newTRENDs

Focus study report Digitalisation in the Tertiary Sector

Deliverable D6.2

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Executive Summary

The 2015 Paris Agreement has the central aim to strengthen the global response to the threat of climate change by keeping global temperature rise in this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. To reach this ambitious goal, two central strategies have to be implemented in most European countries: (i) enhancing energy efficiency (EE) and (ii) decarbonising remaining energy supply and demand, in particular, by large penetration of renewable energy sources (RES). Scenarios with different focuses and assumptions have been developed to map this development until 2050. While these scenarios represent a major step forward beyond previous modelling approaches, most of them are not considered new societal trends. newTRENDs aims to contribute to fill this gap progress by identifying relevant trends and improve their modelling based on recent empirical findings. In this context, the project newTRENDs is developing the analytical basis for a "2050 Energy Efficiency Vision" taking into account New Societal Trends in energy demand modelling.

This report discusses the universal trend cluster of digitalisation. Digitalisation has fundamentally transformed various aspects of our lives and the economy. This report examines how this transformation impacts the past and future energy demand of the tertiary sector, more specifically of the commercial, buildings and data centre sub-sectors. These changes in energy demand shall consequently be implemented in the demand simulation model FORECAST.

The aim of this report is to document the methodological enhancements of the FORECAST simulation framework and the added input data in order to better model these new trends in its tertiary sector module. For testing the enhancement, small and simple scenarios were defined that are suitable to perform plausibility checks in the relevant parts of the model. These preliminary scenarios also highlight the order of magnitude of effects and potential counter-effects, which partly balance each other out. However, final conclusions should be drawn from more specific case studies, ideally based on empirically validated input parameters.

With these new modules of FORECAST, the tertiary module of the forecast simulation framework can be significantly improved and is ready to model the new trends and their impact on the energy demand of buildings.

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List of Abbreviations

AAGR	Annual Average Growth Rate
AEPS	Advanced Energy Performance Standard
BACS	Building automation and control systems
DC	Data Centre
DESI	Digit Economy and Society Index
DR	Diffusion Rate
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHGE	Greenhouse Gas Emissions
EPBD	Energy Performance Buildings Directive
ESD	Energy Service Driver
ESO	Energy Saving Option
FLAP	Frankfurt, London, Amsterdam, Paris
FLH	Full load hours
ICT	Information and Communication Technology
IEA	International Energy Agency
LCA	Life Cycle Analysis
MEPS	Minimum Energy Performance Standard
NACE	Statistical Classification of Economic Activities in the European Community
PUE	Power usage effectiveness
RH	Relative Humidity
SED	Specific Energy Demand
Q	Quantity Structure
WFH	Working from Home

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1. Introduction

Digitalisation has impacted almost every aspect of modern life, from retail, entertainment, navigation systems to buildings. According to the Gartner Glossary (2023), it "is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business".[1]

However, to represent digitalisation in models, more research is needed. The purpose of this focus study is, therefore, to propose and test a simulation framework that incorporates digitalisation in the tertiary (i.e. service) sector. Such a model can then be used to analyse direct and indirect impacts of emerging digitalisation trends on energy demand. In order to integrate digitalisation into the FORECAST simulation framework, we focus on three topics that are relevant for the energy demand in buildings of the tertiary sector.[2]

- E-Commerce: The impact of online shopping and self-checkouts on (absolute and employee-specific) retail floor areas.
- Smart Buildings: The energy saving potential of building automation and control systems (BACS).
- Data Centres: Higher data volume and data processing demand for various reasons and its impact on data centres in dedicated clusters in a few European countries.

We distinguish three types of impact that digitalisation has on the energy consumption of the tertiary sector (and as a consequence on other sectors):

- Digitalisation changes the **type and structure of services** provided by the sector through information and communication technologies (ICT), for instance through e-commerce or e-services in general.
- Digitalisation helps to **improve the energy-efficiency** of services provided by the sector, for instance through building automation.
- Digitalisation **leads to an expansion of data storage and processing** facilities such as data centres.

This report focuses on the implementation of the e-commerce, smart buildings, and data centres into a simulation framework. It is organised as follows: This section explores the relevance of digitalisation in the newTRENDs project. Section 2 explores the literature and theoretical concepts of the three chosen tertiary sub-sectors, including relationships and impacts. Section 3 presents the model implementation in the three applications and the results. Section 4

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[1] see Table 2 in Appendix for other definitions.

[2] All these trends are part of the cluster digitalisation in the NewTrends project (see also Section 1.2). Other trends may also be relevant for the tertiary sector; however, they are not within the scope of this deliverable. Notably, decentralised work is part of D7.2

provides a Proof of Concept to validate the data that our model changes deliver. Finally, Section 5 concludes this report and gives an outlook on future work.

1.1 Relevance in the newTRENDs project

In WP2 of the project newTRENDs, digitalisation is identified as one of the universally relevant trend clusters (Table 1).

Table 1 Summary of trend clusters from WP2

Relevance	No.	Trend Cluster
Universal	1	Digitalisation
	2	Sustainable Cities
	3	Green Transition
	4	Decentralised Work
	5	From Owning to Sharing
	6	Climate Change and Behaviour
	7	Circular Economy
Nice to have	8	Socio-Economic Dynamics (Toward Energy Equality)
	9	Water Issues
	10	Green Finance
	11	Demographic Change
Optional	12	Geopolitics/Global Forces
	13	Great Depression II
	14	New Labour
Parking lot	15	Evolving Democratic Systems

Source: table adapted from Rosa et al. (2022)

In WP3, a concise summary for each of these clusters is given. From these clusters, *Digitalisation* (cluster 1), *Decentralized Work* (cluster 4) and *From owning to Sharing* (cluster 5) is in the scope of the model enhancement of the tertiary sector modules. In the deliverable, we focus on the cluster digitalisation:

- **Digitalisation**: The rise of digital data storage and traffic will drive energy consumption of data centres and digital hardware production. The trend of virtual work also amplifies the impact. Besides, in the industry sector, rebuilding the regional industrial facilities for higher environment standards and digitalisation integration will also impact the energy consumption. Reversely, digitalisation might decrease energy consumption and material use in terms of decreasing demand, for example, for paper (e-media, e-billing), travel demand (home office, web meetings and virtual conferences), and due to smarter and thus leaner logistics etc.

In deliverable 7.2., we focus on decentralized work and the sharing economy:

- **Decentralised Work**: Decentralised work impacts energy demand in transportation systems and domestic lives. If people work from home and move outside of city centres, their commute time will increase but the frequency of work-related travel will decrease.
- **From Owning to Sharing**: The concept of "Owning to Sharing" encompasses multiple fields, ranging from cars and equipment to publications and living spaces. In summary, it decreases energy demand in material extraction, production, and transportation.

So, digitalisation has been identified as an important part of changing societal trends. In this Deliverable, we will discuss the three areas e-commerce, smart buildings and data centres in-depth.

2. Literature Review

This section provides a review of the existing literature related to the effect, the classification, and the impact of digitalisation on energy consumption, structured according to their digitalisation service (e-commerce, smart buildings, and data centres).

The aim of the literature review is to provide the basis for the expansion of the model framework of the FORECAST model. With this, it is possible to answer the research question, how digitalisation impacts energy demand in different aspects of services.

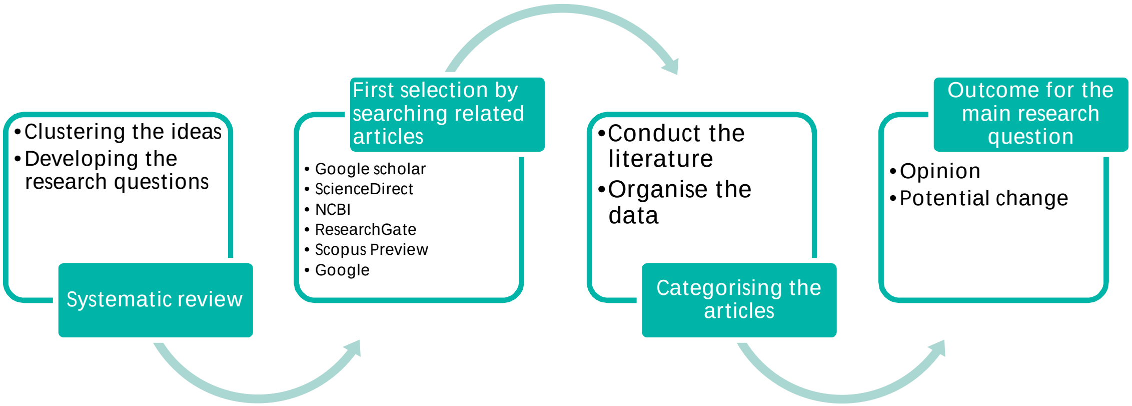
2.1 Methodology of the literature review

This review is conducted using a systematic literature review approach (Pickering & Byrne, 2014) see Figure 1. The final sample consists of case studies focusing on digitalisation and its impact on energy demand in different services. An analytical model was used during the research, investigation, and filtering of the published research in order to collect as much information as possible on the following concepts:

- The direct effects of production, use, and disposal of Information and Communication Technology (ICT)
- The impact of changes in energy efficiency through digitalisation
- The impact of the rebound effect
- Data centres, their infrastructural needs and the energy demand associated with them and the conditions in which unintended effects may outweigh the benefits.

500 articles were sighted during the process of establishing this report. 320 of them were either not relevant for our report or duplicates. They were sorted by scanning the context, abstracts, and the results of the paper. The remaining 180 were scanned fully, 80 of those have reached the same conclusion and used similar data, 45 exhibited similar ideas and 14 were out of scope. The final sample this report is based on consists of 41 papers.

Figure 1 Literature review analysis process



The covered studies used different methods of processing, tackling, and collecting the necessary data for the modelling section. Some of these studies used life cycle analysis (LCA), and other studies used a set of product system configurations, functional units, system boundaries, and allocation rules. Most of the studies limit their attention to direct and indirect effects of digitalisation. Some of the studies indicate the energy savings potential from the electronic economy and fewer potentials from electronic business, while others have not been able to give a clear result.

2.2 Digitalisation and energy

Energy consumption and the change in energy consumption are different from sector to sector, as well as from one sub-sector to another. This report discusses the tertiary sector and the energy consumption in it and how it is related to digitalisation. The impact of digitalisation on the change of energy consumption depends on four aspects:

- The change in the energy consumption of the ICT sector (direct effect)
- The impact of digitalisation on energy efficiency (of affected sectors)
- The impact of digitalisation on economic growth
- The effect on the sub-sectoral consumption on a sectoral level

To study the impact of digitalisation on energy consumption in the sector and how it varies from one sub-sector to another, it is important to define the effects of digitalisation and categorise them in energy increasing – decreasing sets. The energy-increasing effects are the direct effect and the economic growth, whereas the energy-reducing effects are due to energy efficiency improvements and sectorial changes. The comparison of the four effects determines whether digitalisation will increase or decrease energy consumption. Therefore, the more successful digitalisation is in increasing energy efficiency and pushing towards positive effects on economic growth and the direct effect, the more it will help reduce energy consumption.

The four effects are listed in Table 2. Moreover, the table displays the main findings and the explanation of related studies.

Table 2 Summary of digitalisation effect on energy

Effect	Finding	Explanation of the finding
Direct effect	The direct effects from the production, usage and disposal of ICT. Change (increase) in electricity consumption / by the economic agents that increase adoption of digitalisation processes in consumption or production.	The ICT sector has experienced a strong increase of technological energy efficiency but has also strongly grown in terms of data processing (including transformation) and storage building operation. Measurement issue: 'technical growth' (e.g., increases in computing capacity, physical capacity, and energy consumption in the ICT sector) is not proportionally translated into economic growth.
Energy efficiency	Adoption of digitalisation processes improve the efficiency of production. Energy conservation, energy efficiency and energy sufficiency are the most important strategies to achieve absolute.	ICT allows for more efficient production and products, but sometimes also leads to new behaviours that are more energy-intensive. Although digitalisation can enhance the efficiency of ICT services, the associated cost savings may be offset by an increase in ICT demand. ICT services are often complements to rather than substitutes for traditional goods and services.
Economic growth	Positive effect of digitalisation on economic growth. The speed of economic growth is of major importance.	Labour productivity increases due to digitalisation.
Sectoral change	The share of services within the ICT sectors rises. The energy demand and the effect of digitalisation are depending of the subsector Digital services are more energy-intensive than other services. The energy consumption in the subsectors depends on the	The growth of ICT services in some countries does not replace but comes on top of existing production. Therefore, the known effect on tertiarisation is limited to the effect of increasing ICT services.

	development of digitalisation and the demand for digitalisation.	

Source: Extended by TEP based on Lange et al. (2020)

ICT offers many benefits for reducing energy demand and carbon emissions. For example, e-commerce can displace private transport demand and improve logistical efficiency, digital monitoring and control can optimise in-use energy consumption (e.g. building energy management systems, smart homes, industrial process control), and teleworking can displace commuting and business travel. On the other hand, the digital economy possesses a rapidly growing energy and carbon footprint (Galvin, 2015). The continuous improvements in the energy and material efficiency of individual devices are being more than offset by the continuing increases in the number, power, complexity, and range of applications of those devices (Galvin, 2015).

