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

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Acknowledgments

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Overview and summary conclusions

1.1 Context and goals

With the increasing urgency of tackling climate change in a strong and meaningful way across all sectors of activity, it has become crucial to understand the drivers for greenhouse gas (GHG) emissions so we can better understand the possible effects of mitigation programmes. The role of the private sector has been key to drive change and gain important insights to reduce global emissions.

This report is part of an exploration study to understand the role of technology, and in particular, the role of ICT in reducing global emissions. This study explores a methodology to measure the impact that specific technologies have on the carbon footprint of other sectors of activity. By measuring this impact it is possible to have better insights and tools to manage it and drive action to reduce it.

To demonstrate our findings, this study has focussed on modelling the emissions of two sectors: *passenger air travel* and *service buildings*. One of the goals of this study is to test the possibility of using the same or a similar approach to different sectors. The objective being to develop an approach that can be used to model different sectors with low levels of effort, because the main modelling structure would already be defined.

The approach of this study is generic and should be applicable to other technologies and other sectors. For Dell specifically the ultimate objectives are:

- to demonstrate a practical methodology that can assess the impact of Dell's technology on a particular sector or sub-sector's GHG emissions;
- to understand better what this impact is and the drivers behind it;
- from this to understand how Dell can drive change at scale to reduce GHG emissions;
- to deliver results that are actionable to apply, and to prioritise efforts.

1.2 Description of the study

To understand the impact of ICT on a specific sector's emissions, we have used a top-down approach which has the advantages of being more easily replicable across sectors and of allowing to more easily model the impact of technology by looking at the largest trends in each sector.

From this approach, emissions can be defined as arising from two main factors, level of activity and intensity of emissions:

$$\textbf{Emissions} = \sum \{\textbf{volume of activity (units)} \times \textbf{intensity} \ (\textbf{tCO}_2\textbf{e/unit})\}$$

Each sector will have different drivers for both the volume of activity and the intensity.

For example:

Air Travel Emissions (tCO_2) = Activity (passenger.kms) x Intensity Emissions Factor (tCO_2 per passenger.km)

Service Buildings Emissions (tCO_2) = Buildings Energy Use (m^2) x Intensity Emissions Factor (tCO_2 per m^2)

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. Then a further step is to isolate the impact of an individual product or company.

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.

This report also presents an evaluation on how each technology/driver impacted on the sectors' emissions. Technologies could have been key to enabling energy efficiency gains or just had a supporting role to a phenomenon that lead to lower or higher emissions. To distinguish these different levels of influence, five categories have been defined (see box below, and more detailed explanation of categories on page 12).

Levels of Impact

5 – key enabler

4 – major role

3 – direct impact

2 – relevant indirect impact

1 – supporting role

1.3 Modelling drivers

We separated the key drivers into those which impact volume of activity, and those which impact intensity of emissions.

Drivers which change volume of activity

- In most sectors, including the 2 focussed upon here, consumption volumes are continually rising.
- Activity volumes are heavily influenced by **population**: world population keeps increasing, meaning more people flying on aircraft, and more people working in the service sector.
  Common to sectors / Independent of ICT.
- Another common factor is **affluence**: the greater a person's wealth the more air tickets they can buy, and the wealthier an economy is the higher the % of the population who work in the service sector.
  Common to sectors / ICT is a major driver.
- Also playing a large role in activity volume is **affordability**: air travel has in real terms become much more affordable in recent decades largely thanks to ICT, whilst the affordability of service buildings is driven very little by ICT and more by economic circumstances.
  Specific to sectors / ICT may or may not be a major driver.
- Finally **elasticity of demand** varies by sector: Demand of air travel varies greatly with affordability as a 'nice to have' service, whereas energy demand in service buildings is much more inelastic being mostly driven by primary needs (e.g. lighting and thermal comfort).
  Specific to sectors / Independent of ICT.

When modelling:

- Population growth and wealth vary dramatically by country, but poorer countries have higher population growth rates than wealthier countries. Hence, countries have been grouped into four levels of affluence, with population and other trends such as demand for heating/cooling of buildings assigned to these levels.

Drivers which reduce emissions intensity

- **Efficiency improvements**: A continuing trend of improved efficiency in electrical equipment, lighting, engines etc. impacts these two sectors. Many of these improvements are only possible due to computer aided design.
  Specific to sectors / ICT is a major driver
- **Adoption Curve:** One significant difference between the two sectors is how quickly new **technological advances** are adopted, with 2 factors influencing this: **life span** (around 25 year for airplanes[1] compared with 30 to 120 years for buildings[2]), meaning the pool of older buildings is larger than that of older aircraft; and more significantly **adoption rates** (in air travel, efficiency improvements are quickly adopted as they translate to immediate fuel savings and lower costs, whereas in service buildings technological solutions or energy efficiency measures may take decades to be adopted as priority is given to low risk and/or low cost building design). Thus typically in air travel new technological advances are adopted quickly, but for service buildings it is much slower. Legislation can play a role here (particularly with buildings), it can either speed up or slow down the adoption rate.
- **Legislation** plays a crucial role on service buildings as standards for energy efficiency in buildings are the main drivers for the implementation of more efficient technologies/building solutions.
  Specific to service buildings / independent from ICT.
- Role of **new low-cost competitors**: In recent decades, the passenger air travel sector witnessed large changes due to the rise of low-cost airliners. The reduction in price was possible due, not only to a reduction in services, but also an increase in the number of passengers on the same plane. This increased the fuel efficiency on a per passenger basis, which other airlines have followed to remain competitive.
  Specific to air travel/ICT had a direct impact on it

1.4 Sectoral Conclusions

Final results show that ICT has many different technological drivers that are specific to distinct sectors (e.g. how efficiency improvements impact on final emissions), and some constant drivers (e.g. the impact on affluence) that impact all sectors. It shows that some impacts of ICT reduce emissions through efficiency gains, whilst others lead to increased emissions through increased volumes.

When (as in Passenger Air Travel) the increase in volume which ICT enables surmounts the efficiency gains it brings about, ICT is responsible for a net increase in emissions; whereas in sectors where ICT is more disassociated from volume growth (such as in Service buildings) the net impact of ICT is more positive, with the model showing decreasing emissions from the baseline year. Hence, for many sectors ICT may be a net reducer of emissions, but in others it may actually be causing emissions to increase instead of decrease.

[1] Source: https://www.flexport.com/blog/decommissioned-planes-salvage-value/
[2] Source: http://brandondonnelly.com/post/128489870433/the-life-expectancy-of-buildings

Another important difference between the two sectors is the composition of the intensity metric (intensity metric = emissions per energy × energy per activity volume), in particular the impact of technology in the energy per activity volume. In air travel, the impact of technology has led to a reduction in the use of energy whereas in service buildings this link is not as clear.

