. The final part contains a conclusion.

2. LITERATURE REVIEW

Several authors published literature on the topic of data center's current energy consumption, future developments on internet usage and the new products enabled by 5G. L. Belkhir and A. Elmeligi wrote a paper about the trends to 2040 and recommendations for ICT global emissions footprint [6]. In their studies, they covered the production and the operational energy of ICT devices but did not consider the impact of the newest network connectivity generation.

Cisco, an American technology conglomerate working in the networking hardware and software industry, publishes regularly literature concerning data centers and their usage trends. Their research cover estimations on future IP traffic developments and they operate in a worldwide scope. In their estimations of the latest Visual Networking Index [7] they already include the influences of 5G and future estimations of 5G coverage.

The International Energy Agency (IEA) provides data on the field of energy usage and analyses relevant papers. They also list relevant references on the topic of data centers. A.B. Schäppi and B. Przywara published a paper about the energy consumption and saving potentials of servers [1].
The journal "Green Data Centre Technology Roadmap" describes the energy groups of a data center and elaborates on techniques to reduce electricity usage on the cooling and IT side [16].

According to Van Heddeghem et al., data centers consumed 1.4% of the global electricity use in 2012 [23]. They

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also estimate that global electricity demand is growing slower than the electricity consumed by digital devices and infrastructure (3% per year against 7% per year).

"Power Consumption and Energy Efficiency in the Internet" [15] is an article about the overall power consumption in internet infrastructure. The power consumption of data centers is also elaborated, but they choose a different approach. Instead of calculating the annual energy demand of all data centers worldwide, they examined the energy required to download content from a data center.

The growing data center electricity demand is also discussed by J. Morley, K. Widdicks and M. Hazas [19]. They mainly focus on determining the daily peak demand for data and therefore the peak of the electricity demand of data centers. The result of their study is, that "Containing the overall growth in energy demand across digital infrastructures also depends on more than efficiency alone: it requires limiting the growth in traffic, to at least keep in step with efficiency improvements, a balance which has not so far been the case." [18]. This paper lacks the impact of 5G.

Besides that there is "On Global Electricity Usage of Communication Technology: Trends to 2030", the article of Anders S. G. Andrae and Tomas Edler [2]. It estimates global electricity usage and covers the whole sector of Communication Technology. Therefore the electricity usage of data centers is also covered. An absolute rise from 2000 TWh (2010) to 8000 TWh (2030) for the production and operation of ICT is foreseen in this paper. Data centers in 2030 would use 2967 TWh of those 8000 TWh [3].

3. METHODOLOGY

The research is done according to a multi-method design. Based on literature review data is collected, based on this data a modular system dynamics model is constructed. This ensures, that an accurate future estimation can be made.

The literature review integrates a broad variety of future estimations and is mainly gathered from literature databases, but also articles, referred to in found literature, are taken into account. The central literature databases used for this research is Scopus. Side searches are done using Web of Science and Google Scholar. Keywords for the literature research focus mainly on data centers, 5G and the Co2 emissions caused by electricity generators. The English spelling of center - centre - was also considered. All those queries include words like globally, prediction or forecast.

A new system dynamics model is designed using the acquainted knowledge. Instead of just providing a single projection of predicted energy consumption there are multiple outcomes, dependent on different assumptions made. The model is flexible and allows multiple situations to be taken into account while forecasting the future Co2 emissions of data centers. The main time frame starts in 2016, for that year sufficient discussed data is available, and ends in 2035. Adjusting the observed time frame to a longer time period will be possible, as well, but most literature does deliver accurate data to make such foresighted predictions.

The outcome of this model is then discussed critically and set into context. It is also important to elaborate on the likelihood of a prediction to occur in the future. The discussion will also include possible inaccuracies of the simulation model and which information is needed to improve the outcome.

Table 1. Data used in the system dynamics model

Parameter	Value
Electricity Usage (2016)	416 TWh
Electricity Efficiency (Until 2021)	10%
Electricity Efficiency (From 2022)	5%
IP Traffic (2016)	6819 EB
IP Traffic (2017)	9087 EB
IP Traffic CAGR	24.7%
Electricity Footprint (2016)	295.8 g Co2/kWh
Annual Emissions Efficiency	7.48%

4. RESULTS

This section provides a description of the system dynamics model and the data it is based on, followed by the examined observations and ends with the discussion.

