CARBON TRUST

Measuring an industry's impact on GHG emissions inside and outside its own sector - ICT impact on GHG emissions

Methodology Document

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DELL

Acknowledgments

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Table of contents

Table of figures

Table of tables

Introduction

Introduction

With the global call for action to reduce emissions on a larger scale than ever before in order to limit climate change, there is a need to identify actions with large impact and at a larger scale. Given the complexity of today's economic system and the multiple drivers at play, there is a need to understand the drivers behind carbon emissions and how these can be approached to drive emissions down.

The methodology described in this document was developed to model the impact of the ICT sector in the overall economy, by testing its approach in two sectors of the economy – passenger air travel and service buildings. This document describes the approach taken and how it can be applied to any part of the economy, along with a more detailed description (including data and assumptions) of how it was applied to the two sectors chosen. There is also a section regarding limitations of the current methodology and the necessary steps to improve it.

After the refinement of this methodology, the model should be able to show the impact on emissions not only related with increases of efficiency (driving emissions down) but also related with increases of demand (driving emissions up). By using identifiable emission drivers in the model, the intent is to use the results to, not only understand past trends, but to create future scenarios and, most importantly, to inform on future actions and investment decisions.

This Methodology Document accompanies a separate report, "Measuring Impact at Scale "[1], which was prepared by the Carbon Trust for Dell in November 2018. That report presents the results of the analysis, and this Methodology Document describes in more detail the methodology that was used.

[1] Full title: "Measuring Impact at Scale, An exploration into the role of ICT on global GHG emissions in two sectors: Demonstration cases for passenger air travel and service buildings sectors"

Methodology

Methodology

1. Overview

Given the urgency in taking action to address climate change, it is crucial that we dedicate efforts in understanding the impact of economic activity in total world emissions and the drivers behind them. Only by understanding these drivers, it is possible to direct the efforts to the actions that will have a more meaningful outcome. This work intends to study the viability of modelling the impact of a certain industry, in this case, ICT, in the overall economy, by testing its approach in two sectors – passenger air travel and service buildings.

In summary, the approach is to analyse the historical and projected total emissions for a sector, and by removing the impact of other external drivers (such as population, affluence and affordability) isolating the remaining impact of the relevant technology. A further step to this study is to attribute the impact of an individual product or company within the ICT industry.

To model historical and future sectoral emissions, a top-down approach was used. This allowed the use of macro-economic variables/drivers (such as population and affluence) which impacts we wished to remove so we could isolate the technology effects on the level of emissions. Based on this top down approach was the mapping of the volume of activity and the emissions intensity of each sector, to the drivers of that sector. These sector specific drivers are linked to ICT industry's activity and are meant to model the way technology has been linked with the emission trends observed. This methodology was created under the assumption that the role of technology in both volume of activity and emissions intensity could be modelled using a limited number of variables.

Total emissions = activity (units) × intensity (tCO_2e/unit)

The separation of the volume of activity and intensity also allowed us to split the demand versus offer effects on emissions; volume of activity is linked to the demand in each sector and intensity to how that demand is met (offer). In terms of a later use of this approach to derive insights that inform industry action or policy design, this separation might provide especially actionable insights.

Figure 1: High-level Decomposition of Sector Carbon Emissions

At this phase, we focussed our analysis in two sectors that we wanted to be quite disparate in the drivers used and how the activity is structured, so we could test the flexibility of our approach. The two sectors considered were:

- Passenger air travel: emissions from passenger flights including domestic and international flights. For this sector, volume of activity is measured as the number of passenger.kms, and intensity is measured as the emissions per passenger.kms

- Service buildings: emissions arising from all energy uses within non-residential buildings (excluding industry) which includes for example restaurants, public buildings, hotels and offices. This definition is aligned with the one used by both the IPCC and IEA. For this sector, volume of activity is measured as area (m^2) of office floor space, and intensity of emissions as tCO_2e per office floor area (tCO_2e/m^2)

Thus, for the two sectors considered in this study, we have identified the key drivers that impact emissions for the sector, attempted to isolate the impact of the different drivers, and understand the flavour of the different drivers. Comparing the two sectors, we have identified some common drivers, and some discrete ones that are specific to a sector.

2. Identification of drivers

2.1. General approach

The overall approach described above is dependent on the capacity to model the trends of the activity volume and intensity of emissions for each sector. The identification on how to best model these metrics followed a number of steps as described in Figure 2.

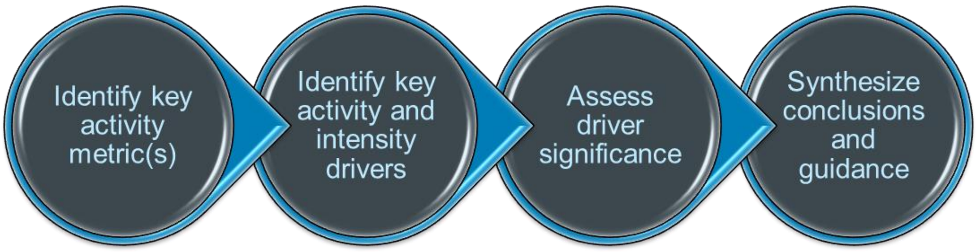

Figure 2: High-level Overview of Methodology

The first step to this modelling was the identification of the main metrics to use to measure both activity volumes and intensity of emissions. This allowed to then list the drivers that are expected to impact these metrics. Data availability and level of significance were two of the factors that were considered in choosing the drivers. Figure 3 provides an overall view of the type of drivers that were identified for both the activity and the intensity metrics. The combination of these drivers and the role of ICT behind the trends of each driver, were the basis to then establish the modelling for the key activity and intensity metrics and hence build the model that was the basis of this study.

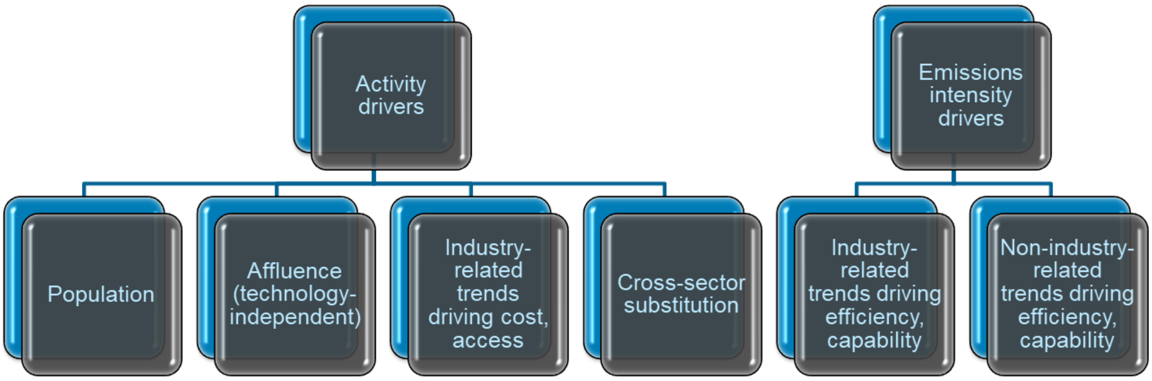

Figure 3: Overview of Activity and Intensity Drivers

2.2. Cross-sectoral drivers

Even though different sectors have specific dynamics and are driven by different factors, there are drivers that are expected to impact on the activity and emissions of all drivers. The most relevant common drivers that were included in the model were population and affluence/affordability. The second is intrinsically linked with GDP even if it can be driven by other factors as explained below.