1.5 Overall conclusions

As a first step of a more exhaustive study, this report brings some light into areas where ICT had an impact upon in the past or is expected to have an impact upon in the future and the respective repercussions in terms of GHG emissions in the passenger air travel and service buildings sectors. To go beyond this analysis and attribute the impact to each type of technology requires further work as more often than not, these technologies work interlinked with each other. Beyond the challenge of separating these effects, one of the largest expected difficulties is the collection of data that could support this analysis. It is possible that certain stakeholders have this information, but from the current research, this information does not seem to be publicly available. This will be a key step to understand the possibility of taking actionable insights from this study. At this moment, however, it is still not possible to correctly evaluate the ability of this; the next step of the study should be looking into more detail into this subject to understand the viability of using this approach to drive change.

2. Summary of impact drivers

On the table below we present the list of identified drivers along with an evaluation of their relevance for the model and for potential action design.

- 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 sectors 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 the push from legislation or other sector-specific action
- Directness (D) relates to the level of directness of ICT in each of the drivers as per table below under the next section
- 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 the how easily available information is; the lowest the score, the more uncertainty there is regarding the data used in the model

ICT driver	Potential impact (P)	Adoption (A)	Directness (D)	Relevance for sector (PxAxD)	Action potential ($PxA^{-1}xD$)	Data availability
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 number of seats per airplane	4	5	2	40	1.6	4
Energy management systems 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
Population						5
Affluence						4
Affordability impact on sector						2
Availability impact on sector						2
Elasticity of demand of sector						2

2.1 Levels of directness of impact

We can define 5 levels of directness of impact:

Key enabler	5 - ICT plays an essential role in the driver's modelled trends
Major role	4 - ICT plays an important role in how the driver evolves but was not essential
Direct impact	3 - ICT plays a direct role in how the driver evolves but is not a particularly central driver
Relevant indirect impact	2 - ICT plays an indirect role that has a relevant impact on the driver's modelled trends
Supporting role	1 - ICT plays an indirect role that supported the driver's trends

The process to determine the level of impact that ICT plays for each driver was a hierarchical one. Thus, the first step is to decide if ICT is essential for the driver to have an impact – i.e. without ICT would the impact still have happened? If classified as essential then a level 5 was assigned. Similarly, the other classifications were considered in turn.

2.2 Population

Population is one of the most relevant factors in both 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.

3. Passenger air travel model

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 be defined as arising from:

$$\sum\{\textbf{volume (units)} \times \textbf{intensity (tCO}_2\textbf{e/unit)}\}$$

3.1 Top ICT drivers which reduce 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 ***4-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 ***5-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 ***5-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 ***3-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 ***2-relevant indirect impact***.

The impacts of these drivers in the time trends of the emissions intensity is shown in Figure 1. It is possible to see that all scenarios show the same behaviour (and hence are overlapped), as emissions intensity is not being affected by either population or affluence but technology improvements alone.

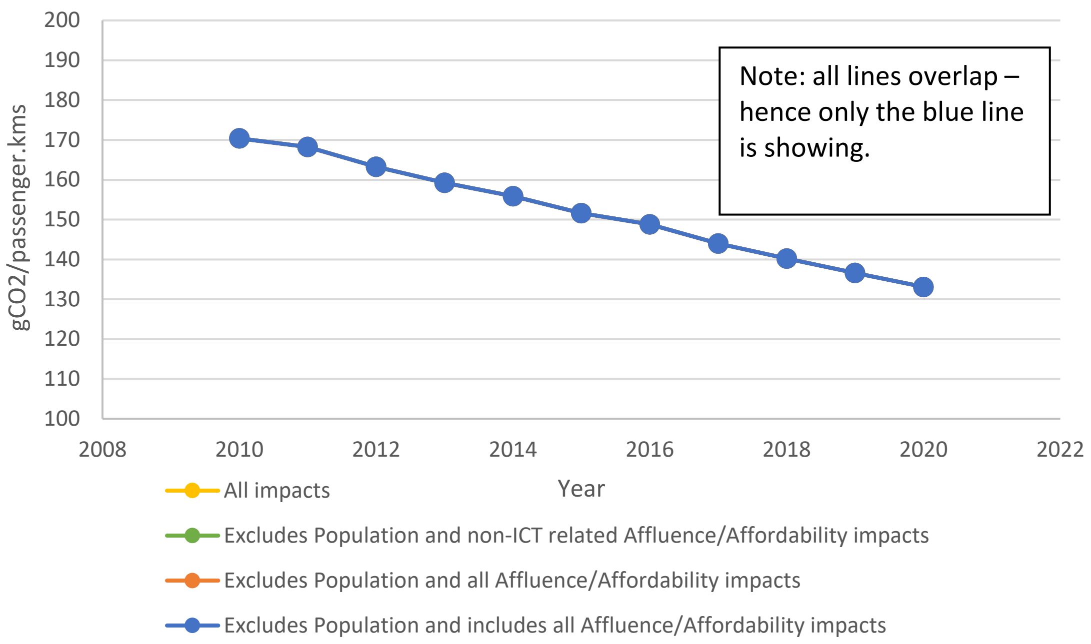

Figure 1. Air travel emissions intensity from 2010 to 2020 (all lines are overlapped)[3]

3.2 Top ICT drivers which change volumes (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 can you 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

[3] For this and subsequent charts, the time period analysed was 2010 to 2020, where mostly the data 2010 to 2015 is historic, and 2015 to 2020 is projected. See Appendix for more details of the data and data sources used.

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***.

All these factors have played to the observed recent large increase in air travel demand. The modelled time trends from 2010 and 2020 of this sector's activity can be seen in Figure 2.