There are several effects of digitalisation on energy consumption, such as the direct, indirect and rebound effect. The first two are quite straightforward but the third one needs clarification. The table below shows definitions of these effects.

Table 3 Definition of rebound effect

Name		**Definition**
Direct effect		The direct impacts include the energy used in the manufacture, operation and disposal of ICT, along with the energy used for the associated data transmission networks
Rebound effect		The adverse effect, which may reduce partially, entirely, or even outweigh the projected (or hoped-for) savings
Indirect rebound effect	Substitution effect	a lower price for goods or services makes it relatively more affordable than another, similar product, or service, which it will subsequently partly substitutes
	Rebound effect	when a technology does not save resources but instead saves time, which in turn is spent on resource-consuming activities
Direct rebound effect	Rebound Effect (W. S. Jevons)	A rebound effect happens when an energy efficient technology is implemented instead of an old one, and when it creates an opposite effect to what could be expected: the new technology does not reduce the total quantity of energy consumed but increases it.
	Rebound effect	**Efficiency gains lead to more consumption of the same good or service**

Most of the studies assume that digital goods substitute material goods and all of them neglect potential rebound effects, hence overestimate the impact of digitalisation on energy savings.

2.3 Impact of digitalisation on energy consumption

There is still a lack of understanding concerning the net energy effects of ICT on different sectors. Therefore, we built a new concept that combines what has been studied and benefits from the results on energy saving and the rebound effect to overcome them. Therefore, it is worth noting that the results of indirect energy impact studies are highly sensitive to scoping decisions and assumptions made by analysts. Uncertainty increases with the expansion of the impact due to the complex and interrelated effects that come in conjunction with the rapid development and complex intervention of digitalisation in various sectors of different degree of complexity. However, there is a consensus that ICT has great potential to save energy, but the realisation of this potential and potential depends largely on the details of the deployment and user behaviour including individuals and companies alike.

All the changes in these sectors lead to changes in energy consumption and demand. Court & Sorrell (2020) studied the scope of the e-materialisation e.g., e-books, video and audio streaming, e-games, etc. Pohl et al. (2019) tackled the same scope. The articles classify the energy impact of digitalisation in different ways, but all share the idea that digitalisation has both direct and higher-order impacts on energy consumption. Horner et al. (2016) provide a precise review of the energy impacts of selected ICT applications, focusing on comparing quantitative estimates. However, it does not systematically examine the factors determining those impacts (see Table 4).

Table 4 The impact of digitalisation on different service

Publication	Temporal coverage	ICT Service	Scope
Pohl et al., 2019	2019	E-books	Energy used to operate an e-reader, Energy used to manufacture the technologies and infrastructure needed to produce, deliver, store, download and read e-books (e.g., data centres, networks e-readers)
Horner et al., 2016	2016	E-books	Energy used to manufacture the technologies and infrastructure needed to produce, deliver, store, download and read e-books (e.g., data centres, networks e-readers)

According to Belkhir & Elmeligi (2018) and Malmodin & Lundén (2018), digitalisation can stimulate demand for existing and new services such as mobile GPS. Simultaneously, the energy demand increases as some of these services require energy-intensive systems such as 4G networks, satellites, and data centres to function. Depending on the system's boundaries and assumptions, the ICT sector was estimated to account for 3.5%–7% of global electricity consumption in 2015 and 1.5%–3% of GHGE. ICT energy use is currently increasing by 5%–10% per year, which means that its share of the total of society's carbon footprint is likely to increase Belkhir & Elmeligi (2018).

Malmodin & Lundén (2018) review other LCAs of ICT services and regular services. They found that relatively few papers compare digital and non-digital products and services, and that most neglect any rebound effects.

IEA (2017) covers the impact of digitalisation on energy demand in transportation, building and industry. The report found that digitalisation in these sectors would allow for a large energy saving potential.

Magazzino et al. (2021) investigate the link between ICT, electricity consumption and carbon emission. The report found a one-way causality between ICT usage and its energy consumption, which in turn increases CO2-emissions.

Similarly, Hopkins and McKay (2019) encouraged technology-enabled changes in working patterns to reduce commuter travel and office-related energy consumption. However, the potential contribution of ICT to low-carbon economies is unclear. Although the net energy-saving effect of the ICT revolution and its potential for green growth is still a disputed topic ICT offers many benefits for reducing energy demand and carbon emissions.

In Table 23 in the Appendix, the scope of other studies reviewed are compiled.

2.4 E-materialisation

Interest continues to characterise the net energy impact of ICT on various areas of life and work sectors, which results from the indirect effects of energy consumed by ICT equipment. These effects may range between negative and positive. Researchers have yet to gain agreement on the direction of this development, i.e., if the energy consumption will increase or decrease. This is also true for the digitalisation of material goods (electronic embodiment). In this section we try to understand the wider impact of digitalisation. We takes the e-materialisation of books, newspapers, and digital games as examples for this effect. We classify them and study the effects of digitizing these commodities on energy consumption and the resulting positive or negative effects.

This includes the impact of automation in the publishing sector in its various fields of reading, audio, and video. Therefore, the review of Court & Sorrell (2020) aims to fill the evidence gap and shed light on this sector in all its forms. Our review is limited to the field of electronic automation, which is defined as the partial or complete replacement of physical products with electronic equivalents. We collect all the insights from different literature studies and the direct and indirect effects of commodity digitalisation on energy consumption covering five categories, namely: “electronic publications” (e-books, e-magazines, e-magazines); “electronic news”; “E-Business”; “electronic music”; and video clips and electronic games.

Table 5 Review of digitalisation services

Author, year	ICT Service	Scope, Summary
Arushanyan et al., 2014	ICT service	Review LCAs of ICT services and services and find relatively few compare digital and non-digital products and services, and neglect rebound effects
Horner et al., 2016	ICT service	Provide an insightful review of the energy impact of selected ICT applications, focusing on comparing quantitative estimates.
Bieser & Hilty, 2018	ICT service	Conduct a systematic review of studies assessing the indirect environmental effects of ICTs and the used method
Pohl et al., 2019	ICT service	Assess whether and how LCA studies consider indirect (higher order) impacts, but do not compare the resulting quantitative estimates
Hankel et al., 2018	ICT service	Conduct a systematic literature review of the factors influencing the environmental impact of ICTs, but do not assess the impact of these factors on the environmental outcomes.
Court & Sorrell, 2020	ICT service	Assess the specific factors that determine the environmental impacts of ICTs in particular applications and link those factors to the magnitude of the impacts of ICTs in those applications

As shown above, many studies and reviews have tackled the scope of e-materialisation, and, interestingly, these studies had different orientations and bases. However, it is worth mentioning that the common goal, despite the multiplicity of orientations, is energy and the impact of digitalisation on energy consumption and the environment.

The studies agree that the evidence for energy saving through e-materialisation is limited. However, most of the studies attribute the sensitivity of the results to the development of technology, the behaviour of the variables and the behaviour of individuals, besides the regressive effects that it entails, which led to the widening of the possible spectrum results.

Court & Sorrell (2020) study this scope of digitalisation and provides some empirical results which are common in most related articles. Also, Court & Sorrell (2020) have tackled the energy consumption and the life-cycle energy consumption and come to the conclusion that the impacts ranges from >90% reductions in life-cycle energy consumption to >2000% increases in energy consumption. Changes to key assumptions can lead to very different estimates within a single study. Key variables influencing energy savings that are common to several goods include the lifetime, utilisation and energy efficiency of user devices, the extent to which personal transport is displaced, the number of users of material and digital products and the choice of functional unit and allocation rules. The estimated impacts are highly sensitive to the technical features of the relevant systems and to the behaviour of users which vary widely from one context to another, as well as over time. Some trends (e.g., more energy efficient user devices) are increasing the energy savings from e-materialisation while others (high-quality video) may counteract those savings. If attention is confined to direct and substitution effects alone, most studies suggest a significant potential for energy savings in e-publications, e-news, and e-music, but less so for e-business and e-videos/games. The extent to which those savings are realised depends upon the technical features of the relevant systems and the behaviour of users. Given the diversity of results, there is no consensus on the magnitude of potential energy savings and there are many circumstances where e-materialisation can increase energy consumption.

Table 6 summarizes the different effects ICT Services can have on these different scopes as follows:

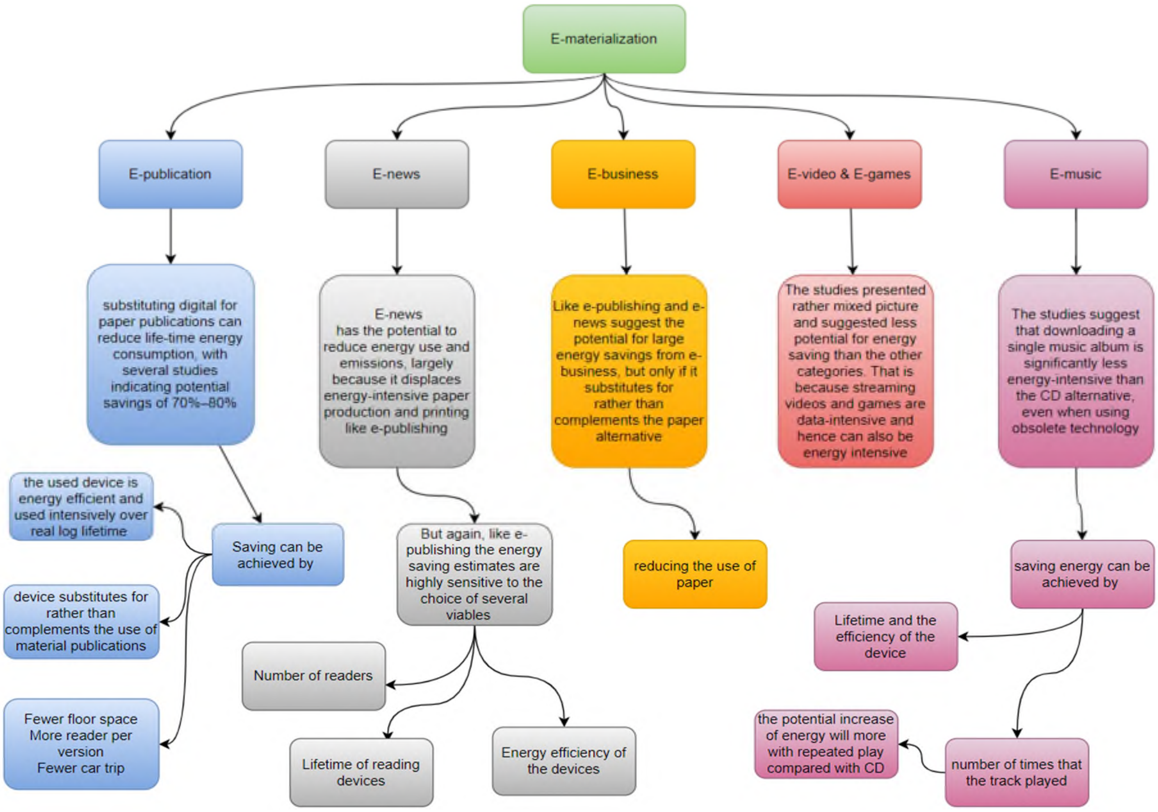
Table 6 The categories of the different ICT-Effects of various ICT Services

Author, year	**ICT Service**	**Impact category**	**ICT effect**			
			Direct	**Re-bound**	**Sub-stitution**	**Opti-misation**
Achachlouei & Moberg, 2015	E-materiali-sation	Different	✓		✓	
G Andrae & Edler, 2010	E-materiali-sation	Energy	✓	✓	✓	
Hochschorner et al., 2015	E-materiali-sation	GHG	✓		✓	
Moberg et al., 2010	E-news	Energy	✓	✓	✓	
Achachlouei & Moberg, 2015	E-publishing	Several	✓	✓	✓	
G Andrae & Edler, 2010	E-materiali-sation	Energy	✓		✓	
Maga et al., 2013	E-materiali-sation	GHG	✓		✓	
Shehabi et al., 2014	E-videos	Energy, GHG	✓		✓	

Mayers et al., 2015	E-games	GHG	✓		✓	
Pohl et al., 2019	E-materiali-sation	Energy	✓	✓	✓	✓
Horner et al., 2016	E-book	Energy	✓	✓	✓	✓
Court & Sorrell, 2020	E-materiali-sation (several)	Energy	✓	✓	✓	✓

In Figure 2, we explain which services e-materialisation entails and how it can influence energy use and the energy consumption in a hierarchical order and provide a suggestion on how to reduce the energy consumption.

Figure 2 The impact of digitalisation on the material side



Source: TEP

2.5 E-commerce

E-commerce, the purchase of goods or services over the internet (Næss-Schmidt et al., 2021), encompasses physical goods (e.g., fashion, electronics, and food), services (e.g., insurances, leisure activities, and travel services), or electronic data (e.g., music, software licenses, and weather data). Fashion, electronics, and computers including software form the largest portion of e-commerce turnover (Zimmermann et al., 2020).

E-commerce includes familiar business-to-customer (B2C) internet outlets (also called online shopping) like Alibaba, eBay, and Amazon, but it also includes back-end business-to-business (B2B) functions such as services that enable just-in-time inventory management. E-Commerce presents itself in various forms (see Table 7).