Population

Population is one of the most relevant factors in the models. World population has been increasing at a rate of approximately 1.2% a year from 2010 (model's baseline year) and is expected to continue to do so at a rate higher than 1% until 2020 (target year). This growth, however, is not homogenous across countries or regions with population in low-affluence countries showing a high increase and high-income countries seeing their population stabilising. This plays an important role as demand trends have been calculated by region and often times, demand per capita is low but rapidly growing in developing countries where population is also increasing quickly.

Population growth is considered to be independent from technology, even though it is arguable that there is an indirect impact through an impact of technology in affluence and life expectancy, this has been assumed for simplicity.

Affluence/affordability

The demand/volume of activity of a sector is also heavily influenced by the perceived affordability of the products/services provided by the sector.

2.3. Sectoral drivers

These have been divided into activity and intensity drivers and intend to represent the main levers that have led to an increase or decrease of emissions within the sector. As the approach taken is to model the impact of ICT in both volume of activity and intensity of emissions, these drivers are crucial in designing the model and to understand technology impacts on both sides.

Activity drivers are factors that can explain the increase/decrease of demand and are mostly related to economic variables (e.g. price or affordability within each sector).

Intensity related drivers are more closely linked with efficiency gains/losses that might have happened throughout time.

More details of the specific drivers for the two sectors used in this study can be found in the appendix.

2.4. ICT impact on affluence/affordability

As one of the goals of this model was to understand the role of the ICT industry in the worldwide level of emissions, there was a need to assess the ICT impact on most of these drivers. This assessment, due to the complexity of this question (how to quantifiably assess this impact) and the lack of dedicated studies over this subject, was largely subjective. For technology-related drivers, this evaluation is more easily justifiable as, in most cases, there is a direct link between ICT outputs, and the relevance of that driver. However, for affluence/affordability, this link is not so easily quantifiable.

For each sector, it was analysed what were the main factors impacting demand and how elastic this demand was to price. For example, whereas in the passenger air travel sector, demand is quite sensitive to price variations, the same does not happen for the service buildings sector.

This factor is especially relevant when the effect of ICT is isolated from others that drive demand up and has a large influence in the final results obtained.

3. Mapping emissions to drivers in the case-studies used

Despite the differences between the two chosen sectors and the drivers of demand and efficiency in each one of them, the basis of the model was similar. Total emissions were calculated from the multiplication of total demand (volume of activity) and the applicable emission factor (emissions intensity) of each sector.

For the demand the intent was to capture as closely as possible the observed trends to replicate those up until the target year (2020). For both sectors, population was used as one of the main drivers for demand and considered to be independent from technology (i.e. not influenced by technology). Beyond population, it was assumed that each sector had two other factors that impacted demand:

1. The level of affluence of a country was modelled using the income class of each country: evaluated as *L* (low income), *LM* (lower medium income), *UM* (upper medium income) or *H* (high income)
2. Sector specific factors:

- Passenger air travel: Rail network quality – This factor was included as train travel is a substitute service to most of short-haul air travel (if within the same continent), but only where there is a good/high quality train network – cross-sector substitution driver as mentioned in Figure 3. Demand for air travel is expected to show different trends for countries/regions that either rely solely on air travel due to poor rail networks (e.g. USA or South America) or where train travel is a competitor to air travel (e.g. Central Europe and Russia). Evaluated as being either *Good* or *Poor*.
- Service buildings: Reliability of electricity network – This factor was included to then calculate the correct emissions intensity for the demand observed. In countries where the electricity network is unreliable, diesel generators are often used as a back-up source of energy during shortages of electricity which has an impact on the final mix of energy usage and hence, the final emissions intensity calculated. Evaluated as being either *Good* or *Poor*.

To capture these multiple dimensions, we have mapped both population and the demand per capita in each of the sectors. This mapping was done by grouping countries with the same characteristics in each year (level of affluence and rail/electricity network quality) – these groups were defined as the modelled regions which were used to obtain time trends. As the level of affluence changed for some countries within the timeframe analysed, these regions were dynamic, i.e. the countries that composed them changed from year to year.

On the emissions intensity side, we have used the identified ICT drivers to model the final emission factor applicable to the sector and type of energy usage. These are expected to drive emissions down.

Figure 4 provides an example for one of the case studies used (Passenger air travel) where the emissions from 2010 (the baseline year) to 2020 (the target year) can be split by driver (population, ICT-related affluence, non ICT-related affluence, and ICT-related efficiency improvements). In this case, all the intensity drivers (which are all technology-based) have been grouped into one.

Figure 5 presents the same graph for the Service buildings case study. In this case the intensity drivers, related with the energy intensity observed (kWh/m2), can be split between ICT influenced and non-ICT influenced. For a more detailed discussion on the results of both Figure 4 and Figure 5 please see the "Measuring Impact at Scale" report, which presents the results of the study.