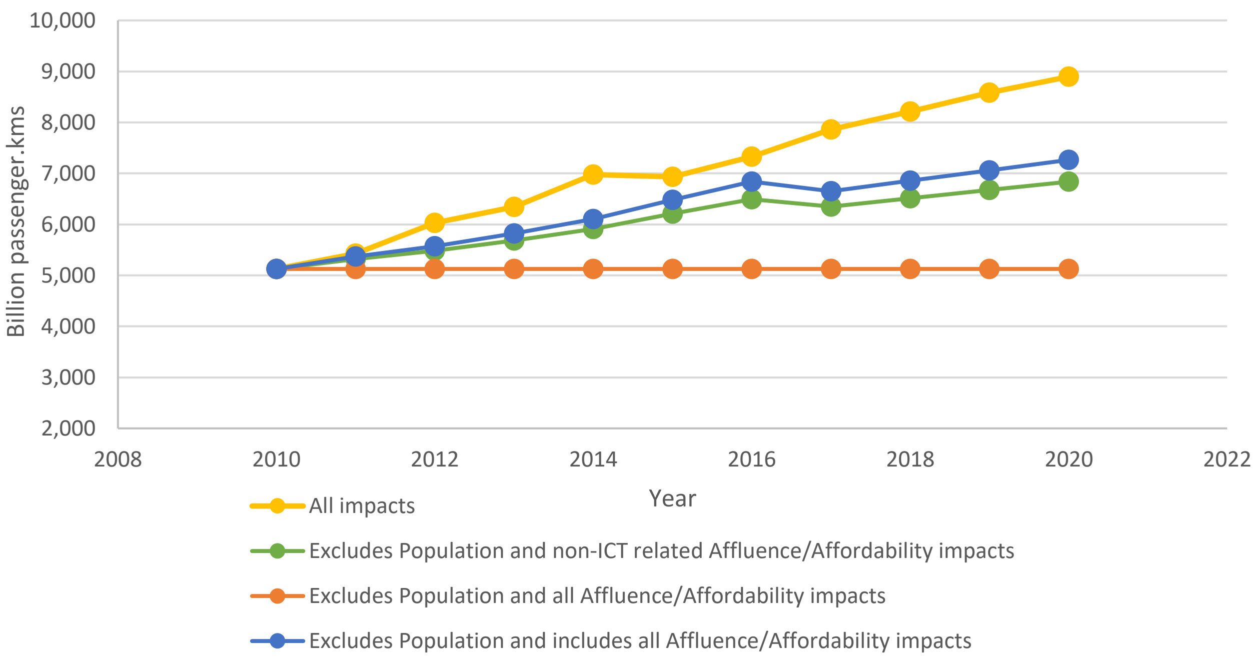

Figure 2. Air travel activity from 2010 to 2020

3.3 Overall model results

Two of the variables that had high impact on the trends observed, are 'demand per capita' and 'population', which together define the total demand (total number of passengers per year). These values have significant variations from year to year (even with a clear increasing trend) and total demand shows a very large growth rate in the time frame analysed. The efficiency trends behave in a much more linear way, and despite significant efficiency gains, the impact on final fuel use is dwarfed by the increase in demand.

This is the reason why the yellow line below (where all impacts are considered), shows such a high increase in emissions despite the efficiency gains in the sector.

By excluding population growth and non-ICT related Affluence/Affordability impacts (green line) we can see the true impact of ICT (both positive and negative impacts on emissions). We still see an increasing emissions trend, but one where the reduction in emissions due to technological improvements has a larger role in balancing the increase in demand (in this case only driven by ICT-related demand per capita growth).

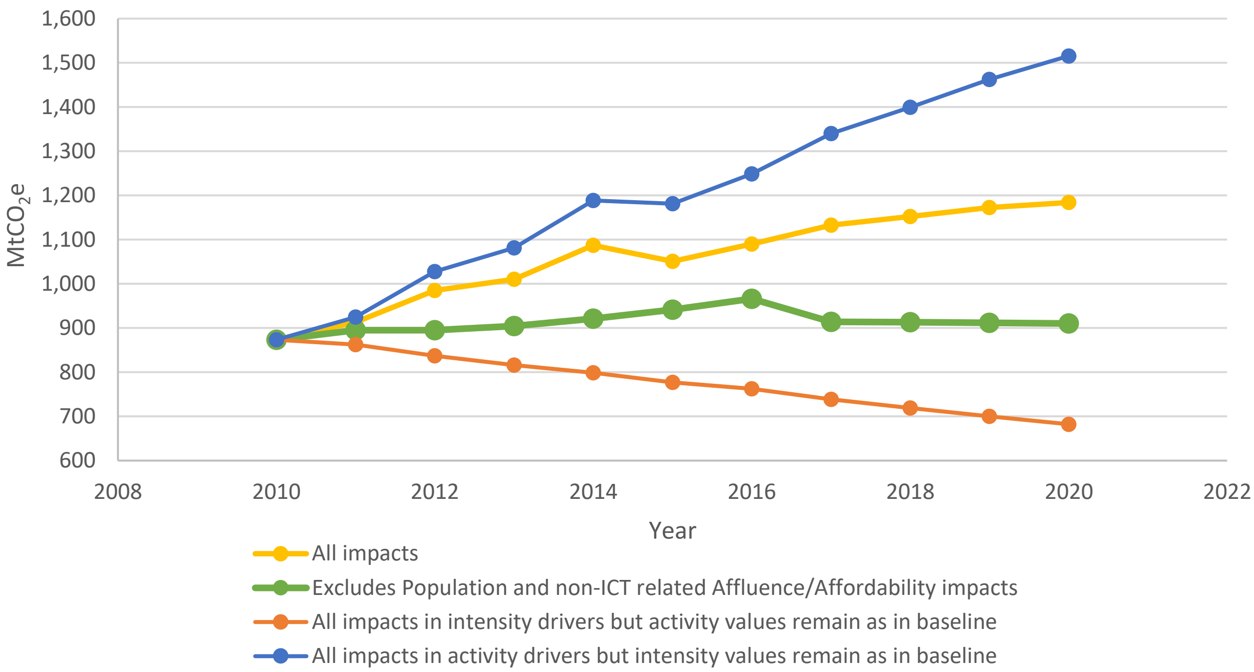

Figure 3. Air travel total emissions from 2010 to 2020

3.4 Sensitivity Analysis

As population is a driver with low levels of uncertainty and is excluded from the most relevant scenario (green line above), it will not be included in this scenario analysis despite being one of the major drivers of emissions.

Of the remaining drivers 'demand per capita' is the one for which there is a reasonable level of uncertainty. To understand the impact that a higher or lower demand increase has on the results of the model we present the graph below. For comparison reasons, we have left the vertical axis scale the same.