Table 7 Definitions of e-commerce

Name	Source	Definition
E-commerce	Bădîrcea et al., 2022	It is a platform that allows customers with mobile devices to access banking services and other commercial facilities through them.
E-business	K. Fritch,2002	Business processes, commercial activities, or other economic tasks conducted over the Internet or computer mediated networks (intranet, etc.).
Teleshopping	Erdmann & Hilty, 2010	Demand-side e-commerce, allowing the purchase of physical goods away from retail.

The literature and studies concerning e-commerce have tackled different aspects of the digitalisation effect in this field, and in this review the focus lies on some of these aspects. The first scope is the effect of e-commerce on retail trade in terms of logistical aspects such as number of retail shops, location, and size of the stores. The second is packaging, and finally, the transportation and the consequent effect on energy demand.

2.5.1 Effect of E-Commerce on Logistics

A switch from brick-and-mortar retail locations to e-commerce has changed how products are delivered from the business to the consumer, replacing over-the-counter sales with home delivery through private transportation and bulk freight delivery to shops or logistic storage.

Risberg (2022) shows the development of e-commerce logistics in Sweden from 2018 to 2022. The main findings of the study illustrate that the retailing landscape is currently changing as a result of the shift from stores to internet-based formats. Businesses strive to deliver a seamless shopping experience, so omni-channel retailing becomes more prevalent in comparison to traditional store-based retailers and as online marketplaces gain importance.

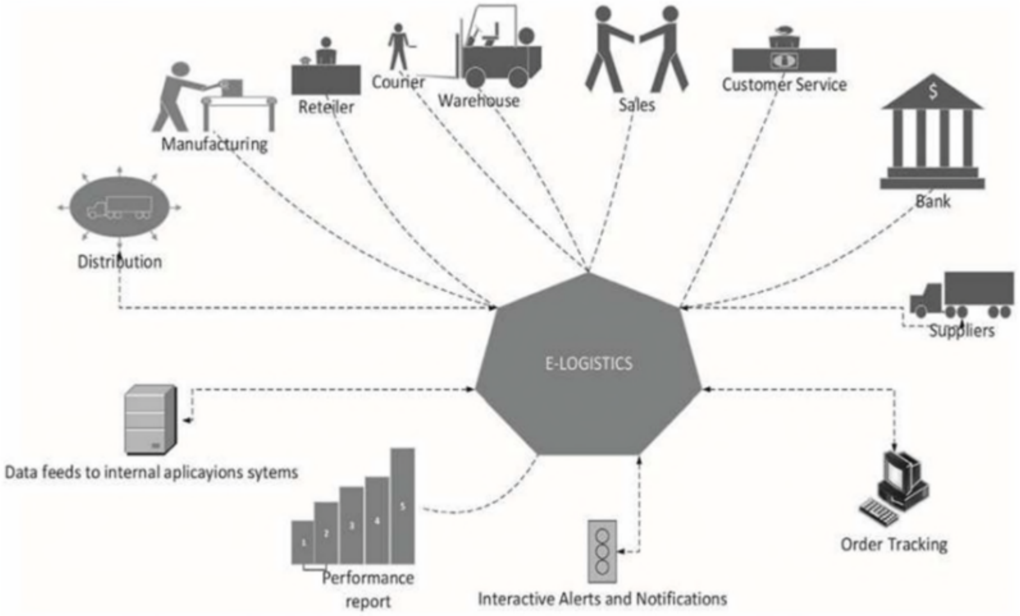
Horner et al. (2016) showed the impact of digitalisation in e-commerce in terms of energy consumption and the net energy effect. It spotlights the economy-wide changes of energy consumption due to the impact of ICT on macro economy across commerce. For example, e-commerce gives retailers the capacity to serve geographically larger markets, which could increase cost efficiency at the expense of energy efficiency. The study mentions the last mile effect and logistical changes, as well as the reduction in production. Through greater coupling of consumers and producers, e-commerce may reduce overproduction. E-commerce also leads to more efficient secondary markets. Through sites like eBay, goods that were either destined for the landfill or sitting unused in storage are put to use, eliminating waste, avoiding additional manufacturing, and reducing storage requirements, which results in reducing waste, less consumed energy and emissions.

E-commerce lowers package density and increases packaging energy by shipping multiple items together. Home delivery in e-commerce means fewer items per package, resulting in more carton usage and environmental impact. In contrast, wholesale delivery requires less packaging, and thus less caron usage (Zennaro et al., 2022).

Argilés-Bosch et al. (2022) studied the comparison between the cost of retail trade versus e-commerce, taking three aspects into account: the cost of goods sold, labour costs, and other operational cost. According to their results e-commerce has a more flexible behaviour in terms of other operational cost than traditional retail firms do. The former applies greater cuts to other operational costs than traditional firms do when activity decreases. Along the same lines, e-commerce firms seem to be more capable of adjusting resources in unfavourable conditions such as the recent Pandemic. This is probably part of a wider ability of digital applications to better adapt to new circumstances. E-commerce is a recent form of business that, in its conception, is knowledge-based. The internet environment in which e-commerce is conducted is fully involved in recording and generating information. It is agile in producing information on business development and gives urgent feedback and responses. E-commerce is not only a different business model, but also a more flexible way of doing business that adds greater economic efficiency.

Erceg & Sekuloska (2019) show the importance of e-logistics and e-supply chain management for the development of e-commerce. The paper took DHL as a case study. E-logistic automates all the steps of the order chain starting from request to the delivery of the order (see Figure 3).

Figure 3 E-logistics



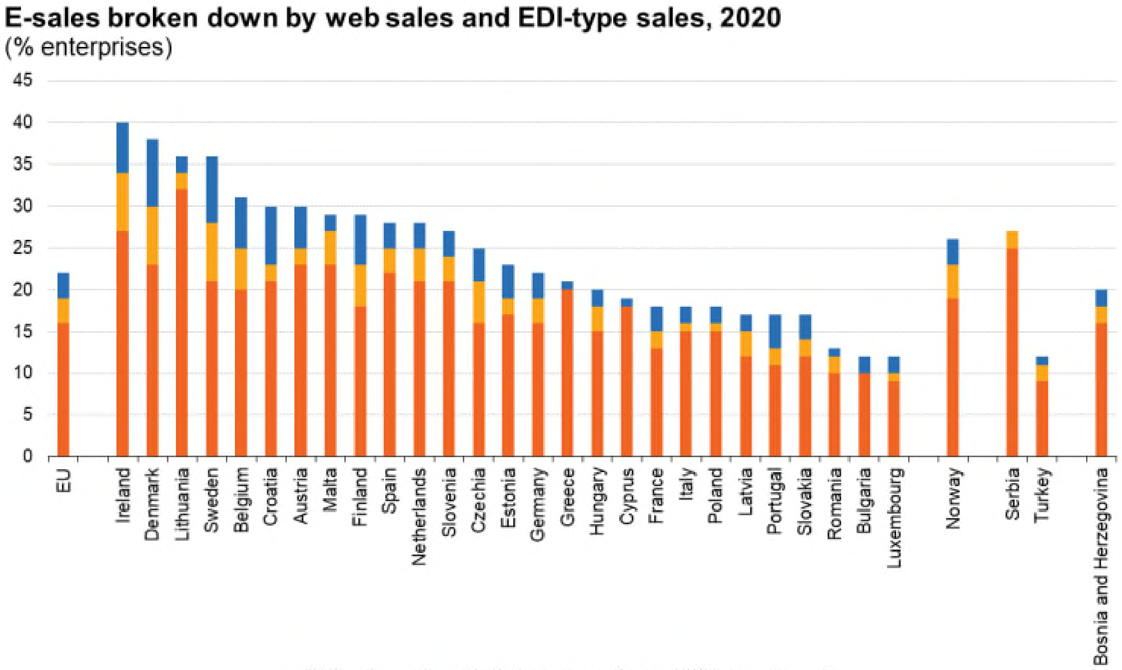
Source: Erceg & Sekuloska (2019)

In conclusion, the share of e-commerce rises as traditional retailers expand their business to online platforms and increasingly more businesses are solely based online. E-commerce may optimise transportation due to the optimisation of shipping ways by delivery companies. However, this may also increase energy consumption by substituting air freight for ground freight. E-commerce can also promote second-hand retailing, which would have a positive effect on energy demand. Finally, e-commerce can be an economically more efficient business as it provides far more data on costumer behaviour etc.

2.5.2 The impact of e-commerce on retail

E-commerce is a good example for a substantiation of a new trend: the share of individuals who bought goods or services over the internet has, on average in the EU, increased by 28% over the last decade (Eurostat, E-commerce statistics for individuals, 2022). Moreover, about one in five enterprises sell goods or services exclusively online (see Figure 4).

Figure 4 Share of European enterprises that provide e-sales in 2020

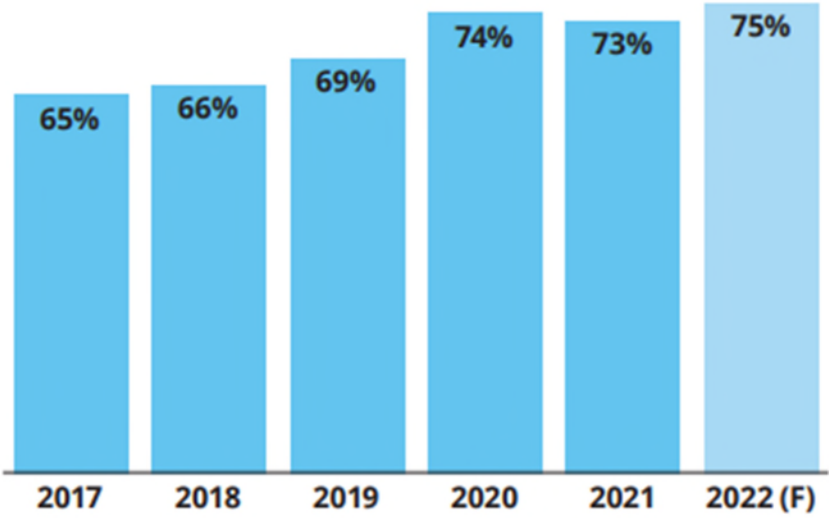


Notes: Only countries with available results for all three indicators are displayed.
The share of enterprises with both types of e-sales in Greece, Cyprus and Bulgaria is less than 1% and not visible in the graph. EDI-type sales for Serbia are less than 1% and not visible in the graph.
Not available: Montenegro (web sales: unreliable), North Macedonia (not available), Albania (EDI-type sales: unreliable)
Source: Eurostat (online data code: isoc_ec_eseln2)

Source: Eurostat, E-commerce_statistics (2022)

According to Lone & Weltevreden (2022), in 2020 more than 57% of the Europeans shopped online. They show that e-commerce has increased in Europe, due to the development in technology. Moreover, the percentage of people shopping online increased more pronounced in 2020 because of the lockdowns due to Covid-19, see Figure 5.

Figure 5 E-shoppers, percentage of internet users that bought goods or services online, Europe

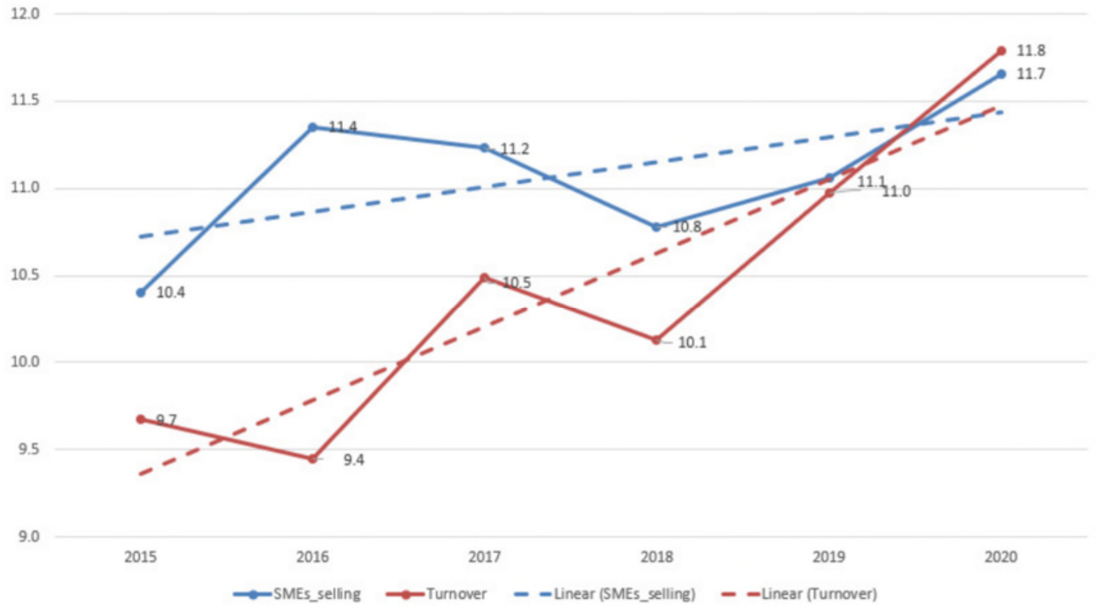


Source: Lone & Weltevreden (2022)

Soava et al. (2022) say the main purpose of this research was to examine the evolution and to provide a forecast for the percentage of e-commerce enterprises and their turnover, as the main subcomponents of the integration of digital technologies by enterprises (the third component of the DESI), as well as the impact on the development of national economies by increasing the share of GDP obtained from e-commerce in total GDP. It shows the Annual Average Growth Rate (AAGR) and the Digit Economy and Society Index (DESI) and, as a result, e-commerce has grown by 2.4% in 2020 compared with 2015.