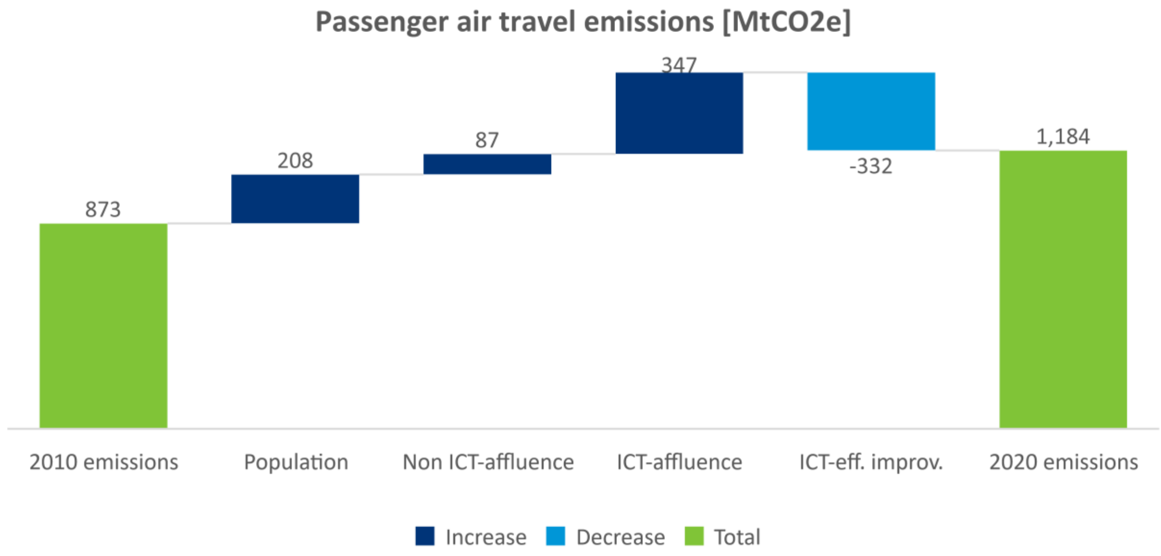

Figure 4. Contribution of different drivers to the evolution of passenger air travel total emissions

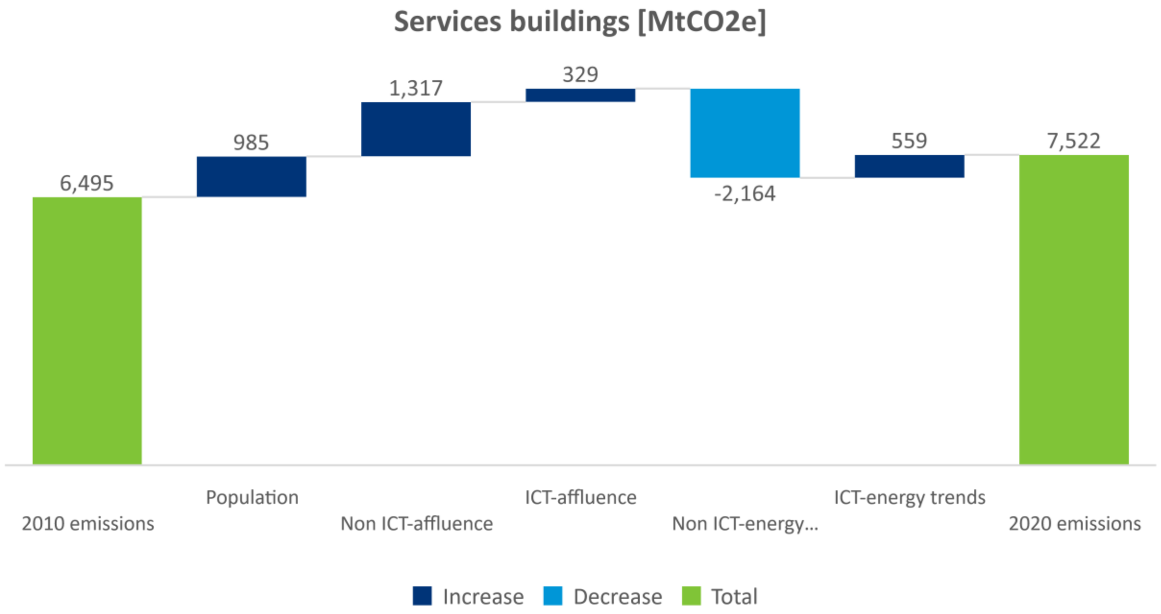

Figure 5. Contribution of different drivers to the evolution of service's buildings total emissions

For a more detailed explanation of how the models have been built for each one of the sectors, please see the Appendix sections.

3.1. Isolating ICT impacts

The model provides an estimation of each sector's emissions up to 2020 (the defined target year). To address this study's goal of understanding the role of ICT in the global emissions trends, attribution percentages were assigned to model how much of the observed annual growth/decrease of the main variable was due to (ICT) technology.

The percentages defined are linked to the role that ICT played in the trends of each driver for the two sectors, but other factors were also considered. Table I presents the attribution percentages used in the model and the justification for these:

Table I. ICT attribution rates and respective justification

	Attribution %	Justification
Population	0%	Considered to be independent from ICT technology
Passenger Air Travel		
Affluence/Affordability	80%	ICT technology was a main driver for the decrease of prices and partly influenced the observed economic growth
Load factor	100%	ICT technology was key in the main changes in the sector that led to an increase of the load factor (e.g. improving booking management systems)
Fuel efficiency	100%	ICT technology was key in the main changes in the sector that led to an increase of the fuel efficiency of flights
Service Buildings		
Affluence/Affordability	20%	ICT technology partly influenced the observed economic growth leading to an increase of services building area, but this impact had a limited reach
Heating energy intensity	40%	Current technology is already relatively mature, change in demand is closely related with improvements in insulation and different needs for thermal comfort
Cooling energy intensity	60%	Technology improvements have only partially been supported by ICT, change in demand is closely related with people having a higher preference for thermal comfort and overall temperature rises
LED technology	50%	The new generation of lamps was mostly due to advances in material's engineering that can only be partly attributed to ICT
LED sensors	100%	Sensors could not have been developed without ICT technology
Appliances and equipment energy intensity	100%	ICT technology was considered key for the development of new appliances and equipment hence leading to its increase in demand

Attribution percentages is one of the largest sources of uncertainty in the model as these have been based on subjective factors rather than data. The translation of subjective considerations to quantitative rates is always the source of uncertainty in a model.

On a next phase, a large part of the research will be dedicated to adjust these rates and justify them in a more quantitative way.

4. How the results can be interpreted and used

For the model being discussed in this report to be relevant, it needs to present actionable conclusions which should be aligned with the questions of:

- Which are the focus points to accelerate impact?
- Which are the areas that should be the main point of focus?

To be able to achieve that, on top of the analysis done in the model, other dimensions need to be evaluated such as Potential for Action and Data Availability. This has a direct impact not only on the drivers chosen, but also on how the results will be interpreted.

In the table below we present a list of identified drivers along with an evaluation of their relevance for the model, for potential action design and data availability. For the model, this evaluation was mostly used to evaluate the impact of technology in the role of each variable.