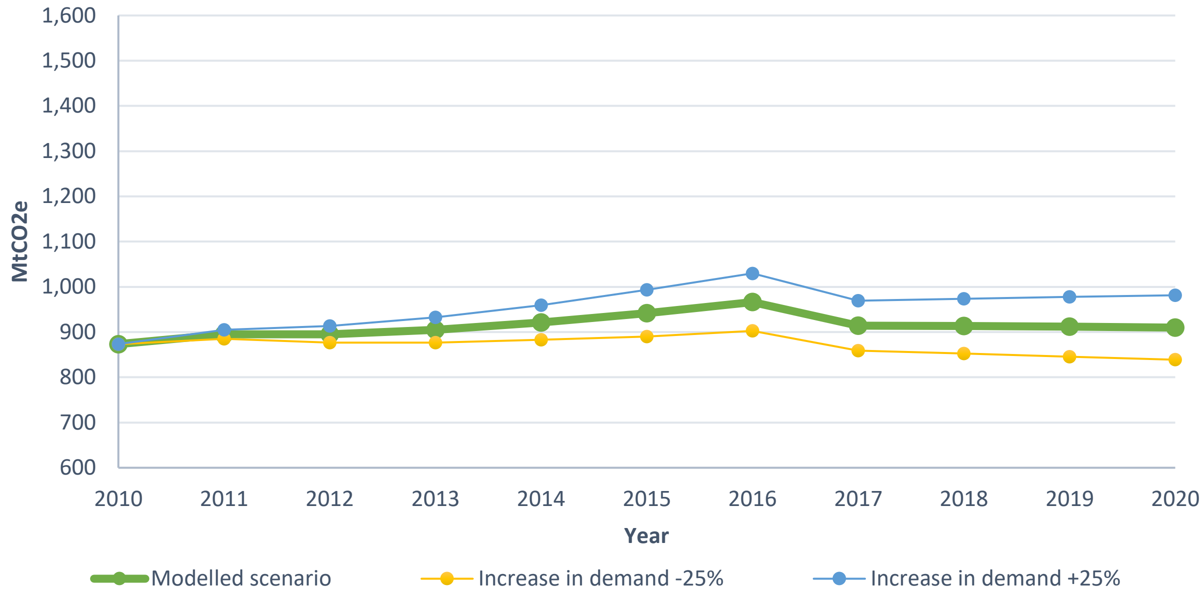

Figure 4. Air travel sensitivity analysis

3.5 Sector Conclusions

Air travel emissions are mostly dominated by the current trends in demand. Despite a large improvement in the fuel efficiency, the emissions continue to rise as the number of passenger.kms continues to surge. Technology lays then a dual role by leading to a reduction in emissions intensity, but largely contributing to the affordability of air travel, thus driving up demand.

This also brings into light the question regarding the link between higher standards of living/quality of life and carbon emissions. The main reason this sector's emissions have increased is because a larger number of people can now afford to enjoy air travel which was also made possible due to ICT. Despite the obvious environmental impact, this has brought important economic and social benefits that should not be overlooked.

4. Service buildings model

In this study, the definition of service buildings sectors refers to 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 IPCC and IEA.

The role of ICT plays in this sector is not as clear as for Passenger Air Travel. Recent development 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, given that emissions can be defined as arising from:

$$\sum \{\textbf{volume (units)} \times \textbf{intensity (tCO}_2\textbf{e/unit)}\}$$

For the services buildings sector, the intensity metric can be divided in 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.

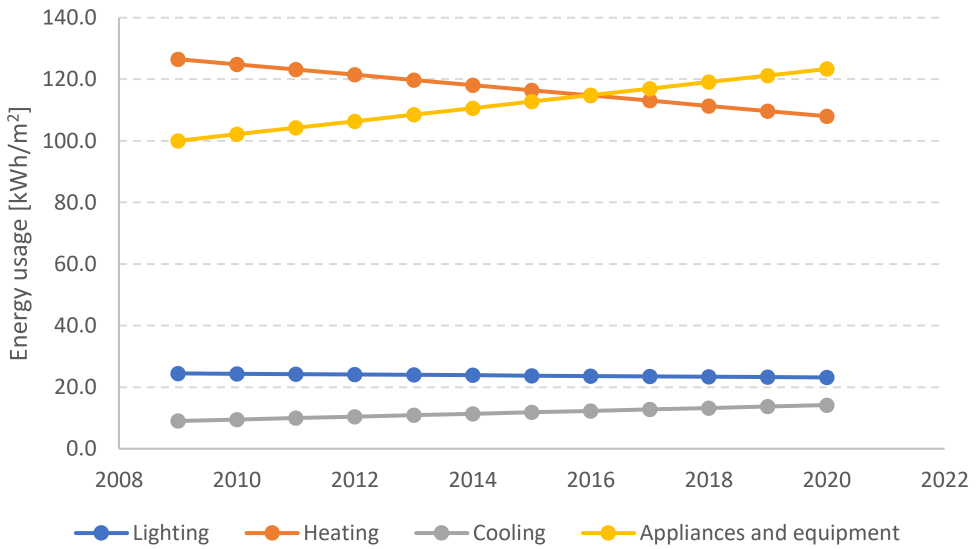

Figure 5. Energy intensity for different types of energy usage in Service Buildings

4.1 Top ICT drivers which reduce emissions intensity ($kgCO_2e/m^2$)

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

1. **Energy management systems 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 ***3-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 ***4-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 ***3-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 ***4-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 ***2-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 ***2-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 ***4-major role***; affecting lighting, heating, cooling and appliances.

The impacts through time of these in the emissions intensity in this driver can be seen in Figure 6.

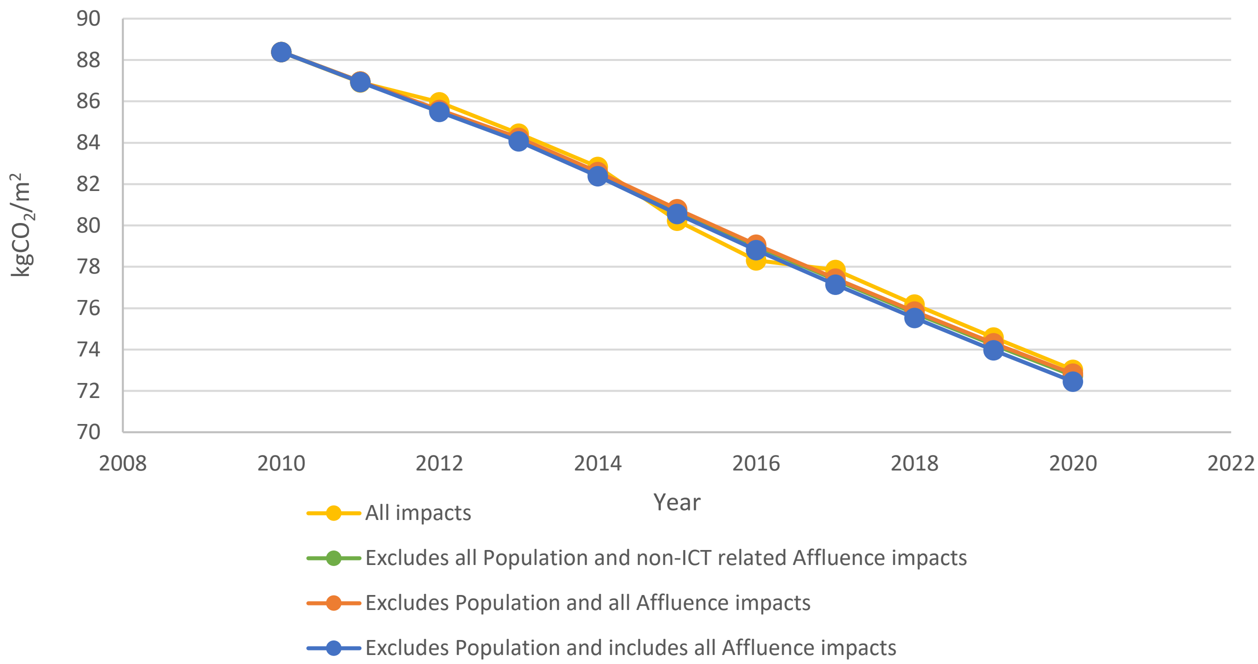

Figure 6. Service buildings emissions intensity from 2010 to 2020

4.2 Top ICT drivers which change volumes (m^2)

Identically to Air Passenger Travel. 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 graphs below).