Soava et al. (2022) have studied and analysed the turnover of e-commerce in Europe and according to Figure 6 the percentage of turnover of e-commerce has increased during the past three years, where it reached 11.8% in 2020. It can be seen from Figure 6 that there are countries that have registered increases below the EU average (Belgium, the Czech Republic, Germany, France, Italy, Portugal, and Sweden).

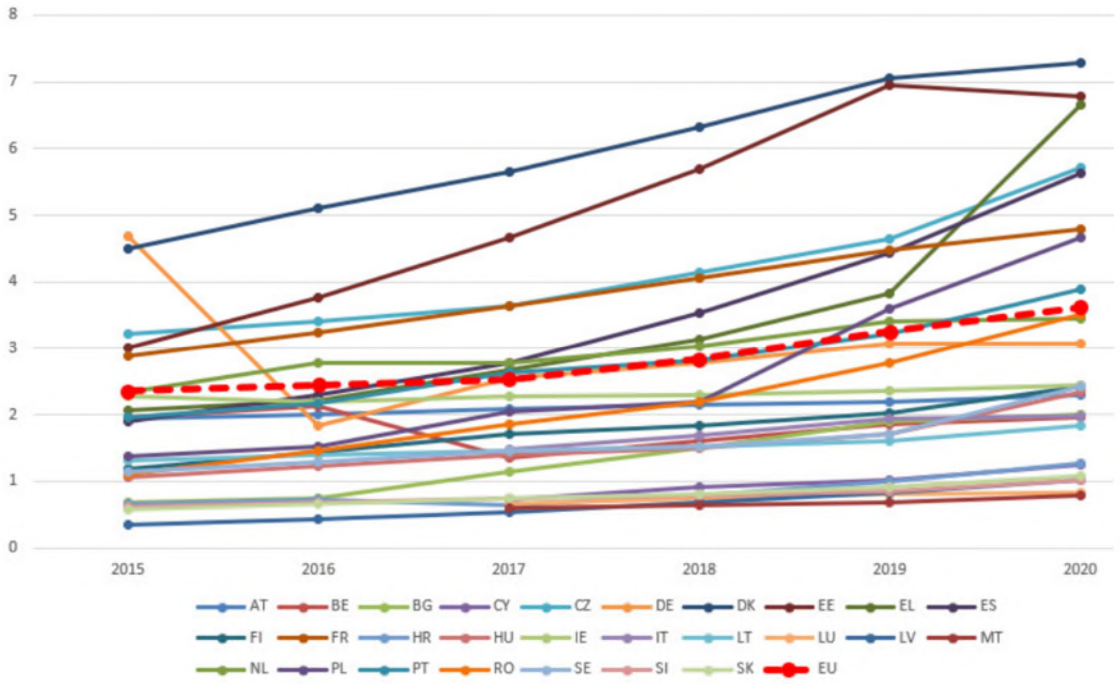
Figure 6 Evolution of the Selling and Turnover for EU



Source: Soava et al. (2022)

Moreover, Figure 7 shows the change in the e-GDP in European countries. The e-GDP measures the percentage of the GDP compromised by e-commerce (Lone, S., & Weltevreden, J., 2022). We can see an increase in the e-GDP in most of the European countries. For example in Denmark, it increased by 7.5%.

Figure 7 Evolution of the e-GDP for period 2015–2020



Source: Soava et al. (2022)

2.5.3 Conclusion

E-commerce can be addressed as part of digitalisation impact on wholesale and retail sub-sector. Moreover, e-commerce has been developed rapidly due to the massive development of information and communication technology. However, the impact of e-commerce on retail sub-sector is not clear in terms of "how many retail stores have been closed due to the spread of e-commerce" for two reasons:

- Most of the studies focus on the growth of e-commerce in GDP per country or in Europe in general.
- There is a lack of data about the affected floor area sizes dedicated to logistics and retail, as well as about the number of closed shops (food and non-food).

2.6 Smart Buildings

Smart buildings rely on building automation and control systems (BACS) to monitor and adjust the energy use of various energy services like ventilation, cooling, circulation pumps and lighting. Concrete measures include on-demand room humidification, demand-based volume flow and pressure control in the ventilation system and pumps, the demand-based control of lighting, as well as daylight-dependent interior lighting. The installation of BACS predominantly leads to a reduction in full load hours (FLH). In some cases, however, indirect effects on the installed capacity may also occur. For example, more targeted lighting may affect the power requirements and may lead to smaller ventilation and cooling systems.

BACS can contribute to final energy savings and greenhouse gas emission reductions. For instance, in Switzerland, the implementation of BACS could contribute to a considerable share of total energy savings (Jakob et al., 2016). In the EU, the Energy Performance of Buildings Directive (EPBD) generally promotes smart technologies and the use of BACS in certain buildings. It also mandates the use of BACS in larger non-residential buildings (European Parliament (2018)). In this context, one study finds that BACS in the EU may contribute to 14% of the total primary energy savings in buildings until 2038 (Waide, 2019). Therefore, integrating BACS in energy modelling is useful and needed.

Jakob et al. (2016) further find that BACS measures only have a specific and isolated effect on the intended use, and that their potential is sometimes highly dependent on the usage profile. Significant efficiency potentials can be tapped through BACS, especially for usage profiles that are highly variable over time (Becker & Knoll, 2011). However, for the potentials to be reached and for an optimal operation of BACS systems, two prerequisites need to be fulfilled. First, the simple operability of the control and guidance systems, and second, trained personnel must be able to plan, commission, calibrate, monitor and, if necessary, adjust the systems.

Furthermore, energy operational optimisation is essential, in other words regular monitoring and adjustment of the BACS parameters. In particular, correctly setting the target and threshold values of such systems is necessary for achieving the highest energy efficiency. Suboptimal set points can lead to reduced or even negative energy saving potentials (e.g., if the CO_2 concentration of the volume flow control is set too low, it could lead to an unnecessary continuous operation of ventilation systems). While the electricity consumption of the BACS-appliances cannot be neglected (Kräuchi et al., 2017). , the European building automation norm (EN 15232) suggests that there is a net saving effect if the automation is correctly implemented.

Through an integral design of the building automation systems, additional potentials are possible for buildings in the tertiary sector (e.g., offices). Overarching measures include the early input of meteorological data for predictive control, the coordination of heating, ventilation and air-conditioning systems and the use of sun protection, including the lighting installation (e.g., daylight-dependent interior lighting), and the integrated and interconnected monitoring of all systems.

We here propose the concept of estimating the effect of BACS in the individual energy services in FORECAST and a new energy saving option in order to reach the full efficiency potential of BACS. In summary, standardised factors from the building automation (norm EN15232) are applied to estimate potential energy savings. We consider this for the tertiary sector and propose diffusion and cost curves (Section 3.2).

2.7 Data Centres

2.7.1 Introduction

According to Avgerinou et al. (2017), data centres (DC) are computer warehouses that store a large amount of data for different organisations process. They contain servers for the collection of data and network infrastructure for the utilisation and storage of the data Avgerinou et al. (2017).

Data centres usually run 24/7 all year round (Oró et al., 2015) and are very energy-intensive. High energy consumption can be attributed primarily to the IT demands, cooling and ventilation equipment, as well as, power provision and other requirements (e.g., lighting). The cooling system consists of chillers, cooling towers and water pumps. Water chillers consume the most energy to supply chilled water to the cooling coil to keep the indoor temperature low enough by removing the heat emitted by the ICT devices. Hence, the improvement of the efficiency of data centre equipment can lead to great energy and financial savings.

Data centres have become more and more important simultaneously with the rapid development of information and communication technologies and the wide impact of digitalisation on various levels. However, this increased demand for IT services and data centres has a major impact on electricity consumption, because data centres in addition to the IT infrastructure (servers, storage, networks, etc.) also require a lot of building services infrastructure (cooling, ventilation, uninterruptible power supply (UPS) etc.). Accordingly, various studies have been conducted in recent years to quantify the electricity consumption of data centres.

According to the International Energy Agency (IEA) nearly 1% of energy related GHG emissions in 2020 are caused by data centres and data transmissions networks (IEA, 2022). Moreover, data centres account to 1-1.5% of the global electricity use in 2021. For long-term net zero targets, emissions must be cut in half by 2030 (IEA, 2022).

The IT demand is even higher in developed countries, and a recent EU study showed, that the electricity consumption accounted to about 2.7% of the total electricity demand in the EU28 with a tendency to further increase in the coming years (Montevecchi et al., 2020). In Switzerland, a country with a very high DC density (CBRE, 2021), electricity consumption of data centres accounted to around 3.6% of the total electricity consumption in 2019 (Jakob et al., 2021; Müller et al., 2021).

Accordingly, a close monitoring of the data centre market is important and efficiency improvements must be pursued, especially due to the expected increase in IT services for various reasons (Internet of Things (IoT), Artificial Intelligence (AI) etc.). The following section gives a brief introduction on electricity consumption in data centres, possible efficiency measures and metrics to measure energy efficiency. Section 2.7.3 provides an exemplified overview of existing studies that analysed the electricity consumption of DC in various regions. Finally, section 3.3 illustrates the main drivers of the electricity consumption in terms of a modelling perspective.

2.7.2 Electricity consumption, energy efficiency potentials and their metrics in data centres

Electricity consumption and efficiency potentials in data centres highly depend on the used technologies and components within the data centre and the already implemented energy efficiency measures. In general, the electricity consumption in data centres can be distinguished on two areas:

1. Data centre infrastructure : Cooling, ventilation, UPS, circulation pumps etc.
2. IT Infrastructure: Server, storage, backup systems etc.

For both, the DC infrastructure and the IT infrastructure, several efficiency measures can be implemented to reduce electricity consumption (see an exemplary overview in Table 8). Previous studies have analysed the impact of such efficiency measures on the electricity consumption both on the DC-specific level (Puntsagdash et al., 2015) and on country-specific level (Jakob et al., 2021; Müller et al., 2021).

Table 8 Examples of energy efficiency measures for the DC infrastructure and the IT infrastructure

Efficiency measures on the DC infrastructure	Efficiency measures on the IT infrastructure
Separation and enclosure of cold and hot aisles	Server

Increase of the system temperature	Increase of virtualisation
Increase of cooling water temperature	Increase of utilisation
Waste heat recovery	Consolidation of applications
Free Cooling	Network
Direct water cooling of servers	Intelligent switches
Cooling system with heat sink in the environment (lake, river, groundwater)	Consolidation of network
Optimised UPS with high efficiency	Storage and backup
Optimised power supplies	Switch to flash storage
	Switch to tape backup
	Efficient power supply in all devices

Source: adopted from Jakob et al. (2021)

Several studies explored energy efficiency metrics for data centres (e.g., Aebischer (2007); De Napoli et al. (2016); Green IT Promotion Council (2012); Maagee (2022); Neudorfer & Ohlhorst (2010); the green grid (2007); Van de Voort et al. (2017); Wang & Khan (2013)).

In terms of DC infrastructure, the most widely used metric is the Power Usage Effectiveness (PUE), which is defined by the ratio of total electricity consumption and the electricity consumption of the IT infrastructure:

$$PUE = \frac{E_{DC\,Infra} + E_{IT}}{E_{IT}}$$

The closer the PUE is to 1, the less electricity is required for the DC infrastructure, and the more efficient the DC is. The PUE is highly dependent on the above presented efficiency measures and also on the location and the technologies used in the specific DC. An empirical study from Switzerland (Jakob et al., 2021; Müller et al., 2021) further showed that current PUE values strongly depend on the DC type. Smaller, internally operated company data centres show higher PUE values (around 1.6) than DC operated by DC service providers (around 1.4). This is mainly due to large number of implemented efficiency measures by the DC service providers. Compared to a previous study from Switzerland (Altenburger et al., 2014), PUE values have significantly dropped (by around 0.2 per DC). A global study by (Masanet et al., 2020) also shows significant reductions in the PUE values and also highlights large differences between the DC types.

2.7.3 Literature on Electricity consumption in Data centres

In the past, several attempts have been made to evaluate the electricity consumption of data centres in entire countries or regions. This section provides an overview about some important studies.