4.1 Data collection

In order to estimate the overall footprint of the scope, we will need to collect significant data of mainly two areas. Those two areas are the annual electricity usage of data centers and the conversion rate from electricity to carbon dioxide. 2016 is the last year for which sufficient data is available therefore that is where the simulation starts. An overview of the data used is displayed in table 1.

4.1.1 Data Center Electricity Usage

Radoslav Danilak, a Council Member of Forbes, states in his article "Why Energy Is A Big And Rapidly Growing Problem For Data Centers" that global data centers used about 416 terawatts in 2016, which equals 3% of the total electricity generated that year [20]. This data is used as a basis for further calculation.

To forecast future values for this electricity usage, the development of the data center efficiency and IP traffic is needed.

The annual electricity improvement can be taken from Anders S. G. Andrae and Tomas Edler [2], who concluded values of 15%(best), 10%(expected), and 5%(worst). Since Moore's Law is not valid anymore for future estimations, according to theoretical physicist Michio Kaku [11], a value of 5% will be used from 2022 for all cases [2].

The total data center IP traffic combines the areas data center to user, data center to data center and within data center. Data center to user defines the traffic that goes from the data center to the end user through IP WAN or through the internet. It already includes estimations on the growth and influence of 5G.
According to Cisco, 5G traffic will reach 12% of the worldwide mobile traffic by 2022. Mobile traffic will seven-fold between 2017 and 2022, assuming that there will be 1.5 mobile devices per capita. They estimate that by 2022, 5G will generate 2.6 more traffic than a 4G connection, on average [8]. Using the data provided by Cisco we get 6819 EB for 2016, 9087 EB for 2017 and 20555 EB for 2021 [9]. This results in a compound annual growth (CAGR) rate of 24.7%.

4.1.2 Carbon Dioxide Emissions caused by Electricity Generation

For the conversion rate of kWh to g of Co2 validated data is needed. The conversion rate for 2016 is 295.8 g CO2/kWh, while it was 442.7 g CO2/kWh in 1996 [13]. This rate, therefore, decreases with a factor of 7.483% and is approximately linear. It is assumed that this rate will still be applicable for the next 20 years.

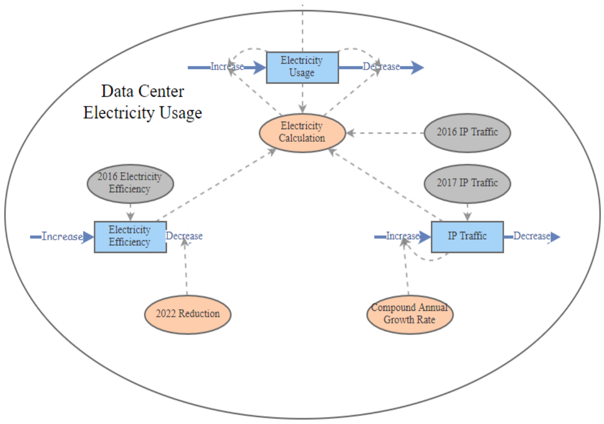

Figure 1. Data Center Electricity Usage part.

4.2 System Dynamics Model

The System Dynamics Model (Appendix A) can be split up into three main parts. In the **Data Center Electricity Usage** part the annual electricity usage of all data centers combined is calculated. The **Carbon Dioxide Emissions caused by Data Centers** part is responsible for delivering an accurate conversion rate of g CO2 per kWh and **Carbon Dioxide Emissions caused by Data Centers**, the last part, combines this data and returns the global, annual CO2 emissions caused by data centers.