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.

The impact of these factors is reflected on Figure 7 below.

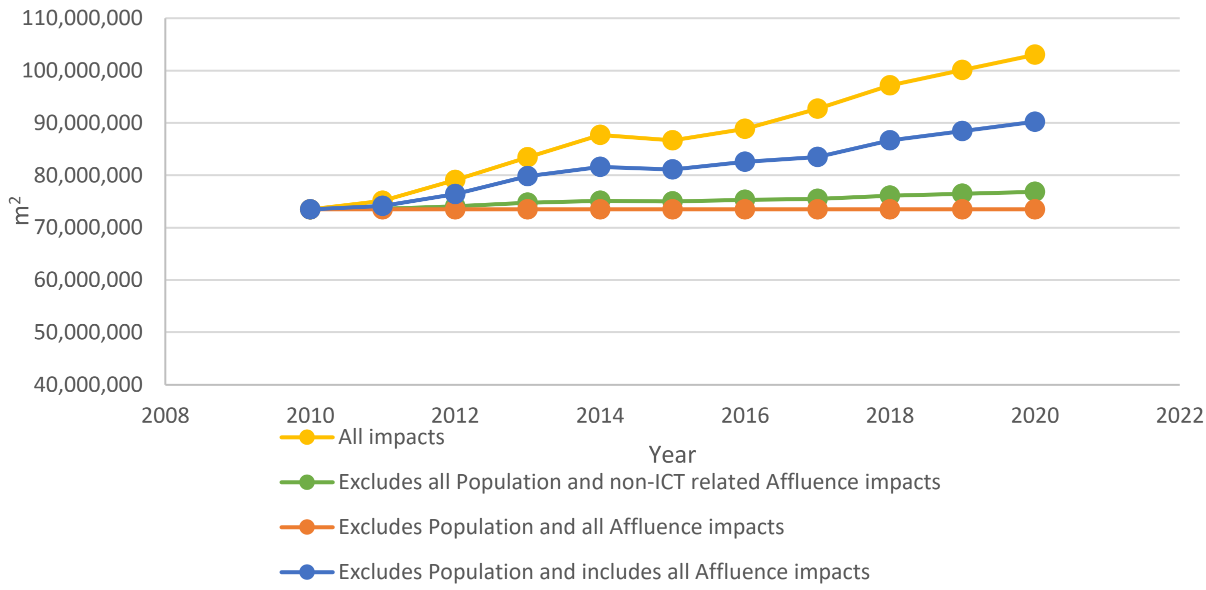

Figure 7. Service buildings emissions activity from 2010 to 2020

4.3 Model results

Total energy demand has been shown to have increased significantly, with a large part of that increase being directly linked to population growth. This can be observed by comparing the emissions trends of the scenario where all impacts are included (yellow line) with the scenario where only population was excluded (blue line). In the scenario where population has been excluded it is possible to see that the increase of energy/carbon efficiency is compensated by energy demand growth in a way that emissions remain relatively stable throughout the years analysed.

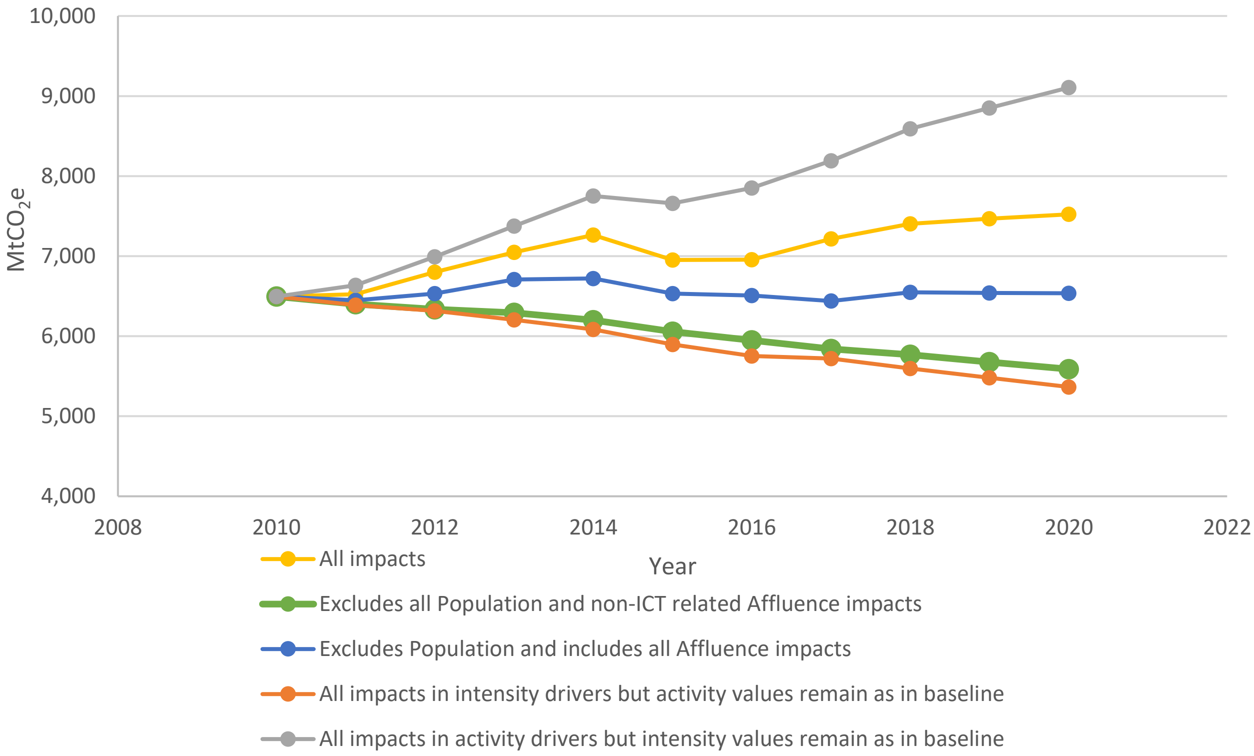

Figure 8. Service buildings total emissions from 2010 to 2020

Most importantly: the emissions of the scenario where both population and non-ICT related affluence impacts are included provide an interesting view as there is a clear decreasing trend facilitated by more efficient use (lower energy use per m^2) and a lowering emission factor for electricity.