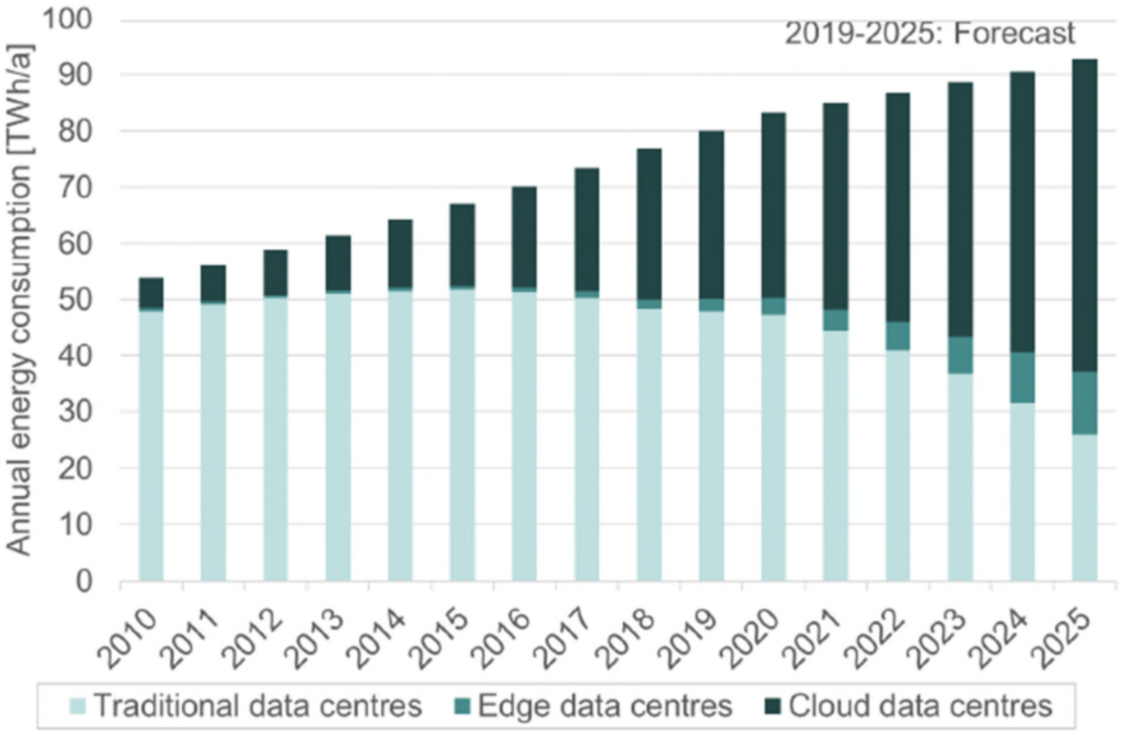
Masanet et al. (2020) estimate the global electricity consumption in DC to about 200 TWh (around 1% of the global electricity consumption) in 2018. Since 2010, electricity consumption of DCs only increased moderately, while the computing workload has increased significantly stronger. Similarly, other studies they highlight a strong shift from traditional data centres to cloud and hyperscale data centres. Furthermore, the study shows that electricity consumption in data centres has increased primarily in the area of servers and storages but has decreased for the infrastructure. This is consistent with the observations from the EU (Montevecchi et al., 2020). In the case of Switzerland, stronger energy efficiency gains were observed for DC infrastructure (cooling, ventilation etc.) (Jakob et al., 2021; Müller et al., 2021).

Malmodin & Lundén (2018) estimated the electricity consumption of the global ICT network operations to around 242 TWh in 2015 related to a carbon footprint of about 169 Mt CO_2-eq. The authors compare their numbers to earlier studies by themselves and highlight the shrinking footprints despite an increasing data traffic.

Similarly, Koomey (2011) estimated the electricity consumption of DC to about 1.3% of the total electricity use on a global level and around 2% of the total electricity use in the US.

A recent study by Montevecchi et al. (2020) analysed and modelled the energy demand of data centres in the EU28. Data centres and server rooms with at least 3 physical servers are considered. The study shows an increase in electricity consumption from 53.9 TWh/a to 76.8 TWh/a (+42%) in the period 2010-2018. The latter number corresponds to around 2.7% of the electricity demand in the EU28. The authors explain the increase in energy by the strong growth in IT services, whereby efficiency gains (of all the infrastructure) could not keep pace. Finally, they expect a further increase to about 92.6 TWh/a in 2025, whereby the growth can especially be attributed to cloud data centres and edge data centres (smaller, specialised data centres with low latency), see Figure 8.

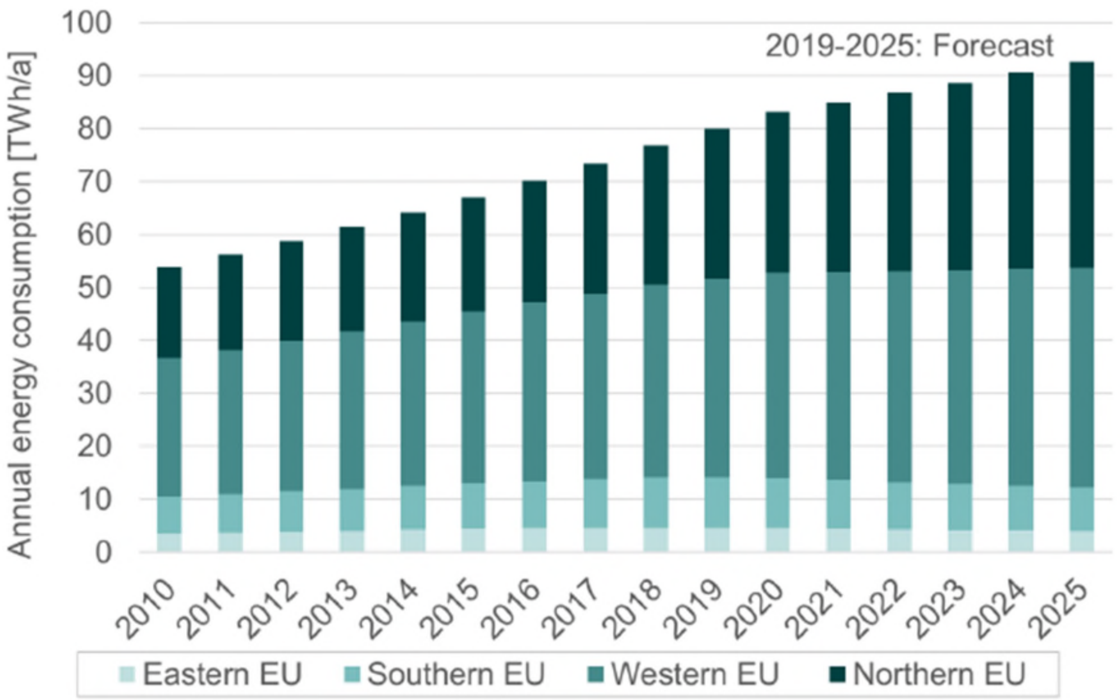
Figure 8 Development of DC energy consumption in the EU28 differentiated by DC type



Source: Montevecchi et al. (2020)

Furthermore, there are large local differences. According to Montevecchi et al. (2020), DC in Northern and Western Europe account for 82% of the energy consumption of DC consumptions of the EU in 2018, with an expected increase (especially in the Northern countries) of this share to about 87% in 2025 (Figure 9).

Figure 9 Development of DC energy consumption in the EU28 by location

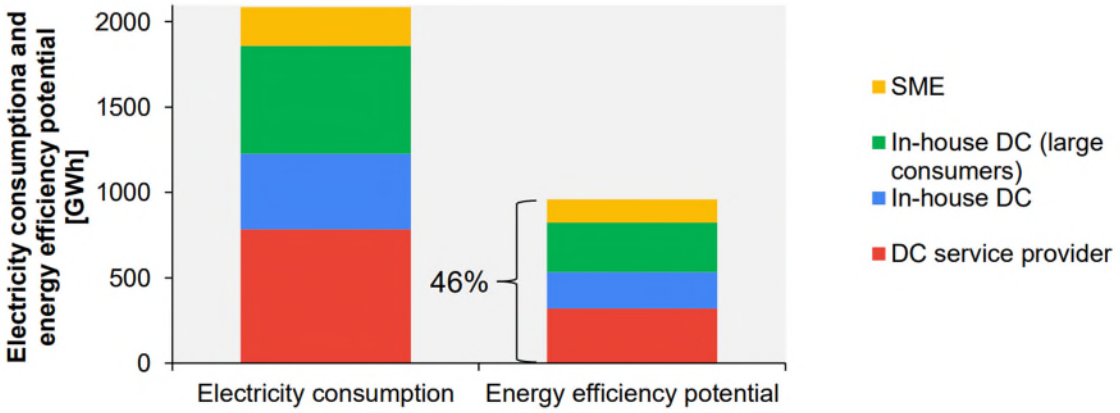


Source: Montevecchi et al. (2020)

Similar developments could be observed in Switzerland (Jakob et al., 2021; Müller et al., 2021). In an empirical study, more than 800 Swiss DC (DC service provider and company internally operated DC (in-house DC), but also server rooms of small and medium sized companies) were surveyed. The study calculated an electricity consumption of about 2.1 TWh in 2019, which corresponds to about 3.6% of the total Swiss electricity consumption. The largest amount is consumed in large data centres of DC service providers, but still a significant amount of electricity consumption is allocated to company internal data centres (cf. Figure 10). The study points towards an energy efficiency potential (considering both data centre and IT infrastructure) of about 46%. The results are also compared to a previous study from Switzerland (Altenburger et al., 2014). The trend between 2013 and 2019 shows that there is a shift from internal data centres to co-location and cloud data centres. Further, significant energy efficiency improvements were observed (for both, IT and DC infrastructure). However, due to a significant demand increase of IT services, the authors expect a net increase of around 8% in electricity consumption during 2013-2019. The study also expects a further increase in electricity consumption from 2020 in Switzerland due to locational advantages (political stability, qualified staff, secure power supply and the central location in Europe) but also increasing IT services demand (e.g., due to IoT, AI, Cloud computing etc.). (Fasan, 2020) analysed planned and future construction and expansion projects in the data centre sector in Switzerland based on a telephone survey. The study assumes a growth of up to 2.5 GWh if all planned projects are realised.

As described above, one of the main findings in Jakob et al. (2021) was also the significantly higher energy efficiency in larger, professionally operated data centres (usually DC service provider). This shows that further potential can be exploited by moving from in-house data centres to co-location and cloud data centres.

Figure 10 Estimated electricity consumption and energy efficiency potential in Swiss data centres



Soruce : Jakob et al. (2021) ; Müller et al. (2021)

These outsourcing effects were examined in a subsequent empirical study by Jakob & Müller (2022). More than 100 companies were asked about energy-relevant variables in their data centre, but specifically about workload distribution (internal, co-location and cloud) and their expected development over the next 5 years. The study showed that only the planned shift of IT workload from internal data centres to co-location and cloud data centres could save around 4.5% of the today's total electricity consumption. This number does not include efficiency improvements in the IT infrastructure and future progress at the component level.

Hintemann & Hinterholzer (2020) expect an increase of the electricity consumption of European DC to about 98 TWh/a by 2030. The study shows that investments in energy-efficient data centre infrastructures in the past led to a reduction in the share of technical building equipment for air conditioning, power supply etc. Similarly, high energy efficiency gains were achieved for the IT infrastructure. According to Hintemann & Hinterholzer (2020) the power consumption per GB of data transferred in data centres was reduced by a factor of almost 12.

Avgerinou et al., (2017) analyse the energy consumption and energy efficiency for 289 data centres participating in the European Code of conduct for Data Centre energy efficiency. The DC were reported in the period 2009-2016, whereas more recent PUE values are significantly lower (average:1.8).

2.7.4 Location impacts on DC energy efficiency

Within Europe, data centres are distributed very unevenly. Various factors such as electricity prices, climate conditions, safe and stable power supply, political stability, connectivity, tax advantages, etc. influence the location choice for new, large cloud and co-location data centres.

Montevecchi et al. (2020) estimated the electricity consumption of DC in Northern and Western Countries in 2018 to about 82% of the total DC electricity consumption in the EU28. Table 9 shows the distribution of data centres participating in the European Code of conduct (Bertoldi et al., 2017), reported DC between 2009 and 2016. Particularly interesting are the average PUE values, which are significantly lower in the Nordic countries, especially compared to the Southern European countries. Thanks to the lower outdoor temperatures in the Nordic countries, significantly more free cooling can be used, hence, the conventional cooling load can be significantly reduced, which in turn has a strong influence on electricity consumption.

Table 9 Temperature Range of facility, Relative humidity (RH), Average PUE and number of DC by geographical area

Geographical zones	Countries	Temp. range (°C)	RH (%)	Avg. PUE	No. of Data Centre
Nordic countries	Denmark, Finland, Norway, Sweden	18-26	20-80	1.71	13
UK and Republic of Ireland	England, Scotland, Wales, Northern Ireland, Republic of Ireland	17-30	8-80	1.83	116
Northern/Central Europe	Austria, Belgium, France, Germany, Hungary, Luxembourg, Netherlands, Portugal, Poland, Switzerland	14-28	16-75	1.72	122
South Europe /Mediterran	Gibraltar, Greece, Italy, Malta, Spain, Turkey Monaco, Romania, Bulgaria	16-26	20-80	2.00	30

Similarly, (Depoorter et al., 2015) analyse the data centres location on the energy consumption. They find that the use of direct air free cooling is proved to be beneficial to reduce the energy consumption of the entire data centre between 5.4% and 7.9%, depending on the location. The article covers Barcelona, Amsterdam, London, Stockholm, Frankfurt. Monthly results show an increase of the total energy consumption during summer due to the reduction of available free cooling hours and the lower efficiency of the chiller. In Mediterranean location like Barcelona this increase could be more than 10%.

PGIM (2021) also point out the large regional differences and show in particular the importance of the 4 locations Frankfurt, London, Amsterdam and Paris (FLAP), cities are strategically located (proximity to large base of end users, excellent fibre accessibility to global networks). The authors estimate the third-party DC capacity in these four markets to about 1950 MW for 2021 which corresponds to about 20% of the global market size. CBRE (2021) attributes more than 2220 MW in the FLAP market in 2022.