- Potential Impact (P) relates to the expected change in this driver in relation to the specific sector's emissions; a 5 means that it is expected that this driver will show and/or has shown a significant increase/decrease and that this will have a high impact on the sector's emissions.
- Adoption (A) relates to the speed of implementation of the listed drivers. Where adoption is high (5), it is more probable for this specific driver to be implemented after it is "technically" available. Where it is low (1), adoption of such driver might need support from legislation or other sector-specific action
- Directness (D) relates to the level of impact that ICT plays for each of the drivers, with the following levels: Key enabler (5); Major role (4); Direct impact (3); Relevant indirect impact (2); Supporting role (1)
- Relevance for sector is the multiplication of factors above and signifies how impactful the ICT role is through each one of the drivers, and hence its relevance for this present model
- Action potential indicates the potential impact of actions to promote this driver and it is obtained by multiplying P, D and the inverse of A
- Data availability refers to how easily available information is; the lower the score, the more uncertainty there is regarding the data used in the model

Table II. Summary list of drivers

ICT driver	Potential impact (P)	Adoption (A)	Directness (D)	Relevance for sector (PxAxD)	Action potential ($PxA^{-1}xD$)	Data availability
Passenger Air Travel						
Improvement in aircraft design	4	5	4	80	3.2	4
Engine efficiency	4	5	5	100	4	4
Fuel efficiency	1	5	5	25	1	2
Load factor increase	4	5	3	60	2.4	4
Average of seats per airplane	4	5	2	40	1.6	4
Service Buildings						
EnMS optimisation	3	3	2	18	2	2
Availability of equipment	3	5	4	60	2.4	3
Lighting technology improvement	2	3	3	18	2	4
Building Design	4	1	4	8	16	2
Greener electricity	5	2	2	20	5	5
Electrification	5	1	2	10	10	2
Smart grids	2	1	4	8	8	1
Others						
Population						5
Affluence						4
Affordability impact on sector						2
Availability impact on sector						2
Elasticity of demand of sector						2

Colour Legend:

Red	Low potential/impact/data availability
Orange	Medium-low potential/impact/data availability
Yellow	Medium potential/impact/data availability
Light green	Medium-high potential/impact/data availability
Green	High potential/impact/data availability

5. Limitations and uncertainty

The large limitations found in the construction of the models were mostly linked with the lack of detailed data to represent the identified drivers and demand trends in each sector. Specifically, in obtaining country specific data for a significant period of time. This limitation was more prominent for the Services Building sector than for Passenger Air Travel, as the available databases regarding the building's energy consumption and characteristics are very limited.

Another point for development is a better view over what "cross-sector substitution" might mean for the modelled trends. In this study, the effect of switching between air and train travel has been considered, but broader concepts of this substitution could also be considered. For example, the increase of the efficiency and quality of teleconference technology could be related to a lower demand for business travel. The same driver can also be related to more flexible working arrangements allowing for a decrease in office floor area. Due to lack of data in which we could sustain our analysis, this has not been included in this model, but should part of the focus of future work.

An additional point of uncertainty is the forecast of the emission factor applied to electricity as there are many factors that can impact it. This mainly impacts the Services Building sector as the main source of energy in the Passenger Air Travel sector is jet fuel.

Another point for improvement is the justification of the attribution rates presented in section 3.1. These have been defined mostly from a qualitative analysis of the data and the knowledge/experience of the project team in the modelled sectors and ICT. However, these factors can have a very large impact on the results, especially in the analysis of the role of technology and ICT on the emissions trends shown in both sectors.

Appendix

Appendix A: Air Passenger Travel

a) Sector drivers

ICT plays a strong role in driving not only the efficiency of air travel but also the trends in the demand. With the ICT/technology (r)evolution, a number of services that used to be limited to a few, became available to everyone due to both price reduction and ease of access; this phenomenon is called the "democratisation of travel".

This section discusses the top ICT factors that contributed to this phenomenon. It looks separately at ICT drivers which impact volume and intensity, given that emissions can are defined as their multiplication as previously said.

Drivers that impact on emissions intensity (kgCO_2e/passenger.km)

1. **Improvement in aircraft design was only possible due to computer modelling.** Specifically, the optimisation of aircraft design, especially in regards to aerodynamics – fluid dynamics is one of the most complex areas of physics to replicate and complex fluid flows have only been possible to replicate using fluid dynamic software. ICT had a ***major role***;
2. **Engine efficiency improvements due to computer modelling.** Similarly to the above, the limits of hand calculations had made the improvements of engine efficiency more difficult if not impossible. Computer modelling made it possible to continue to achieve improvements in engine fuel efficiency. ICT was a ***key enabler***;
3. **Fuel efficiency improvement due to route optimisation.** Routes are defined by distances, but also with information about winds, other planes routes and airspace regulations. With this large number of variables and the use of live information the use of ICT becomes crucial to the calculation of optimal routes. ICT was a ***key enabler***;
4. **Load factor increase due to internet booking and instantaneous updates**. The use of internet booking systems has allowed airlines to achieve higher occupancy rates. These systems can be accessed anywhere and information is always updated so it contributes to a more efficient seat allocation. ICT had a ***direct impact***;
5. **Average number of seats per airplane.** The growth of budget airlines on short-haul routes, and the steps flag-carrier airlines have made to compete with these have increased the number of seats per plane dramatically, simply by squashing more people into a plane. The emergence of budget airlines was only possible due to internet systems on which they heavily rely on. ICT had a ***relevant indirect impact***.

Drivers that impact volumes of activity (passenger.km)

Technology has enabled increases in **affluence** (i.e. having more money to spend) – economic growth per person (which could be measured as GDP per capita) is largely enabled by technology. Technology "freed" assets (in particular labour) from the primary sector to the industry sector, and afterwards to the tertiary sector. ICT in particular, also enabled the sharing of information in a more immediate way, which allowed any innovation to have a more direct impact (e.g. on efficiency gains).

Technology has also greatly improved **affordability** (i.e. how much you can buy with your money) in this sector. Flight prices have dropped dramatically in the last few decades, improving affordability -

and in a sector with a high level of price elasticity for a 'nice to have' service, this has resulted in greatly increased demand.

Prices have been influenced mainly by two factors:

1. **Increase of fuel efficiency.** By increasing fuel efficiency per passenger (fuel consumed per passenger.km) has dropped substantially in the last decades due to the various factors described in the previous section. Lower fuel means lower costs per passenger and the possibility of offering lower prices. ICT had a ***major role***;
2. **Overall price reduction due to growth of budget airlines.** The growth of budget airlines on short-haul routes, and the steps flag-carrier airlines have made to compete with these have not only increased the number of seats per plane but also decrease the number of complimentary services which allowed for a price reduction of each seat. ICT had a ***relevant indirect impact***.

The combined impact of affluence and affordability has had a major role in this sector.

Given the high level of impact that technology had in driving prices down, the estimated impact that ICT had on affluence/affordability has been defined quite high at 80% of total impact.