4.4 Sensitivity Analysis

In service buildings, emissions are influenced by a larger number of factors. Energy demand can now be broken-down into energy use per area (m^2), total area of service buildings per capita and population. In addition, emissions calculation are also influenced by the estimated energy breakdown of the different energy uses and the trends of electricity production emissions.

As in Passenger Air Transport, population will not be included in the sensitivity analysis as uncertainty behind this data is low and the most relevant scenario excludes the effect of population growth. Of the remaining drivers, the ones that have a larger impact are: area of service buildings per capita, energy use per area and the electricity emission factor. Of these, the ones that present a larger uncertainty are the last two.

Energy use per area has been estimated using data regarding the EU building stock with information being transferred to the regions included in the model by using a "normalisation" factor. These factors are assumptions made taking into consideration the characteristics of the countries included in each region, but there is still a large level of variability inherent to it. The sensitivity analysis provides an optimistic view (with lower energy consumption factors) and a pessimist view (with higher energy consumption factors).

Estimates of the electricity emission factor involve making assumptions on the relative costs of production technologies, future investments (mostly) in renewable technology, governmental decisions, demand pressure regarding renewable energy and a number of other factors. These estimates have always proven a challenge and there is a large uncertainty surrounding this even if there is a consensus regarding a large deployment of renewables. To do the sensitivity analysis, two scenarios were used, one where the reduction in the emission factor is half of what has been modelled and a second scenario where the reduction is slightly higher (10%).

The graph below presents the results of this sensitivity analysis. Again, for comparison purposes, the vertical axis scale was left the same. It is possible to see, that due to a higher level of data certainty, the range of results is much wider than for air travel.

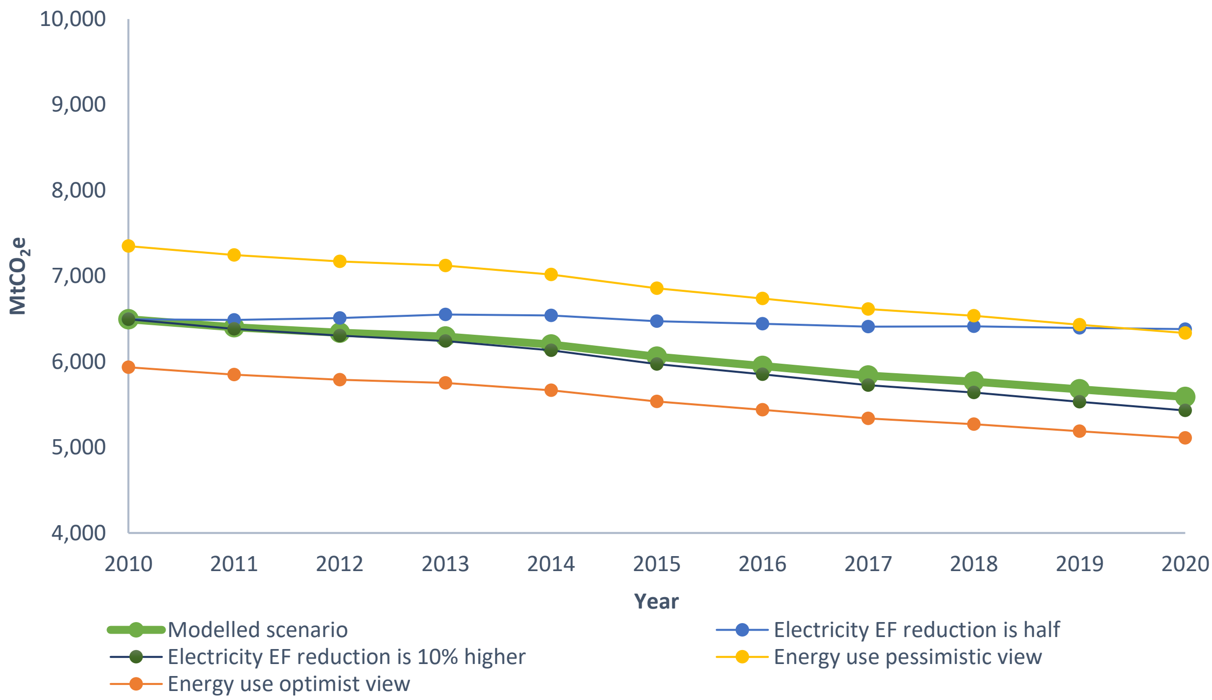

Figure 9. Services buildings sensitivity analysis

4.5 Sector Conclusions

One of the largest differences between the service buildings and air travel sectors is the set of drivers behind emissions intensity. Whereas in air passenger travel the observed trend is of a decreasing energy and emissions intensity, in the service buildings the energy use per m^2 has shown a decrease for heating and lighting, but an increase for cooling and appliances and equipment. The increases are mostly linked with the increase in demand for space cooling driven by higher levels of affluence in warmer countries and the change in use of buildings (such as an increase in the number of restaurants, and an increase in use of refrigeration in the retail sector). Thus, for the service buildings sector, ICT appears to be driving a decrease in emissions intensity for some energy uses, and at the same time increases for other energy uses. This leads to a more complex analysis on the role of ICT in this sector's emissions.

For service buildings, technological advancements has a dual effect. One that relates to a clear improvement in efficiency of equipment and of energy management systems (e.g. lighting and thermal sensors) and thus to a reduction of the sector emissions; the other that leads to a higher consumption of energy, through an increase in affluence, and greater affordability of electricity using equipment. The increase in emissions intensity for 'appliances and equipment' is overshadowing the reductions for heating and lighting (because of its greater intensity and greater rate of increase), thus the total effect from ICT for Service Buildings is to decrease the emissions intensity, which at first sight seems counter-intuitive, and is the opposite effect observed for Air Travel, as shown in Figure 10 below. For the analysis of service buildings, this suggests that further research would be useful to study the impact on different types of buildings, and to refine the attribution factors used. This would require more granular data and some specific data to support the attribution factors used.