However, for the future, Brown et al. (2022) assume that due to natural constraints for the FLAP markets, other European cities emerge as DC hotspots, Berlin with its vibrant tech sector, Warsaw with strong support by the government, Oslo and Zurich due to the availability of renewable energy, Milan with its strong financial sector, Vienna because of its access to Eastern Europa, Marseille due to sub-sea cable connectivity. However, they primarily point to Ireland, where Dublin has grown to one of the biggest DC hubs in Europe (mainly hyperscalers), due to favorable tax conditions and the transatlantic connectivity.

To conclude, various studies have analysed the power consumption of data centres over the last 15 years, both model-based and also empirical. The literature points to increasing power consumption, but also shows that IT services are increasing far more and have long since decoupled from electricity consumption. A wide variety of measures have thus succeeded in increasing energy efficiency in data centres. It could also be shown that the DC density is very heterogeneous, with a strong surplus in Western and Northern European countries. Thus, both, energy efficiency improvements (technical or by outsourcing) as well as location preferences are important factors to consider in the modelling of future electricity consumption by DC.

In terms of IT infrastructure efficiency metrics are rather new and several options have been proposed, e.g., the IT Efficiency factor by (Jakob et al., 2021; Müller et al., 2021), the ITIE by the Swiss Datacentre association (SDEA, 2019).

3. Modelling Implementation

3.1 E-Commerce

The FORECAST simulation framework before the newTRENDs project models eight sub-sectors in the service sector as shown in Table 10 on the left side. The sub-sector “Wholesale and retail trade” bundles all trading activities and is subject to change with rising shares of e-commerce. As the trend of e-commerce affects the wholesale and retail trade very differently, the sub-sector has been divided into two separate sub-sectors in the new rendition of the FORECAST model (shown on the right side of the Table).

Table 10 Structure of sub-sectors of service sector in FORECAST model before and after improvement

Former FORECAST Model		**Improved FORECAST Model**	
ID	**Sub-sector**	**ID**	**Sub-sector**
1	**Wholesale and retail trade**	**1**	**Wholesale trade**
2	Hotels, cafes, restaurants	2	Hotels, cafes, restaurants
3	Traffic and data transmission	3	Traffic and data transmission
4	Finance	4	Finance
5	Health	5	Health
6	Education	6	Education
7	Public offices	7	Public offices
8	Other services	8	Other services
		9	**Retail trade**

Therefore, the updated FORECAST model has implemented e-commerce as part of the newTRENDs project using new sub-sectors and parameters, including:

- the absolute number of employees in the newly introduced sub-sectors *wholesale* and *retail trade,*
- the share of employees of these sub-sectors that are dedicated to e-commerce activities, and
- the specific floor area per employee in these sub-sectors and differentiated by conventional and e-commerce trading.

The following section describes the implementation and the analysis of the input data in detail. Results are provided in Chapter 4.

The primary variables we use to define e-commerce scenarios in FORECAST are the gradient factor and the saturation threshold. The gradient factor determines the rate at which e-commerce is adopted compared to the reference diffusion, while the saturation threshold defines the maximum turnover share that originates from e-commerce. More details on the saturation threshold and its relationship to turnover are given in Section 3.2.3.

The main impact of e-commerce on the energy consumption is the change of floor area and its linked energy consumption. Inside the trading sub-sector, the following types of floor areas are differentiated:

- Shopping and exhibition area: decreasing with the ongoing e-commerce trend.
- Back-office area: decreasing decentral on-site but increasing central and increasing workload in ICT sub-sector (handled in trend “Data Centre”).
- Storage area: increasing with the ongoing e-commerce trend.

While the wholesale sub-sector is dominated by storage and back-office areas, the retail sub-sector is predominately defined by shopping and exhibition areas. The approach to improve the trading model of FORECAST in order to handle e-commerce consists of the following steps:

1. Splitting the trading sub-sector into wholesale and retail trade
2. Specifying the employees per conventional and e-commerce trading
3. Defining values of floor area for the two new sub-sectors and both for conventional and e-commerce trading

3.1.1 Allocation to new sub-sectors

To capture the distinct impacts of e-commerce on energy consumption and employment in the wholesale and retail trade sectors, it is necessary to separate these sub-sectors. We rely on data from Germany[3] to allocate the number of employees in all modelled EU countries (Table 11). In future addendums to this report, country-specific values might be used.

Table 11 Statistical data on employees in trading sub-sectors, example of Germany in 2020

NACE Category		Number of employees in Germany in 2020
WZ08-45	Motor vehicle trade, maintenance and repair	847.331
WZ08-46	Wholesale (without motor vehicle trade)	1.911.389
WZ08-47	Retail (without motor vehicle trade)	3.558.955

Source: Destatis Genesis Table 45341-0001

In the former input data set of FORECAST, the three NACE categories WZ08-45, WZ08-46 and WZ08-47 formed the trading sub-sector. In the new FORECAST

---

[3] Current number of employees in each subsector are not available for all European countries. The latest data available from Eurostat dates back to 2000 (LC_N00NUM1 table).

sub-sectors, WZ08-45 and WZ08-46 are assigned to wholesale and WZ08-47 to retail.

Figure 11 shows the split of employees into the sub-sectors wholesale and retail. In a first step, its ratio is assumed to be constant over the course of the years for all scenarios. However, when the trend of e-commerce is modelled, the different efficiencies in the sections e-commerce and conventional trading will cause a different need for employees in these two sub-sectors. The influence of efficiency is described later in 4.1.1.

Figure 11 Number of employees assigned to the new sub-sectors wholesale and retail trading at the example of Germany

3.1.2 Derivation of the floor area

The specific floor area is defined as the average floor area per employee and in the case of the trading sub-sectors, this being either shopping and exhibition, back office or storage. The previous version of the FORECAST model had one average value per year for the trading sub-sector (i.e. wholesale and retail trade). However, in the updated model, we have split the trading sub-sector into wholesale and retail trading and differentiated between conventional and e-commerce trading. As a result, we now use four time series to define the specific floor area (Table 12).

Table 12 Assumptions about the specific floor area in improved FORECAST model

	Wholesale	**Retail**
Conventional	Specific floor area dominated by storage and back office; values smaller than in previous trading sub-sector.	Specific floor area dominated by shopping and exhibition; values bigger than in previous trading sub-sector.
E-Commerce	Specific floor area similar to conventional wholesale trading.	In comparison to conventional retail trade, less specific floor area due to obsolete shopping areas.

In the proof-of-concept phase, (for this deliverable) we assume that the specific floor areas in wholesale trading sector for both, the conventional and e-commerce activities, are 20% smaller than in the previous trading sub-sector. The floor area in the e-commerce section of retail trading is aligned to typical office-dominated sub-sectors (sub-sector “Finance”). The specific floor area of the conventional retail trading is consistent with the dataset of the previous model.

3.1.3 Turnover of e-commerce in retail and wholesale

In order to model the trend of e-commerce, the modelled employees are differentiated by their trading activities into the groups of conventional or e-commerce trading[4].

Statistical basis

Eurostat (table ISOC_EC_EVALN2) provides information about the e-commerce share of the turnover on sub-sector level. However, the data set doesn’t seem to be very consistent, as it can be seen in the following samples:

- The share of the e-commerce turnover in the wholesale sub-sector of three big European countries and of the EU27 average is presented in Figure 12 (left side). The data sample shows that in the case of Germany, the data is fluctuating significantly from one year to the next. In the case of Italy, no data is available for the wholesale sub-sector.
- The same data sample for retail trading (Figure 13, left side) contains values for Italy, but only from 2015 onwards. The German data set shows gaps in the years 2011 and 2017. For France, there is no data available for 2022 yet.

In order to use the statistical data as a basis for the development of e-commerce until 2050, the following data cleaning procedure is applied:

1. Interpolating gaps in past years linearly;
2. Applying moving average (window size of 2 years);

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[4] As FORECAST is not modelling on the level of individual employees, it is not an issue if an individual person cannot be assigned clearly to one of these two groups.

3. Using EU data as backup if no country data is available.

Figure 12 and Figure 13 each show the data set of wholesale and respectively retail after the data cleaning process on the right side.

Figure 12 Data on the share of turnover in wholesale trade relative to the entire economic activity. Left: statistical raw data, Right: cleaned data

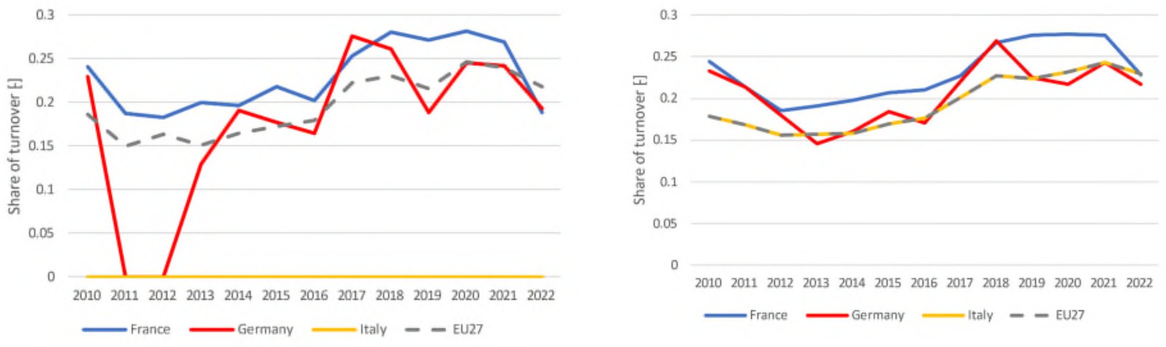
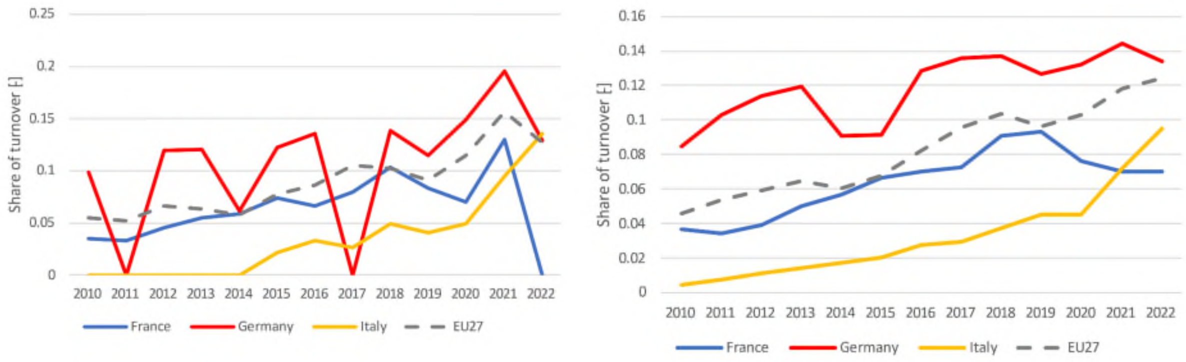


Figure 13 Data of the share of turnover in retail trade relative to the entire economic activity. Left: statistical raw data, Right: cleaned data



Trajectory of share of e-commerce turnover

As the FORECAST model usually works with a time horizon until 2050, input data of the development of e-commerce during the whole period is needed. The share of turnover that is allocated to e-commerce activity in the trading sub-sectors is used as a central indicator. Its trajectory is based on scenario assumptions.

Starting from the last statistical year, a constant increase is assumed in a first phase. A second phase may occur if the share of turnover reaches a certain level of saturation. In this case, the yearly increase slows down steadily. To model this, we define the saturation phase as a parameter, the *saturation threshold*.

Figure 14 shows the trajectory of the share of turnover that is allocated to e-commerce with Denmark as an example. The example of Denmark is chosen, as this country has a high share of e-commerce turnover and reaches the saturation in the second phase of the simulation period. The saturation threshold in this example is set to 0.7 for both sub-sectors, wholesale and retail. The data up to 2022 is the cleaned statistical data. From 2023 onwards, the importance of e-commerce increases at a constant gradient. Starting in the mid-2030s, the yearly increase goes down and keeps the value of 2050 below the threshold of 0.7.

Figure 14 Share of turnover that is allocated to e-commerce in the trading sub-sectors in Denmark

3.1.4 Number of employees and efficiency

Statistical data from Eurostat[5] provides the total number of employees in the trading sub-sector but does not differentiate between conventional and e-commerce trading. As the model requires this differentiation as a key factor for determining floor area demand and energy consumption, we use the e-commerce turnover rate as a proxy value. We also assume that e-commerce trading is less labour-intensive. To generate the same turnover, fewer employees are needed in e-commerce compared to conventional trading. In FORECAST, we represent this assumption by the factor “efficiency of the e-commerce employees”. In the scope of this focus study, we assume that the efficiency in e-commerce is higher than in conventional trading, namely by a factor of 1.5. for wholesale trading and 2.5. for retail trading.