Demand of air travel, being very elastic as previously mentioned, is highly influenced by the levels of affluence and affordability. As more people have disposable income and prices decrease, the percentage of leisure travel has increased greatly. In parallel, business travel has been extended to companies of all sizes and is no longer only accessible to large companies - it should be acknowledged, however, that business travel growth is expected to peak soon as better video conferencing technology will make it a choice rather than a necessity. There is also another way ICT has impacted demand:

3. **Internet causes demand for flights** as people see what they can afford and purchase flight tickets much more easily than before. ICT had a ***major role***.

b) Model

As previously mentioned, the emissions of the passenger air travel sector have been defined as the multiplication of the volume of activity (measured in passenger.kms) and the emissions intensity observed (tCO_2e per passenger.km) for each of the modelled regions:

$$Emissions_{air\ passenger\ travel} = \sum_{i}^{regions} passenger.kms_{region\ i} \times tCO_2e/passenger.km$$

As the modelled emissions intensity is the same for all regions, the equation could be simplified to multiply the demand of all regions against the modelled emissions intensity. Figure 6 shows how the model works and the data flows up until the final result.

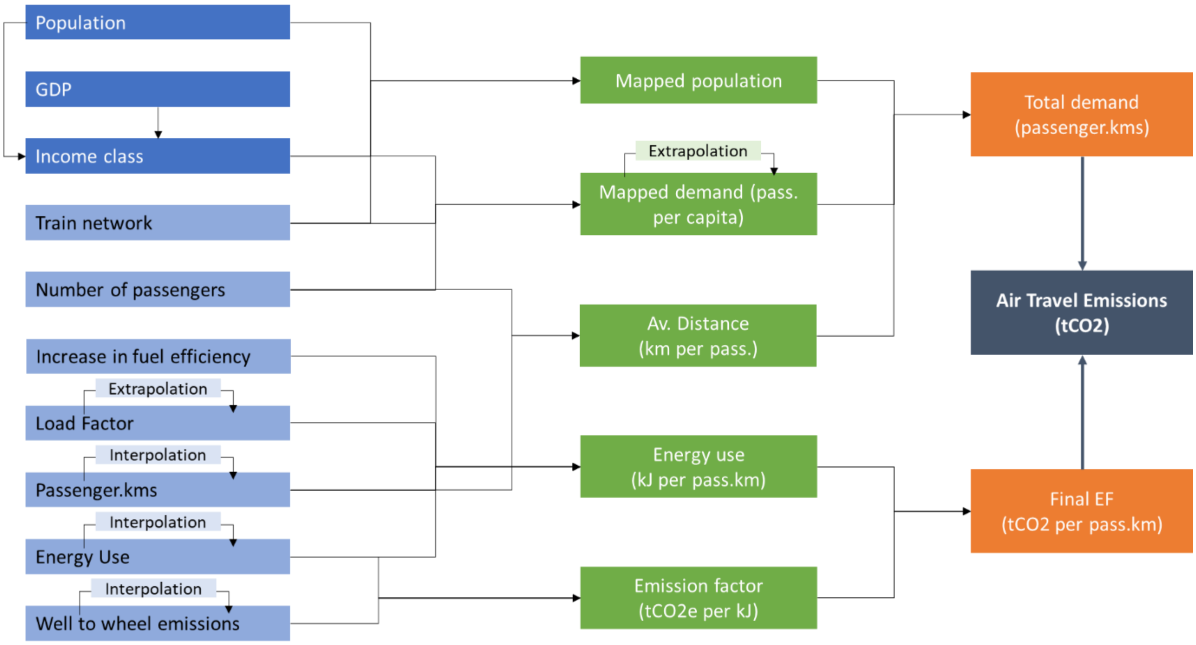

Figure 6. Passenger air travel data flow diagram

On a step-by-step description, the modelling of the passenger air travel emissions is done in the following way:

SECTOR'S DEMAND

1. Train data was used to classify countries as having a good or poor train network
2. Class income from 2016 to 2020 was obtained by estimating GDP/capita projections using World bank data, IEA GDP growth rates and UN's population projections
3. Population was mapped into regions against the quality of the train network classification and income class in each year
4. Demand per capita up to 2016 was calculated using the number of passengers and population for each country
5. Demand per capita up to 2016 was mapped into regions in accordance to the quality of the train network classification and income class in 2016 to 2020
6. A linear regression was made to each modelling region to extrapolate demand per capita up to 2020
7. Total number of passengers was calculated by multiplying the mapped population and mapped demand per capita
8. Average distance was calculated using passenger.kms from IEA data and number of passengers from World bank data. This data was assumed to remain constant for all years
9. The number of passenger.kms was estimated by multiplying the total number of passengers (calculated in step 7) and the average distance travelled (calculated in step 8)

SECTOR'S EMISSION FACTOR

10. Load factor percentages were extrapolated before 2004 and after 2017 using the data available and a load factor variation rate is calculated for each year using 2014 as a baseline

11. Fuel efficiency (energy per passenger.km) was calculated using IEA data for 2014. Expected improvements of fuel efficiency were taken from an ATAG report ("Beginner's Guide to Aviation Efficiency", 2010). From this, a fuel efficiency variation rate is calculated for each year using 2014 as a baseline

12. Average energy per passenger.km in 2014 (kJ/passenger.km) was calculated using IEA data - total World number of passengers and total energy consumed

13. Average energy per passenger.km in any specific year was estimated by applying the load factor and fuel efficiency variation rates calculated in steps 10 and 11

14. The emission factor per energy unit (tCO_2e/kJ) was taken from IEA data. This was assumed to remain the same during the time period modelled

15. Final emission factor was calculated by multiplying the energy per passenger.km value and the emission factor per energy unit obtaining tCO_2e/passenger.km

Appendix B: Services Buildings

a) Sector drivers

The role of ICT plays in this sector is not as clear as for Passenger Air Travel. Recent developments in smart buildings/offices, the use of sensors and the use of fluid dynamics to optimise natural cooling are examples obviously linked with technology, but passive measures of energy efficiency and implementation of already existing engineering solutions have been factors that have impacted the energy usage in buildings that have happened independently of ICT.

This section discusses the top ICT factors that contributed to this phenomenon. It models emissions relating to lighting, heating, cooling and appliances separately, as these vary by region and are impacted by different technologies. It also looks separately at ICT drivers which impact volume and intensity, as before.

For the service buildings sector, the intensity metric can be divided into 4 types of energy usage which show different energy intensities and distinct trends leading to different emissions intensity:

- Lighting: it has a low intensity (kW/m^2) with a decreasing trend
- Heating: it has a high intensity (kWh/m^2) with a decreasing trend
- Cooling: it has a low intensity (kWh/m^2) with an increasing trend
- Appliances and equipment: it has a high intensity (kWh/m^2) with an increasing trend

'Appliances and equipment' includes all energy use in service buildings not related with the other three categories. This includes cooking equipment, refrigeration units along with any other electrical equipment.