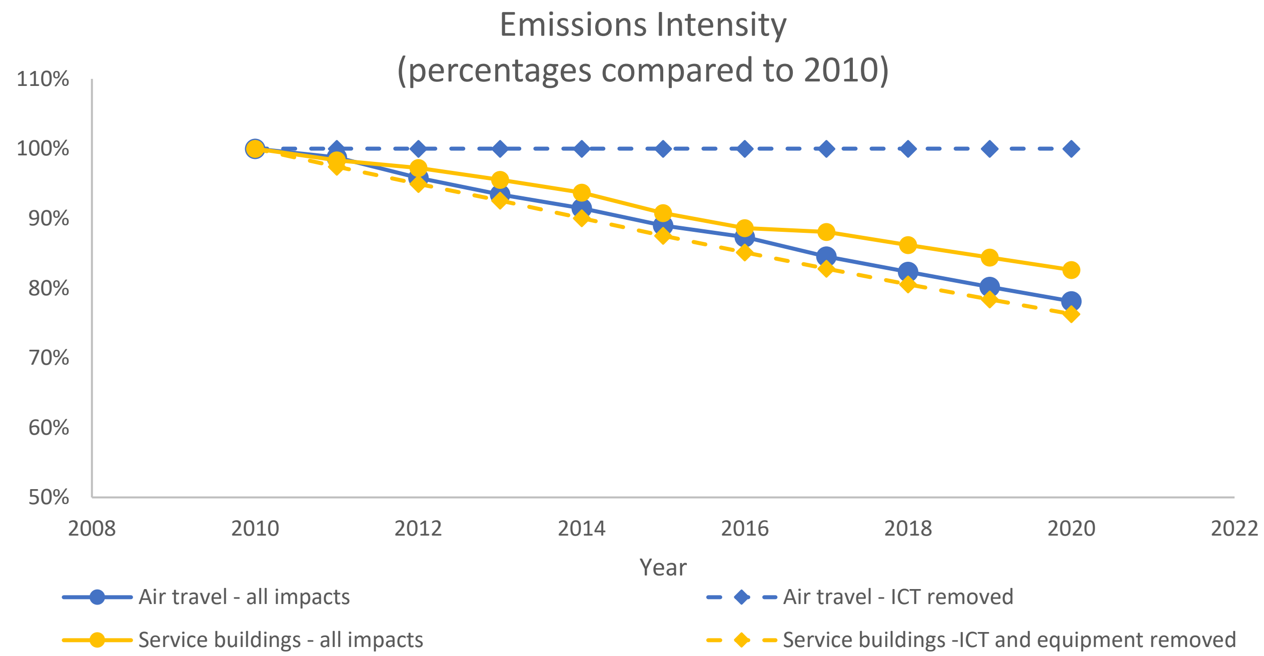

Figure 10. Air travel and Services buildings' emissions intensity trends from 2010 to 2020 compared with baseline year (2010)

5. Conclusions – Study results

This study has found that ICT has dissimilar roles in separate sectors and, despite common sense, it might actually influence those sectors' emissions to increase instead of decrease. This happens when the increase in demand that it enables surmounts the efficiency gains it brings – as was the case of air travel. In sectors where it is more disassociated with demand growth (such as in service buildings) the role of ICT seems to be more positive with the model showing decreasing emissions from the baseline year. The graph below shows the large difference in activity volume for passenger air travel (passenger.kms) when the effect of ICT is removed and the much lower effect of ICT on the services buildings sector activity (measured in m²).

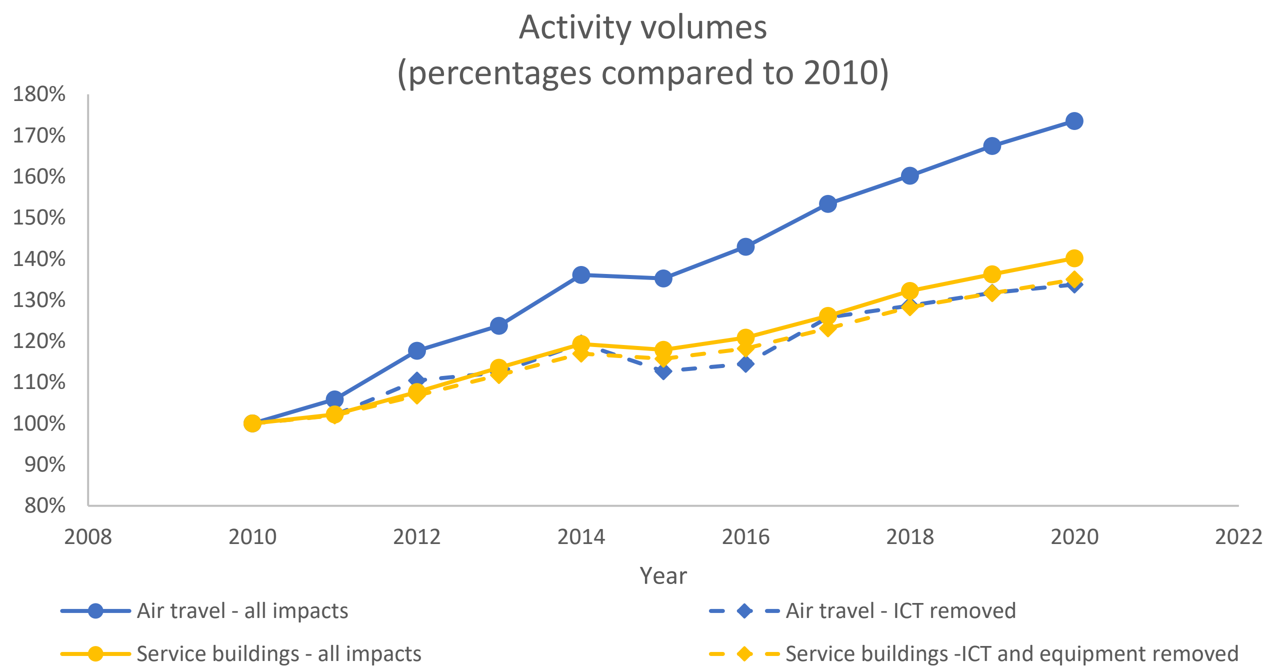

Figure 11. Air travel and Services buildings' activity volume trends from 2010 to 2020 compared with baseline year (2010)

Another important difference between the two sectors is the role technology plays in driving the emissions intensity (as previously discussed in the service buildings' conclusions section). For passenger air travel, this seems to be a relatively linear relation as ICT has enabled an increase in efficiency that led to a decrease of emissions intensity that would not be possible without technological improvements (all the negative impacts of ICT lie on the side of the activity volume side). For services buildings, technology leads to both a decrease in emissions intensity due improvements of efficiency, but also to an increase due to greater demand for cooling and changes in building use, with an increase in energy-using appliances. In the scope of this report we have not been able to separate these two effects as data for that was not readily available.

There are however, important similarities in terms of the drivers for demand. Even though the level of impact of technology in affluence trends is different, this is a crucial driver for both sectors, along with population. In both sectors, it is also possible to see that overall emissions are the result of a balance between increasing activity volume and decreasing emissions intensity. There are also similarities in the structure of the model, which seems to prove that subsequent models can be built for the remaining sectors with reducing effort for each new sector.