4.2.1 Data Center Electricity Usage (Figure 1)

The equation of Anders S. G. Andrae and Tomas Edler [2] is used as a basis for calculating the annual electricity usage of data centers. It combines the electricity usage of the previous year with expected IP traffic and expected improvements in the field of electricity efficiency inside data centers:

$$E_{2017+n} = \left(\frac{IPT_{2017+n}}{IPT_{2016+n}}\right) \cdot E_{2016+n} \cdot \left(\frac{(100\%) - EE\%}{100}\right)$$

where

E_{2016} = electricity usage in 2016, TWh
E_{2017} = electricity usage in 2017, TWh
IPT_{2016} = global data center IP traffic in 2016, EB
IPT_{2017} = global data center IP traffic in 2017, EB
EE = electricity efficiency improvement
n = 0,1,2...,19

The electricity usage is included as a stock, which is influenced by an incoming flow if the usage increased, compared to the previous year, or influenced by an outcoming flow if the usage decreased. The electricity efficiency is designed as a stock, as well, and stays at the value of 2016 until it gets set to 5 in 2022. The stock of the IP Traffic uses the traffic of 2017 as an initial value and increases according to the calculated CAGR.

4.2.2 Carbon Dioxide Emissions caused by Electricity Generation (Figure 2)

The conversion rate of g Co2 per kWh is resembled in a stock with the rate of 2016 as the initial value. For the following years the emissions efficiency either increases or decreases this stock, based on the set value.

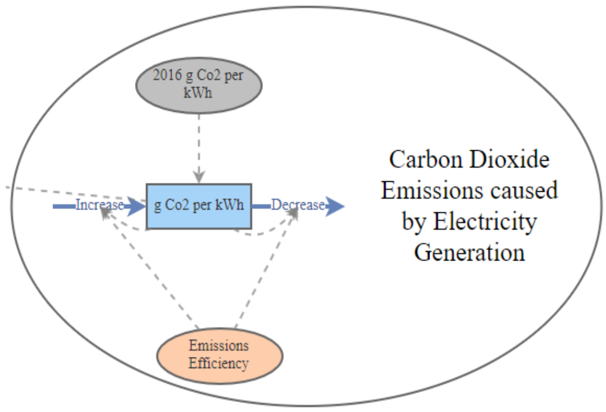

Figure 2. Carbon Dioxide Emissions caused by Electricity Generation part.

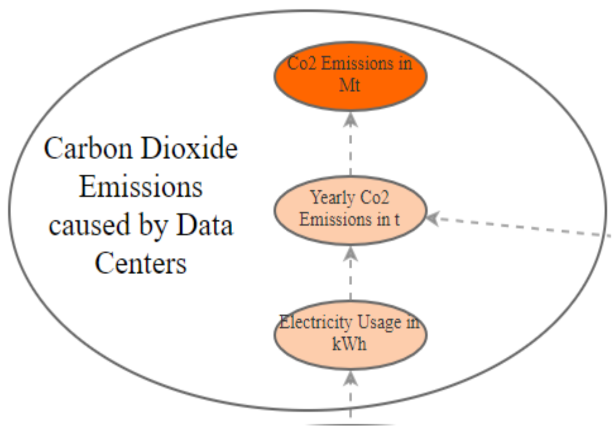

Figure 3. Carbon Dioxide Emissions caused by Data Centers part.

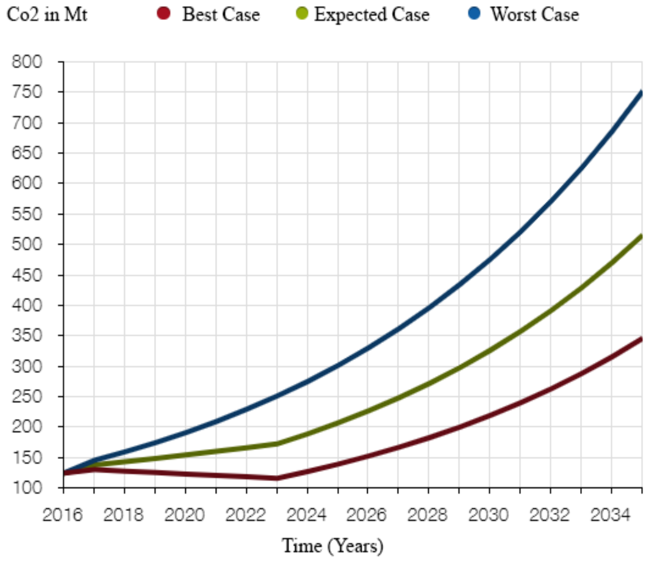

Figure 4. Future Data Center's Carbon Dioxide Emissions.