Drivers that impact on emissions intensity ($kgCO_2e/m^2$)

There are several technology trends that are driving reductions in service buildings' emissions intensity:

1. **Energy management systems (EnMS) optimisation.** This can take the form of use of various types of sensors (e.g. temperature, light or motion sensors) to control the usage of equipment such as temperature controls or lights. These systems usually rely heavily on technology. ICT had a ***direct impact***; affecting lighting, heating and cooling;
2. **Availability of equipment.** Technology advancements have also brought a higher number of devices and equipment that became common place in the office buildings thus increasing the energy consumption per m^2. The ICT had a ***major role***; affecting appliances;
3. **Lighting technology improvement.** One area that has seen a great level of improvement is lighting technology, more specifically, with the appearance and improvement of LED technology, which has simultaneous advantages in emissions, cost and low maintenance – which has driven a relatively high rate of adoption. ICT had a ***direct impact***; affecting lighting;
4. **Building Design.** Computer modelling of air flows, insulation, heating/cooling solutions and natural light, has enabled the development of thermally efficient properties with maximised natural ventilation and lighting to become readily available - if requested and implemented into building design. Ultimately taking the form of 'passive homes'. Not only have computers enabled this modelling for each unique building, the internet and various building design applications have proliferated the technology and know-how to all architects and civil engineers to include such technologies with ease. Whilst this is readily available, it does not as yet have a high adoption rate. The reasons for this are many-fold, including chiefly risk-

averseness and lack of demand driving a business incentive. Up to a point implementing such technologies has a good return on investment, whilst full deployment of passive home technology does not (as yet). Even those technologies with good financial returns are adopted all too rarely. ICT had a ***major role***; affecting lighting, heating and cooling;

5. **Greener electricity.** This relates to a greater use of renewable electricity (e.g. wind and solar), in the energy used by the buildings. It may arise from the gradual decline in average grid emissions in most countries, or the specific purchasing of low carbon electricity, or the installation of on-site renewables. For on-site renewables, this would typically be from fitted solar PV panels. Depending on geographical location, new buildings often have these fitted as standard (or the design allows for easy addition), while older buildings made need physical changes to retrofit renewables. ICT had a ***relevant indirect impact***; currently mainly affecting lighting and appliances;

6. **Electrification.** As low carbon energy supplies have become more available and price competitive vs fossil fuels to the end user, advanced companies with an eye on reducing their emissions in line with requirements to ensure the world does not exceed 2 degrees of warming have already begun the process of electrification. That is the adoption of electricity as the energy source for space heating, space cooling and water heating in place of fossil fuels. This adoption is being witnessed in new builds even if in the immediate term grid mix electricity emissions per kWh exceed those of gas in a country, on the realistic expectation that grid mix will fall below gas levels relatively shortly into the lifetime of the building, or the company has chosen to buy/generate green electricity. Whilst this is encouraging to see by leaders it is not commonplace. ICT had a ***relevant indirect impact***, affecting heating and cooling;

7. **Smart grids.** Smart grids enable more dynamic management of the electricity demand and supply on the grid. This is increasingly important for electrification of buildings and transport (thus changing patterns of demand), and supply of renewables (being more distributed and with some degree of intermittence, thus changing patterns of supply). To manage this new supply and demand complexity, it is necessary to have a grid that is able to channel and prioritise electricity production to make sure that demand is met and that there are minimal losses. Smart grids (enabled by ICT) have had a big role in performing this. ICT had a ***major role***; affecting lighting, heating, cooling and appliances.

Drivers that impact on volume of intensity (m^2)

Identically to what happens for the passenger air travel sector, technology causes **affluence** (i.e. having more money to spend) – economic growth per person (which could be measured as GDP per capita) is largely enabled by technology. Technology "freed" assets (in particular labour) from the primary sector to the industry sector, and afterwards to the tertiary sector. ICT in particular, also enabled the sharing of information in a more immediate way, which allowed any innovation to have a more direct impact (e.g. on efficiency gains).

The impact of ICT on **affordability** (i.e. how much can you buy with your money) in this sector is not as clear as it is for passenger air travel. The costs associated with Service Buildings can largely be subdivided between: land/property prices, (which ICT has no impact upon); construction prices (which ICT has reduced marginally), energy prices (which ICT has no impact upon, and at a smaller scale, equipment (e.g. electrical equipment, HVAC equipment) prices (which ICT had some impact upon). For these reasons, ICT is deemed to have no noticeable impact upon affordability, but only affluence. (Hence the term of affordability has not been used for this sector, with only affluence being referenced in the analysis).

Energy demand and related emissions are influenced by affluence levels. For this sector, this link is mostly due to the share of service-related jobs in the total job market (which leads to the number of people working in service buildings) which is usually higher in more affluent countries.

Energy demand in this sector is also more inelastic, which means that consumption levels might show small to no impacts due to price (affordability) changes. This is especially true for essential uses of energy such as lighting and the use of electronic equipment. Energy uses related with comfort such as heating and cooling (especially the latter) is more elastic with more affluent countries showing to have a larger energy consumption per m^2. The existence of a building stock with a high lifespan and construction options that often times do not consider energy efficiency gains during the operation phase also diminishes the impact of ICT and affluence in the energy demand of service buildings.

As the role of affluence in modelling demand and the impact of technology in driving the affluence and affordability in this sector are not clear, the estimated impact that ICT had in affluence (/affordability) has been defined quite low at 20% of total impact.

b) Model

For the service buildings sector, the volume of activity is measured in m^2 of service buildings' floor area and the emissions intensity observed (tCO2e per m^2 of service buildings). Contrary to the passenger air travel sector, the modelled emissions intensities vary across regions. Another difference is the fact that there are various types of energy usage (e.g. lighting, heating and cooling) each one with a distinct energy mix profile, and hence emission factor. The final emissions have slight variations due to the expected impact of the reliability of the electricity network for each of the modelled regions:

$$Emissions_{service\ buildings} = \sum_{i}^{regions} \sum_{j}^{energy\ uses} m^2{}_{region\ i} \times tCO_2e/m^2{}_{region\ i,energy\ use\ j}$$

Where,

$$tCO_2e/m^2{}_{region\ i,energy\ use\ j} = kWh/m^2{}_{region\ i,energy\ use\ j} \times tCO_2e/kWh_{region\ i,energy\ use\ j}$$

Figure 7 shows how the data flows across the model for this sector. Due to lack of data, assumptions had to be made to:

- estimate the impact of light efficiency in the lighting energy usage emissions intensity; and
- differentiate energy intensity amongst regions as the only available data was for a small group of affluent European countries