As a first step, this study seems to bring some light into the areas that technology can impact and what are the repercussions of it in terms of carbon emissions. We have also listed technologies that are at play in each of the two sectors and the nature of its impact (direct or indirect). This effort was, however, only qualitative as a quantitative attribution is out of the reach of this stage of the study. To do a more in-depth analysis on the impact of each technology one needs to also look into the interdependency of the drivers. For example, routes optimisation requires the use of a communication system to receive information about the location of other airplanes and updated weather information and computing capability to process all this data and calculate the optimal route for each airplane. To understand which part of the resulting fuel efficiency is attributable to the communication system or to the computer itself is a task that is beyond the information now available to us.

However, to prove (or disprove) if this study can actually provide actionable insights, we will need to shine light onto these relations. This will mean having access to sectoral insights and data that do not seem to be publicly available. As a next step to this study, we will need to list the information that can help with the issues of attribution and engage with stakeholders that might provide access to relevant information.

6. Conclusions – Methodological approach

The aim of this study was to test out a methodological approach to assess the impact of ICT on GHG emissions. Previous approaches have done this at an individual solution or product level, the intention here was to attempt to do this at a more macro sub-sector level, using actual total emissions trends for the sub-sector and analysing the impact of different activity and intensity drivers to understand the impact that ICT has on the sub-sector. To illustrate and demonstrate the methodology we chose the two sub-sectors of passenger air travel and service buildings.

6.1 Key conclusions about the methodology

- Broadly the approach works, and at the generic level there is consistent time-series data available for the analysis (e.g. total emissions, population, GDP)
- Sector specific data is needed in order to do more than generic analysis, and in order to draw sector specific conclusions (e.g. number of air passengers, aircraft fuel efficiency etc.). This data is partially available, although may require extensive research to get to it.
- The attribution of ICT impact to drivers is partially subjective (some is more obvious than others), we used best judgement, supported by some data and expert opinion from industry specialists.
- The analysis identified some trends that might not have otherwise have been obvious, and in some cases was counter-intuitive.
- The analysis highlighted the indirect impact that ICT has through increasing affluence and affordability, which drives increase in activity. This effect of ICT is not usually considered when looking at the impact of ICT on emissions.
- There is often an interdependency between different drivers, making it difficult to isolate the impacts from a specific driver.
- The analysis inherently considers both positive and negative impacts, as it is looking at total sub-sector emissions (for example, as demonstrated by the impacts of different types of energy use for the services buildings sector). Thus this analysis can also be applied to sub-sectors where ICT is contributing to increases in emissions (e.g. the impact of ICT in the oil and gas sector).
- This analysis is not for the faint-hearted! It involves collecting, collating and analysing some complex data, and then bravely attempting to draw consistent conclusions.

6.2 Areas for further research

- Further analysis on the impact of different drivers. This requires more detailed, sector-specific data, which may be available with further research effort. This could also further subdivide the impact of both activity and intensity drivers.
  - For example, air travel could be subdivided into business and leisure travel.
  - Service buildings could be subdivided into usage types such as restaurants, public buildings, hotels and offices.
- The impact that technology in a different sector can have on sector activity could be further studied – e.g. the impact of video conferencing on reducing business travel.

- Further research (and data) would be useful to determine better attribution factors. Particularly the attribution of what influence ICT has on specific drivers, which, as already noted, is based largely on subjective judgement in the current study, and can have a significant impact on how the results are interpreted.

- The analysis could be done at the national level using more detailed national data, with the results being used to help determine public policy.

Appendix

Appendix 1: Data sources used in the study

This report is not intended to give a full description of the methodology. The objective of the study was to test out the methodological approach and demonstrate it using two example sub-sectors. It is intended to document the methodology more fully at a later stage, following some further analysis and testing of the methodology, and further feedback from other parties.

For reference we list in the table below the main sources of data that were used in the study. Again, these descriptions would be expanded on in a full methodology description.

Key data is from publicly available sources including the UN, the World Bank, and IEA (International Energy Agency). Sector specific data is from industry sources such as ATAG (Air Transport Action Group) for air travel.

The time period analysed was 2010 to 2020, where mostly the data up to 2015 is historic, and post 2015 is projected.

DATA	SOURCE	TIME PERIOD	GRANULARITY	NOTES
Population	UN	Yearly from 1950 up to 2015 and every 5 years from 2015 to 2100	Country level	
GDP	Historical data: World Bank; expected yearly growth rates: IEA	Yearly from 1990 up to 2016	Country level	Data after 2016 calculated using IEA growth rates (by region)
Income class	World Bank	Yearly from 1987 up to 2016	Country level	Data after 2016 calculated using GDP per capita values and defined thresholds
Train network	UIC and other official national statistics	2015 and 2016	Country level (100 countries)	
Number of passengers	World Bank	Yearly from 1970 up to 2016	Country level	
Fuel efficiency	ATAG report	Applicable after 2010	Worldwide	
Load factor	Statistica	Yearly from 2005 up to 2017	Worldwide	Data extrapolated for years before 2005 and after 2017
Passenger.kms	IEA Energy Technology Perspectives Report	2014, 2025, 2030	IEA Regions and Worldwide	Linear interpolation between 2014 and 2025, and extrapolation for years prior to 2014

DATA	SOURCE	TIME PERIOD	GRANULARITY	NOTES
Energy use	IEA Energy Technology Perspectives Report	2014, 2025, 2030	IEA Regions and Worldwide	Baseline year of 2014 was used - changes of this variable were estimated using load factor and fuel efficiency trends; Worldwide value used
Well to wheel emissions	IEA Energy Technology Perspectives Report	2014, 2025, 2030	IEA Regions and Worldwide	Baseline year of 2014 was used (considered to remain the same in other years); Worldwide value used
Electrification rate	World Bank	2016	Country level	
Services employees per capita	World Bank	Yearly from 2000 to 2017	Country level	
Area (service build) per employee	IEA Energy Indicators Database for IEA member countries	Yearly from 2000 to 2015	Country level (only 8 countries provided good data for all years)	Data extrapolated for years after 2015
LED impact on lighting energy. eff.	Luminous efficacy for LED and other lighting technologies from US DOE	N/A	N/A	Assumptions: Large roll-out of technology modelled to have started in 2014 with a worldwide penetration rate of 90% in 2025
Energy use region factors	Carbon Trust expertise	N/A	Defined regions	
Energy consumption per area	EU Buildings Database	Yearly from 2000 to 2013	Country level	Data only available for a small number of countries, all of them EU members. Averages and extrapolations calculated using only countries with data in all years.
Energy Mix	IEA Energy Technology Perspectives Report	2014, 2025, 2030	IEA Regions and Worldwide	Linear interpolation between 2014 and 2025, and extrapolation for years prior to 2014
Energy sources EFs	DBEIS database for fossil fuels.			

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- measures and certifies the environmental footprint of organisations, products and services;
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