4.2.3 *Carbon Dioxide Emissions caused by Data Centers (Figure 3)*

The Co2 emissions in t are calculated by first converting the electricity usage from TWh to kWh and then combining this value with the conversion rate:

$$EM = (\frac{E \cdot CR}{1000000})$$

where

EM = emissions, t
E = electricity usage, kWh
CR = conversion rate, g Co2/kWh

Finally, this value gets converted from t to Mt for improved readability.

4.3 Observations

Running the simulation with the time frame from 2016-2035, we get the graph displayed in figure 4. The initial value for 2016 is 123.05 Mt of Co2 emitted for data centers. Until 2023 the three covered cases progress differently.

For the best case scenario, the emissions get reduced to 114.68 Mt of Co2 (2023). After that, the predicted emissions grow exponentially and reach 344.51 Mt of Co2 in 2035.

The expected case grows nearly linear to a value of 171.10 Mt of Co2 (2023). It then also continues with exponential growth and reaches 514.02 Mt of Co2 in 2035.

For the worst case scenario the growth is exponential all the time and in 2035 data centers would be responsible for 750.49 Mt of Co2.

While the IP traffic is expected to grow constantly in the next years (Figure 5), electricity generation can be done more efficiently (Figure 6).
Furthermore, the expected demand for electricity is increasing more significantly than the Co2 emissions caused by data centers. This development is displayed in the graph of figure 7.
From the 416 TWh in 2016 the electricity usage growths exponentially to a value of 705TWh in 2020, 1399 TWh in 2025, 3264 TWh in 2030, and 7616 TWh for the year 2035.

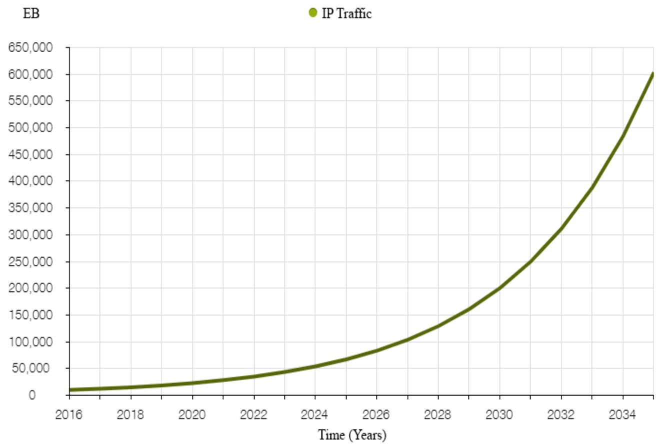

Figure 5. Future Data Center's handled Ip Traffic.

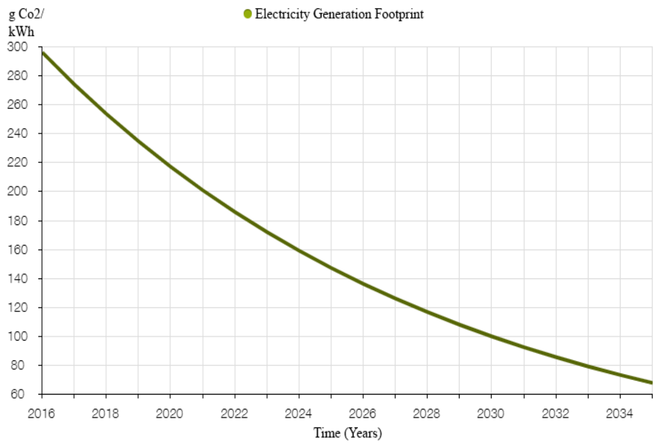

Figure 6. Future Electricity Generation Footprint.