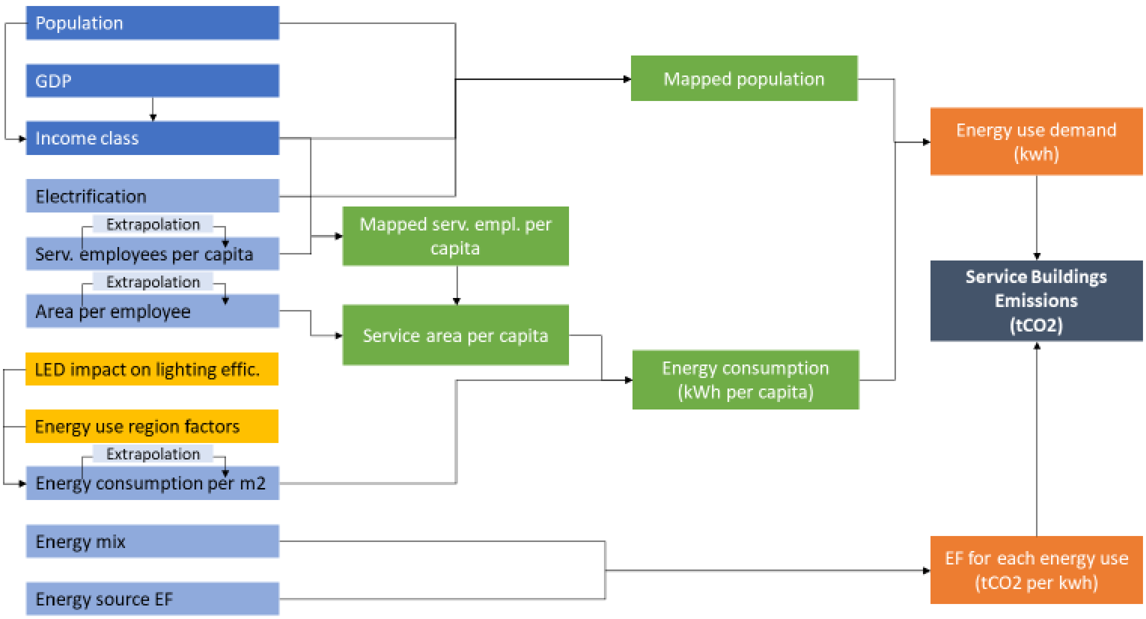

Figure 7. Service buildings data flow diagram

For the service buildings sector, the modelling was done through the following steps:

SECTOR'S DEMAND

1. Electrification rate was used to classify countries as having a good or poor electricity network
2. Class income from 2016 to 2020 was obtained by estimating GDP/capita projections using World bank data, IEA GDP growth rates and UN's population projections
3. Population was mapped in accordance to the quality of the electricity network and income class in each year
4. Service employees per capita was modelled for each country using three complementary data sets: percentage of population aged 0-14 years of age (from which we extracted the population aged 15+), employment rate (calculated over the population aged 15+), and services employment rate (out of all the population that is employed, how many are in the services sector) – all of these data sets have been taken from the World Bank database
5. Service employees per capita was mapped in accordance to the quality of the electricity network and income class in each year
6. Area per employee was derived from the IEA energy indicators database (for simplification purposes, it was assumed to be the same across all regions) and multiplied by service employees per capita to obtain a mapping across modelled regions of the services floor area per capita
7. Multiplying the mapped population and service buildings floor area per capita, we obtain the total office floor area in each region

SECTOR'S EMISSION FACTOR

8. Data from the EU Buildings database was used to calculate the average kWh per m^2 for each of the energy usages. This was applied to the region of *H* (High income class) & *Good* (electricity network reliability).

9. To estimate the average kWh per m^2 for each of the energy usages in the remaining regions, adjustment factors were applied to increase or decrease the values calculated for the *H* & *Good* region (see list below in Table III). These factors were based on overall characteristics of the countries that made each country and the team's knowledge of usual energy consumption trends

10. Energy mix was derived from IEA World data. This was considered to represent the regions with a good electricity network reliability. Electricity percentage in the energy mix was considered to be slightly lower in *Poor* countries

11. The tCO2e/kWh emission factor of each energy usage and each region was calculated by applying the energy source's emission factors to the energy mix of each one of them

12. Data from steps 9, 10 and 11 were multiplied to obtain the final tCO2e per m^2 in each region as described in the formula above

Table III. Energy intensity (kWh/m^2) region adjustment factors for each energy use and region

	Lighting	Heating	Cooling	Appliances and equipment
H & Good				
H & Poor	100%	100%	100%	100%
UM & Good	85%	85%	85%	90%
UM & Poor	85%	85%	85%	90%
LM & Good	100%	25%	50%	85%
LM & Poor	100%	25%	50%	85%
L & Good	100%	15%	35%	80%
L & Poor	100%	15%	35%	80%

Appendix C: Data sources

Below you can find a list of the "primary" data used in this model. Given the diverse nature of this data, we present key characteristics such as the source of the data used, time period covered by the original data, level of spatial granularity and other relevant notes such as further analysis done to complete gaps in the data sets or how the data was incorporated.

a) Common data

Population

Source:	United Nations (https://esa.un.org/unpd/wpp/Download/Standard/Population/), retrieved at 23rd April 2018
Time period:	Historical data - From 1950 to 2015, yearly Projections - From 2015 to 2100, every 5 years
Granularity:	Country level
Other notes:	A linear interpolation was applied to the population projection for all intermediary years

GDP

Source:	Historical data - World Bank (https://data.worldbank.org/indicator/ny.gdp.mktp.pp.cd), retrieved at 16th May 2018
Time period:	Historical data - Yearly from 1990 up to 2016
Granularity:	Country level
Other notes:	GDP, PPP at current international $ Data after 2016 was calculated using IEA's GDP CAAGR (by region)

GDP CAAGR

Source:	IEA ETP 2017 Model assumptions (https://www.iea.org/etp/etpmodel/assumptions/)
Time period:	Fixed values within time periods of 2014-20 and 2020-30
Granularity:	IEA region
Other notes:	Growth rates based on GDP in United States dollars (USD) in purchasing power parity (PPP) constant 2015 terms

Income class

Source:	Historical data - World Bank (http://databank.worldbank.org/data/download/site-content/OGHIST.xls), retrieved at 11th June 2018
Time period:	Yearly from 1987 up to 2016
Granularity:	Country level
Other notes:	After 2016 countries were classified as being L (low income), LM (lower medium income), UM (upper medium income) or H (high income) through the application of GDP per capita thresholds. These thresholds were set in line with the averages GDP per capita of each class in historical years (L < $3.5M, $3.5M <= LM < $10M, $10M <= UM < $25M, H >= $25M). The values of GDP per capita were obtained with the projections of GDP and population for each country

b) Passenger air passenger travel data

Train network quality

Source: UIC (https://uic.org/IMG/pdf/synopsis_2016.pdf), other official national statistics, and desk research by the team