Figure 15 shows how the share of turnover allocated to e-commerce defines the share of employees in the e-commerce section. Due to the higher efficiency of

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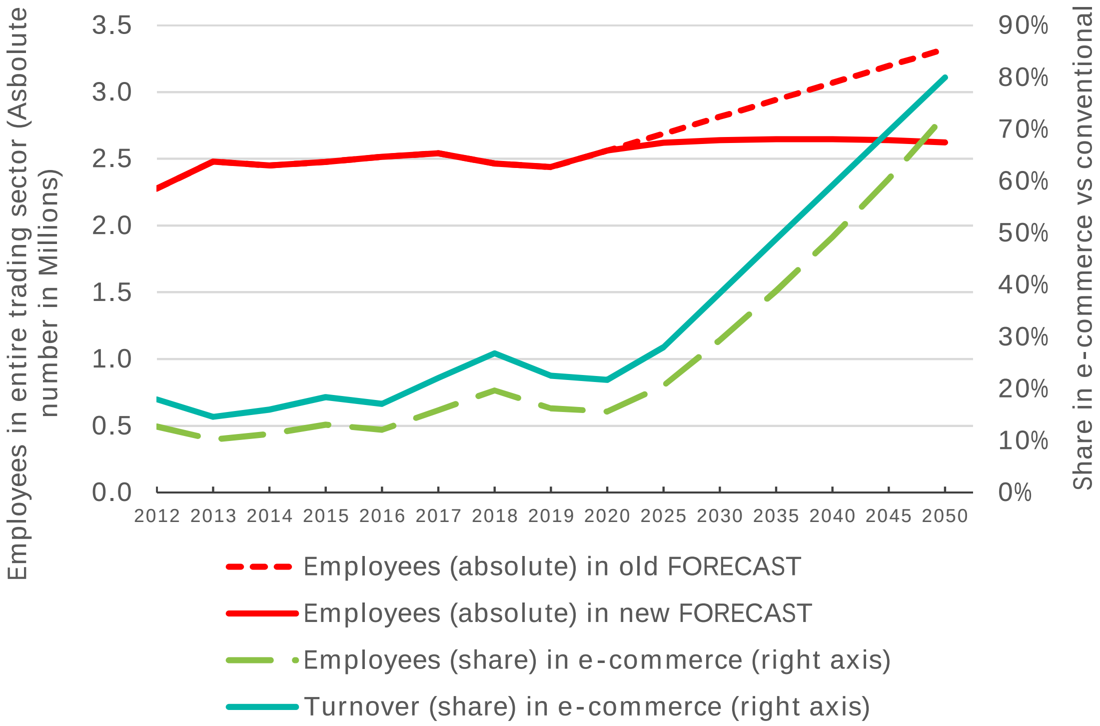
[5] Eurostat LC_N00NUM1, Destatis Genesis Table 45341-0001

e-commerce trading, the absolute number of employees in the trading sub-sector decrease compared to the former model that was not explicitly considering e-commerce.[6]

Figure 15 Relationship between turnover share and the share of employee in e-commerce compared to the absolute number of employees in trading (e-commerce and conventional)



Source: This example is based on our scenario EC3 (see Section 4) for Germany.

3.2 Smart Buildings

Improving the modelling of smart building concepts in the FORECAST simulation framework does not require a change in the model source code but can be done by adjusting the input data. FORECAST allows to add additional energy saving options (ESOs) without programmatic changes. This section describes how these ESOs can be adapted to model the different levels of smart building concepts.

3.2.1 Savings and relevance

The proposed quantification and modelling of smart building measures in FORECAST (Fraunhofer ISI et al., 2011, Jakob et al., 2012) is based on its electricity demand model and on estimations from the European building

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[6] Variables such as turnover are not considered in the same manner in the previous FORECAST model. Hence, a direct comparison is challenging.

automation norm (EN 15232). The norm is described further below, and the electricity demand model, according to Jakob et al. (2012) is described by the following formula:

$$E = \sum [Q \cdot ESD \cdot SED \cdot (1 - DR \cdot ESO)\,]$$

With E as electricity demand, Q as quantity structure (e.g., floor area), ESD as energy service driver, SED as specific energy demand, DR as diffusion rate and ESO as energy-saving option. For instance, in lighting, Q is the floor area [m^2], ESD the share of lighted area per floor area [%/m^2], SED the energy consumption per year [J/y], DR the percentage diffusion, and ESO the percentage saving of a saving option such as LED lighting as compared to a reference technology. This results in the electricity demand [J].

The central features of the demand model, relevant in this works' context, are the energy saving options (ESO) and energy services. Energy services represent services that require energy to perform specific functions. They relate to an energy service driver (ESD) such as the floor area of buildings. ESOs reduce the specific energy demand of energy services in the model's base scenario. The extent to which an ESO is taken up and applied to a specific energy service depends on its diffusion model, specific costs, and other model drivers.

Of the 12 energy services in FORECAST, we here analyse a selection of five (see Table 13). We selected these energy services because some of the related ESOs have all an effect on the full load hours by using BACS, whereas ESOs in the heating or office ICT energy services mainly save energy by reducing the installed power[7].

Table 13 Relevant energy services, energy drivers and description

Energy service	**Description**	**Energy service driver (ESD)**
Lighting	Lighting of different types of room	Floor area of buildings
Ventilation	Ventilation of rooms and buildings	Share of ventilated area
Cooling in Server rooms	Cooling in server rooms	Floor area of buildings
Room Air Conditioning	Cooling of rooms and buildings	Share of ventilated area
Circulation pumps and other heating auxiliaries	Energy-using technologies, which transform the energy needed for distribution of fluids and aux units such as pumps and blowers.	Floor area of buildings

Source: Adapted from Jakob et al. (2012)

Regarding the diffusion, we apply the autonomous and maximum diffusion rates. The autonomous diffusion can be expected if current policies are implemented and slightly tightened in the future, reflecting "what is perceived

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[7] Installed power is not strongly affected by BACS

to be technically and economically viable by […] users" (Fraunhofer ISI et al., 2011). In contrast, the maximum diffusion rate represents an upper limit of the technical and economic feasibility of a measure.

Overall, the base model includes two different groups of ESOs, the *minimum energy performance standards* (MEPS) and the *advanced energy performance standards* (AEPS). MEPS "are regulatory measures that stipulate minimum efficiency levels [… while …] AEPS are more ambitious but technically feasible" (Fraunhofer ISI et al., 2011). The original specification of MEPS and AEPS were based on existing norms such as SIA 380/4.In contrast, we here base potential energy savings on the building automation norm EN 15232.

The amount of potential energy savings from BACS (Building automation and control systems) is adopted from *BACS-factors* listed in EN 15232. Because this factor-based method is simplified, it does not fully account for the occupant's behaviour in very specific contexts (Van Thillo et al., 2022). However, the factors still provide an adequate ballpark figure of the expected energy savings from BACS because the figures are based on comprehensive building simulations. See Table 14 for an overview of all classes.

Table 14 Overview of BACS energy classes, incl. description

Level	Energy class and description
A	Level A corresponds to highly energy-efficient BACS and technical building management systems including - interconnected room automation with automatic demand detection - regular maintenance - energy monitoring - sustainable energy optimisation.
B	Level B complies with advanced BACS and technical building management systems including: - interconnected rooms without automatic demand detection - energy monitoring.
C	Level C corresponds to standard BACS-systems with - interconnected building automation of the primary systems - no electronic room automation, - thermostatic valves on heating radiators - no energy monitoring
D	Level D corresponds to BACS systems that are not energy efficient. Buildings with such systems are to be modernised. New buildings must not be built with such systems - no interconnected building automation functions - no electronic room automation - no energy monitoring

Source: Jakob et al., (2016)

BACS-factors represent four efficiency levels: from energy inefficient systems (level D) to highly automated system (level A). At level A, most or all of the measures from A to D are installed and correctly, meaning that corresponding systems tap into the full BACS-potential.

According to the *Energy Performance of Buildings Directive* (EPBD), a high level should be reached by 2025 in most of the larger non-residential buildings in the EU (with “heating or combined heating and ventilation systems with an effective rated output of over 290 kW”). Waide (2019) states that these are about 37% of non-residential buildings and that the minimum response to the EPBD provision is a shift towards class B. Moreover, it is likely that the provision will be lowered to smaller buildings starting from 2030 (i.e., >70kW rated output).

3.2.2 Assumptions

To integrate BACS-factors into the FORECAST model, several assumptions are made. First, we assume that BACS measures only lead to energy savings through a reduction of full load hours (FLHs) in each of the energy services (see Section 3.2.1). Thus, we keep the installed power constant, in other words a 10% saving of final energy from C to B is assumed to be a 10% reduction of FLHs. In the current implementation, indirect effects on installed power are ignored. Which in some cases is a simplification as also the installed power might be reduced if properly designed.

Table 15 Analysed energy saving options (ESO) in FORECAST and the corresponding EN 15232 levels. Shown are ESOs with effects on full load hours

Energy saving option	Energy service	Description	Mapped BACS-level
Advanced EPS for Lighting	Lighting	Increased use of daylighting technologies and occupancy controls	C to B
Advanced EPS for Ventilation	Ventilation	Variable speed drive, air quality related controls.	C to B
Advanced EPS for cooling servers	Cooling in Server rooms	Improvement in cooling systems	C to B
Advanced EPS for air-conditioning	Room Air Conditioning	Variable speed drive, air quality related controls.	C to B
MEPS for Ventilation	Ventilation	Efficient electric motors	D to C
MEPS for Circulation pumps and other heating auxiliaries	Circulation pumps and other heating auxiliaries	Variable speed drives	D to C
MEPS for cooling servers	Cooling in Server rooms	Improvement in cooling systems	D to C
MEPS for air-conditioning	Room Air Conditioning	Appropriate operation	D to C

Source: Descriptions of the ESOs are based on the model description (Fraunhofer ISI et al. (2011); Wietschel et al. (2011), Jakob et al., 2012)

Second, the frozen efficiency scenarios in FORECAST, corresponding to assumptions from the mid-2000s, are relatively inefficient baselines. Therefore, we use it as BACS level D. Furthermore, we assume that a change in BACS efficiency level can be mapped by an ESO (Table 15). Existing ESOs with effects on FLHs already contain some BACS functions and have already considered some energy savings from BACS (Table 16). Thus, our approach is to tap into the full potential of BACS using a new ESO.

To map building types from EN 15232 to corresponding sub-sectors in FORECAST (e.g., offices in finance and public offices), we make the necessary assumption that a single building type predominates in each sub-sector. While this assumption is simplifying the modeling of BACS, it is important to note that in reality, there are variations in building types within a sub-sector. Furthermore, to map the hotel and restaurant building types, as well as the school and auditorium types to the sub-sectors education and hotels, café and restaurants, we calculate arithmetic averages of the factors. Finally, we do not explicitly differentiate between building sizes but use an average estimation over the building stock.

3.2.3 Building automation and control systems (BACS) representation in previous FORECAST results

The two existing types of ESOs in the previous version of FORECAST approximately cover a change from level D to B[8], in other words, a progression from inefficient to more advanced BACS systems. These are the *minimum efficiency performance standard* (MEPS) and the *advanced efficiency performance standard* (AEPS) options of several energy services. Full load hour (FLH) and installed power saving assumptions for these ESOs are based on literature (Jakob et al., 2006; Ott et al., 2009; Wietschel et al., 2011, Jakob et al. 2016), interviews, norms and standards about thermal energy (SIA 380/1).

We compare BACS coverage in previous FORECAST models in Table 16. If the average savings in Table 16 are below 100%, MEPS and AEPS options save fewer full load hours (FLHs) than a highly efficient BACS system in most sectors (i.e. A-level BACS, which is 100%). For instance, MEPS and AEPS in the finance sector cover only 43% of the potential full load hour savings achievable by A-level BACS. Therefore, additional potential remains, which we implement by and additional energy saving option (see next Section).

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[8] In some subsectors and applications even the full BACS-potential, see Table 16. For these sectors, no additional A-level BACS are assumed.

Table 16 Average savings over all countries form existing MEPS and AEPS in FORECAST. 100% denotes the savings achievable by A-level BACS.

Sub-sector	Circulation pumps / heating aux.	Cooling in Server-rooms	Lighting	Room Air Conditioning	Ventilation	Average BACS coverage
Education	63%	53%	49%	53%	86%	61%
Finance	53%	31%	43%	31%	53%	43%
Health	157%	NA	150%	NA	143%	150%
Hotels, cafes, restaurants	87%	56%	75%	56%	138%	82%
Public offices	53%	39%	58%	39%	66%	51%
Wholesale and retail trade	103%	35%	220%	35%	117%	102%

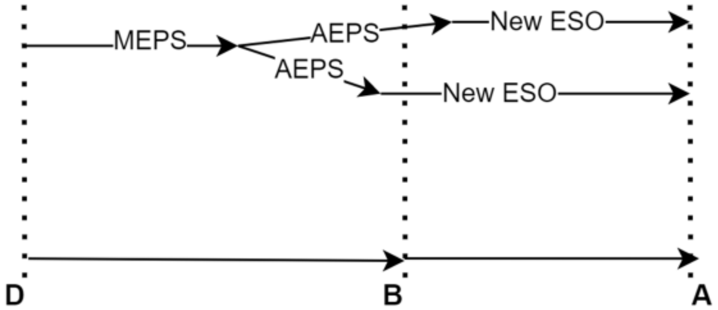
Source: Based on a comparison of full load hour savings from A-level BACS and MEPS/AEPS of the 4th version of FORECAST

3.2.4 Reaching full BACS potential

To tap into the full smart building potential using the FORECAST model, we introduce an additional ESOs for reaching the most efficient level A, labelled “A-Level BACS”. Conceptually, the ESO bridges the “gap” between the already covered FLH savings of the ESOs and the full potential according to the norm (Figure 16).