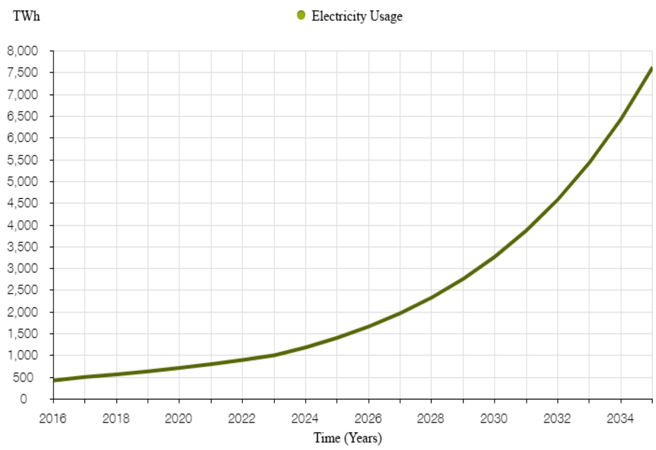

Figure 7. Future Data Center's Electricity Usage.

4.4 Discussion

The goal of this research was to visualize and discuss the impact of 5G on future data center's carbon dioxide emissions with the help of a system dynamics model. The simulation of this model shows, that exponential growth of carbon dioxide emissions can be expected. The future reduction of Co2 emitted by electricity generation can not cope with the growth of IP traffic.

Comparing the electricity usage for 2030 predicted by this model *(A)* with a forecast from 2015, which did not include the influence of 5G *(B)* [2] we get the following results:

A = 3264 TWh
B = 2967 TWh

This shows that the expected electricity demand for the year 2030 increased by 9%. The previously discussed result of the research of J. Morley, K. Widdicks and M. Hazas [18] also approves the continuous growth of electricity demand for data centers.

Since current power grids, e.g. the power grid of Amsterdam [21, 5], are already at the limit of their capacity, data centers continuously growing demand for electricity could become problematic. The result of this model shows, that 5G has an influence on the growth of electricity demand and therefore on the ecological footprint.
Nevertheless, there are improvements made in the field of heat usage. The heat caused by data centers is already used in some cities to heat up the homes of the citizens [4]. Also moving the data centers into countries with a cooler ambient temperature (Natural Cooling Technology) can reduce the energy needed for cooling and therefore reduce the overall carbon dioxide emissions [24].
Another way of emission limitation would be the reduction of IP traffic and therefore the limitation of internet usage. All those inventions, which are made possible through 5G, the companies which outsource their storage system to the cloud or the streaming providers, which constantly improve the quality of their media and therefore the needed traffic, they all lead to this development.

Limitations of this model are mainly the availability of data for the global scope. There is a larger availability of data for smaller regions or countries, but covering this scope is only possible when accepting the disadvantages of not having data for every data center.
More detailed data on how the efficiency of data centers will develop, especially considering new cooling techniques, faster algorithms or improved CPUs are not included separately. Instead, only one number represents this whole area. A more detailed version of the system dynamics model would, therefore, improve the usability and adaptability to other innovations.
The same limitation can be found on the IP traffic side. One number is used to resemble the expected growth rate of IP traffic, including all influences, e.g. caused by 5G or the growing population. But having the data for all those influences separately would presuppose a wider selection of research results available.

The provided system dynamics model acts as a foundation for future work in this field. For that, three parts can be adjusted. These parts are the electricity efficiency of data centers, the expected IP traffic, and the future electricity generation footprint. If the variables influencing those stocks are filled with different data, the outcome changes. The model could also be used to test how specific innovations influence overall Co2 emissions. Discussions about the need to regulate IP traffic in the future can also be held on the basis of this model. Therefore it is accessible online and can be used for research purposes [14].

5. CONCLUSION

The research aimed to create a system dynamics model, which can display the future influence of 5G on the electricity usage of data centers and the connected Co2 emissions. This was done using current literature and models and delivers justified outcomes.

Carbon dioxide emissions caused by worldwide data centers are expected to grow exponentially and reducing future IP traffic and increasing the energy effectiveness of electricity generators and data centers are the possibilities to reduce this predicted development.
Especially the already existing scarcity of electricity in some power grids gets negatively influenced by the predicted electricity consumption. Power grid providers in those areas should make provisions immediately, taken expected energy consumption developments of data centers into account.

Based on the validity of the model, it can be used for further researches in the field of Co2 emissions and electricity usage of data centers.

6. ACKNOWLEDGEMENTS

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APPENDIX

A. SYSTEM DYNAMICS MODEL