Time period: 2015 and 2016

Granularity: Country level

Other notes: Quality of the train network was evaluated as being "good" or "poor" using the value of number of passengers per capita. Countries considered to have a "good" train network presented 1, or more, passengers per capita.
For countries where no passenger data was available, a research on each country's general information and train connections was done; a judgment on train network quality was done based on that information

Number of passengers

Source: Historical data - World Bank (https://data.worldbank.org/indicator/IS.AIR.PSGR), retrieved at 22nd May 2018

Time period: Yearly from 1970 up to 2016

Granularity: Country level

Other notes: This list has a few gaps (for some countries the data only exists for a subset of the time period covered).
After 2016 data was extrapolated by using a trend line plotted for each Affluence/Train network region

Fuel efficiency improvement rate

Source: ATAG (2010), Beginner's Guide to Aviation Efficiency Report

Time period: Applicable after 2010

Granularity: Worldwide

Other notes: The number used is based on the commitment made by members of ATAG up to 2020.
Before 2010, it was assumed that this number was 1%

Load factor

Source: Statistica (www.statistica.com/statistics/658830/passenger-load-factor-of-commercial-airlines-worldwide/), retrieved at 28th June 2018

Time period: Yearly from 2005 up to 2017

Granularity: Worldwide

Other notes: Data extrapolated for years before 2005 and after 2017

Passenger.kms

Source: IEA 2017 Energy Technology Perspectives Report

Time period: 2014, 2025, 2030

Granularity: IEA Regions and Worldwide

Other notes: Linear interpolation between 2014 and 2025, and extrapolation for years prior to 2014. This was not used for the calculation of the activity level as the level of disaggregation did not allow for an in-depth analysis on the demand by country as it was intended. This variable was mostly used to calculate the ratios average distance per passenger and energy per passenger.km throughout the years

Energy use

Source: IEA 2017 Energy Technology Perspectives Report
Time period: 2014, 2025, 2030
Granularity: IEA Regions and Worldwide
Other notes: Value for 2014 was used as baseline from which other years were estimated. Energy use in other years were estimated by using load factor and fuel efficiency trends; Worldwide value was used and applied to all regions

Well to wheel emissions

Source: IEA 2017 Energy Technology Perspectives Report
Time period: 2014, 2025, 2030
Granularity: IEA Regions and Worldwide
Other notes: Value for 2014 was the one used and it was considered that these remained constant in the time period analysed;
Worldwide value was used and applied to all regions

c) Service buildings specific data

Electrification rate

Source: World Bank (https://data.worldbank.org/indicator/eg.elc.accs.zs), retrieved at 24th July 2018
Time period: 2016
Granularity: Country level
Other notes: This data was used to assess the quality of the electrification rate which was evaluated as being “good” or “poor”; a country was classified as being “good” if the electrification rate was 90% or higher.

Population under 14 years old of age

Source: World Bank (https://data.worldbank.org/indicator/SP.POP.0014.TO.ZS) retrieved at 07th of August 2018
Time period: Yearly from 1960 to 2017
Granularity: Country level
Other notes: NA

Employment rate

Source: World Bank (https://data.worldbank.org/indicator/SL.EMP.TOTL.SP.ZS) retrieved at 07th of August 2018
Time period: Yearly from 1991 to 2017
Granularity: Country level
Other notes: NA

Services employees percentage against total employment

Source: World Bank (https://data.worldbank.org/indicator/SL.SRV.EMPL.ZS) retrieved at 07th of August 2018
Time period: Yearly from 1991 to 2016
Granularity: Country level
Other notes: NA

Area (service build) per employee

Source: IEA Energy Indicators Database for IEA member countries
Time period: Yearly from 2000 to 2015
Granularity: Country level (only 8 countries provided good data for all years)
Other notes: Data extrapolated for years after 2015

LED impact on lighting energy efficiency

Source: Luminous efficacy for LED and other lighting technologies from US DOE https://www.energy.gov/eere/ssl/led-basic, retrieved at 07th August 2018
Time period: NA
Granularity: Applied worldwide
Other notes: Assumed that a large roll-out of technology modelled to starts in 2014 with a worldwide penetration rate of 90% in 2025

Energy consumption per m^2 (Total, Space heating, Space cooling, Lighting)

Source: EU Buildings Database (https://ec.europa.eu/energy/en/eu-buildings-database) retrieved at 04th August 2018
Time period: Yearly from 2000 to 2013
Granularity: Country level
Other notes: Data available for most EU member countries but for a short period of time (3 to 4 years). Only a limited number of countries had data for the entire time period covered. As time trends were the main objective, averages and extrapolations were calculated using only the countries that had provided data to all years.

Energy consumption (Space heating, Space cooling, Lighting)

Source: EU Buildings Database (https://ec.europa.eu/energy/en/eu-buildings-database) retrieved at 04th August 2018
Time period: Yearly from 2000 to 2013
Granularity: Country level
Other notes: Averages and extrapolations calculated using only countries with data in all years. This data, combined with Energy consumption per m^2 from the same source, was used to calculate "Other energy usage per m^2" in European countries.

Energy use region factors

Source: Carbon Trust expertise
Time period: NA
Granularity: Defined regions
Other notes: Rationale for group of countries

Energy mix

Source: IEA 2017 Energy Technology Perspectives Report
Time period: 2014, 2025, 2030
Granularity: IEA Regions and Worldwide
Other notes: Linear interpolation between 2014 and 2025, and extrapolation for years prior to 2014

Energy sources' emission factors (fossil fuels)

Source: BEIS GHG conversion factors (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/7

15426/Conversion_Factors_2018_-_Full_set__for_advanced_users__v01-01.xls) retrieved at 07th August 2018

Time period:	2018
Granularity:	NA
Other notes:	Considered to be constant throughout time and across regions

Energy sources' emission factors (electricity)

Source:	Buildings Pathway Model (linear progression) - raw data from IEA
Time period:	From 2010 to 2025
Granularity:	Worldwide
Other notes:	Average used for all regions

References

References

ATAG - Air Transport Action Group. (2010). *Beginner's Guide to Aviation Efficiency.*

IEA - Internacional Energy Agency. (2017). *Energy Technology Perspectives Report.* www.iea.org/etp2017.

IEA - International Energy Agency. (2017). *Energy Efficiency Indicators Database.*

World Bank. (2018, March 4). *Air transport, passengers carried.* Retrieved from https://data.worldbank.org/indicator/IS.AIR.PSGR

World Bank. (2018, June 11). *Historical classification by income.* Retrieved from http://databank.worldbank.org/data/download/site-content/OGHIST.xls

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