Reasonable cost and diffusion assumptions for the new ESOs in FORECAST are crucial. We, therefore, base the new costs and diffusion curves on the well-tested data of the MEPS and AEPS. For the final change to level A, we assume that this is a more expensive change with lower diffusion rates than the MEPS and AEPS options (resulting diffusion rates are illustrated as a proof-of-concept in Section 4.2.1).

Figure 16 Covering the full saving potential in FORECAST. MEPS and AEPS cover some but not all of the full load hours that BACS saves. To reach the full potential, a new ESO is introduced



Investment costs are roughly based on current market prices for the installation of BACS, which we gathered from online sources from the service sector (Rüesch, 2014; GRYPS, 2023). These indicate that investment costs per square meter floor area are very heterogeneous but, on average, range from under 100 € to over 200 € per m^2 floor area. These aggregated costs include several interconnected BACS measures of various energy services like heating, lighting, and cooling. Because MEPS and AEPS already cover a certain share of BACS savings (see above), the costs of these existing ESOs must be considered in the investment cost assumption of the new ESOs.

We assume that the investment costs of the new ESOs are about 30% higher than the summed costs of MEPS and AEPS in each sector Table 17. Applying this ballpark figure, costs reach 200-300 € per m^2, representing a more expensive but full-fledged BACS-system. The same approach is taken for the operation & maintenance costs, which are assumed to be 10% higher than the existing costs.

Table 17 Aggregated investment costs of existing and new ESOs in € per driver (€/m^2)

Sum over all energy services and average of all countries for the example year 2020

Sub-sector	**Costs per ESO €**			**Total cost €**
	MEPS	AEPS	New ESO	All ESOs
Education	59	101	48	208
Finance	93	118	63	275
Health	69	101	51	221
Hotels, cafes, restaurants	69	109	54	232
Other services	60	127	56	243
Public offices	55	101	47	202
Wholesale and retail trade	78	109	56	244

Table 18 Aggregated OM costs of existing and new ESOs in € per driver and year, here always €/(y m²)

Sum over all energy services and average of all countries for the example year 2020

Sub-sector	**Costs per ESO €**			**Total cost €**
	MEPS	AEPS	New ESO	All ESOs
Education	0.9	0.6	0.2	1.7
Finance	1.4	0.9	0.2	2.5
Health	1.0	0.6	0.2	1.9
Hotels, cafes, restaurants	1.0	0.8	0.2	2.0
Other services	0.9	1.0	0.2	2.1
Public offices	0.8	0.6	0.1	1.6
Wholesale and retail trade	1.2	0.6	0.2	1.9

To further improve the modelling of smart buildings, future implementations should differentiate the diffusion rates of BACS according to regional differences and sample costs from manufacturers. Furthermore, to represent the EU directive for having BACS (meaning at least level B) in non-residential building with more than 290kW installed power, the modelling should be able to distinguish between larger and smaller buildings.

3.3 Data Centres

3.3.1 Implementation

To start with, the modelling of data centres can be done without changes to the source code of the tertiary module of the FORECAST simulation framework. The less tangible terms of ICT workload or ICT demand needs to be expressed as a power parameter of the installed ICT infrastructure. In the model, the power of the ICT infrastructure works as an energy service driver. It is an input to the model and needs to be forecasted over the simulation time horizon. In practice, this is not an easy task due to missing information about the volatile development of the future ICT power demand.

Energy saving measures of data centres can take place in two ways: either in the periphery of the data centre (the building technology infrastructure), especially in the fields of cooling, heat recovery and the provision of backup power. In the model, these options are modelled as energy saving option (ESO) that can be parameterised with efficiency gains and costs. The internal decision model selects the most economic options based on the current energy prices and the achievable savings.

Other saving measures take place internally, in the way the hardware is installed and used, and the software designed. The keywords of these measures are virtualisation and green code. These measures are hard to capture in the model and are considered in the trajectory of the future ICT infrastructure IEA. (2022).

In summary, the model already implements the following components that are suitable to model data centres:

- Energy Service Driver: ICT infrastructure, expressed as server units or more general as compute instances
- Installation: Electric power per server unit, respectively per compute instance
- Utilisation Rate: Full load hours per server unit, respectively per compute instance

Regarding the modelling of the efficiency development, the following distinct options, which are all independent of each other but relate to energy consumption in data centres, are already implemented as separate ESOs:

- Saving options of building technology in data centres
- Saving options regarding the bundling effects of servers
- Minimum energy performance standards (MEPS) for cooling servers
- Advanced energy performance standards (AEPS) for cooling servers
- A-BACS (advanced building automation and control system) for cooling in server rooms

In conclusion, while the increased ICT demand could be represented by a model enhancement and source code changes, we choose to rely on various existing model components and to introduce a suitable parameterisation.

4. Proof of concept

In this chapter, we test the implementation of digitalisation described in section 3. For this, the focus lies on selected countries (Germany and Italy) and a set of scenario definitions (Table 19). These proof-of-concept results illustrate that the developed implementation of digitalisation in FORECAST leads to measurable and considerable effects, thereby, improving the former model implementation.

Table 19 Scenario overview

Scenario	Application	Description
EC1	E-Commerce	Low diffusion and maximal turnover
EC2	E-Commerce	Medium diffusion and maximal turnover
EC3	E-Commerce	High diffusion and maximal turnover
Ref	Smart buildings	Standard BACS measures.
BA1	Smart buildings	Medium diffusion of A-Level BACS (new ESOs)
BA2	Smart buildings	High diffusion of A-Level BACS (new ESOs)
DC0	Data Centres	Low development of ICT demand
DC1	Data Centres	Medium development of ICT demand
DC2	Data Centres	High development of ICT demand

4.1 E-Commerce

4.1.1 Share of employees

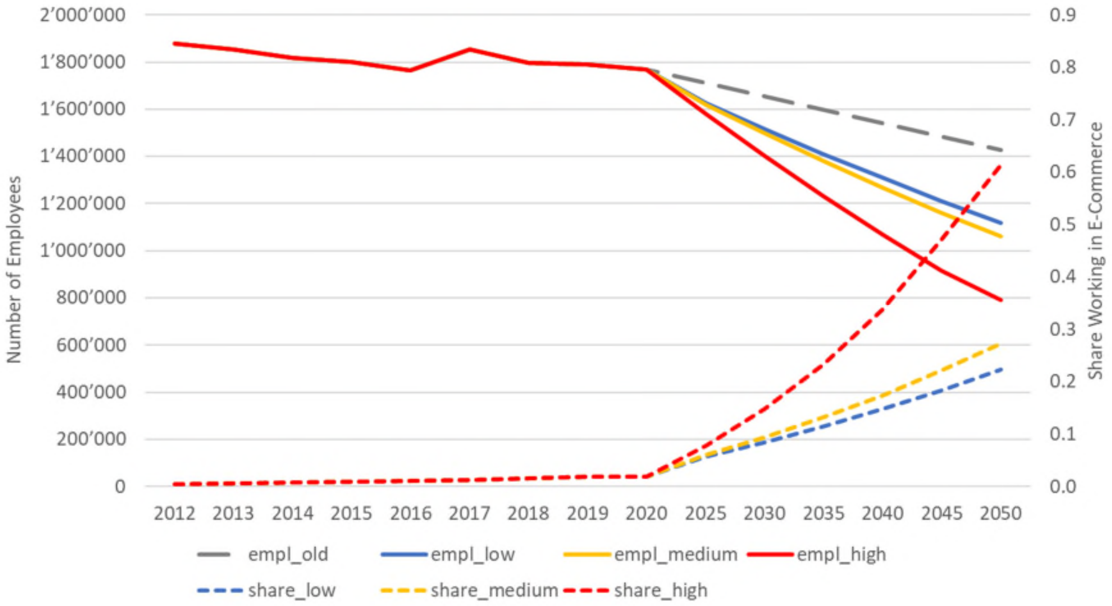
In this section, we apply the parameters introduced in Section 3.1 and Figure 15.

The following charts show the absolute number of employees in the sub-sectors wholesale and retail trading for the three scenarios defined in Table 19. These numbers comprise all employees of the sub-sector, both in the conventional and e-commerce section. The share of employees dedicated to the e-commerce trading is shown in the same charts.

Comparing the situation in the wholesale (Figure 17) and the retail sector (Figure 18), a parallel development of the absolute number of employees in the former model is observed, as these numbers are generated by a split of the former trading sub-sector with constant proportion.

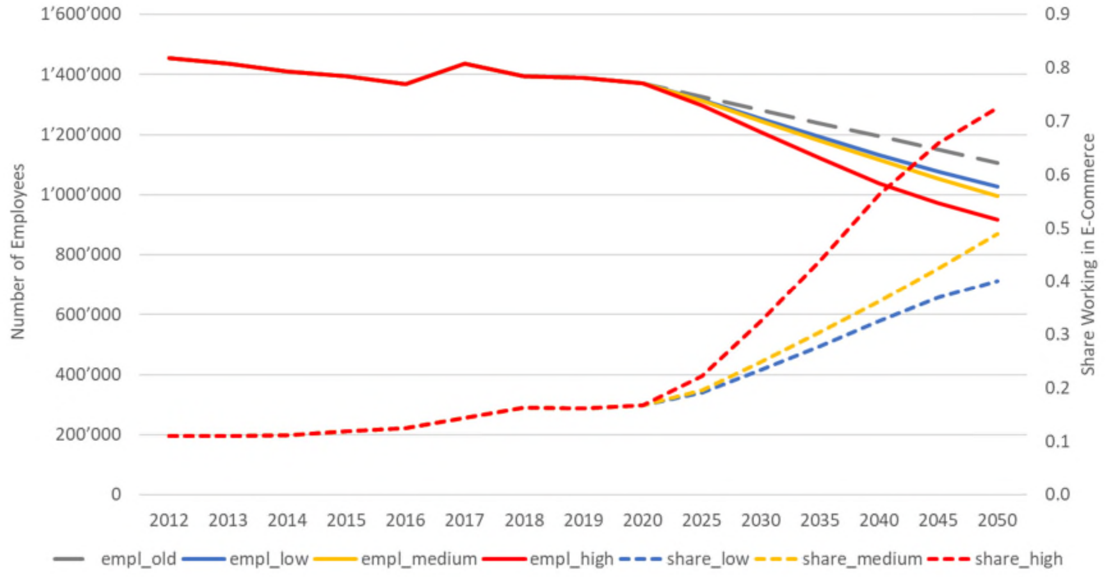
The differences of these two sub-sectors come from the different basis of e-commerce, that are more common in wholesale trading than in retail trading. The influence of the different scenarios can be seen through the share of employees working in the e-commerce section. Due to the higher value added in terms of turnover per employee, the number of employees is reducing as a function of the share of employees in that scenario.

Figure 17 Employment situation in the sub-sector wholesale trading for the different scenarios, for the example of Italy



Note: Scenario description see Table 19

Figure 18 Employment situation in sub-sector retail trading for the different scenarios, based on the example of Italy



Note: Scenario description see Table 19

These results show the effect of e-commerce trading on the number of employees in the various wholesale and retail trade sections. The scenario definition is based on assumptions about the trajectory of the turnover in e-commerce, the share of employees dedicated to e-commerce and the linked specific floor area. The presented outcome of the new e-commerce module seems to produce appropriate input to the FORECAST simulation framework and allows, in combination with the former model, to investigate the final energy demand in the tertiary sector for different levels of e-commerce development.

4.1.2 Final energy

To explore the impact of e-commerce on the final energy demand, we evaluated three different scenarios based on parameters for diffusion, namely gradient factors, and maximum turnover rates and saturation thresholds (see Table 20 and Section 3.1). The “efficiency of the e-commerce employees” describes how much more turnover is produced by an e-commerce employee compared to his colleague in conventional trading. This factor is higher in retail trading, as the conventional retail subsector is more labour intensive and moving to e-commerce has a higher impact than in the wholesale subsector.

Overall, the simulation results show that the aggregated net effect of e-commerce is small across all scenarios (see Figure 19). However, starting in 2035, we observe significant effects in scenario EC3, with a notable increase in energy demand.

However, on the level of distinct sub-sectors, the effects are more pronounced. Opposite trends in the retail trade and wholesale trade sectors partly compensate each other (Figure 20 and Figure 21). For instance, in scenario EC3, e-commerce leads to a considerable reduction in energy demand in the retail sector, while increasing activity in the wholesale sector largely offsets these energy savings.

Table 20 E-Commerce scenario definition. Efficiencies denotes the efficiency change between conventional trade and e-commerce.

Scenario	Gradient factor	Saturation threshold	Efficiency wholesale	Efficiency retail
EC1	1.0	0.5	1.5	2.5
EC2	1.2	0.7	1.5	2.5
EC3	1.5	0.8	1.5	2.5

Source: assumptions by TEP Energy

Figure 19 Final energy demand in both the wholesale and the retail trade sectors in Germany, all energy applications.

Figure 20 Final energy demand in the retail trade sector in Germany, all energy applications

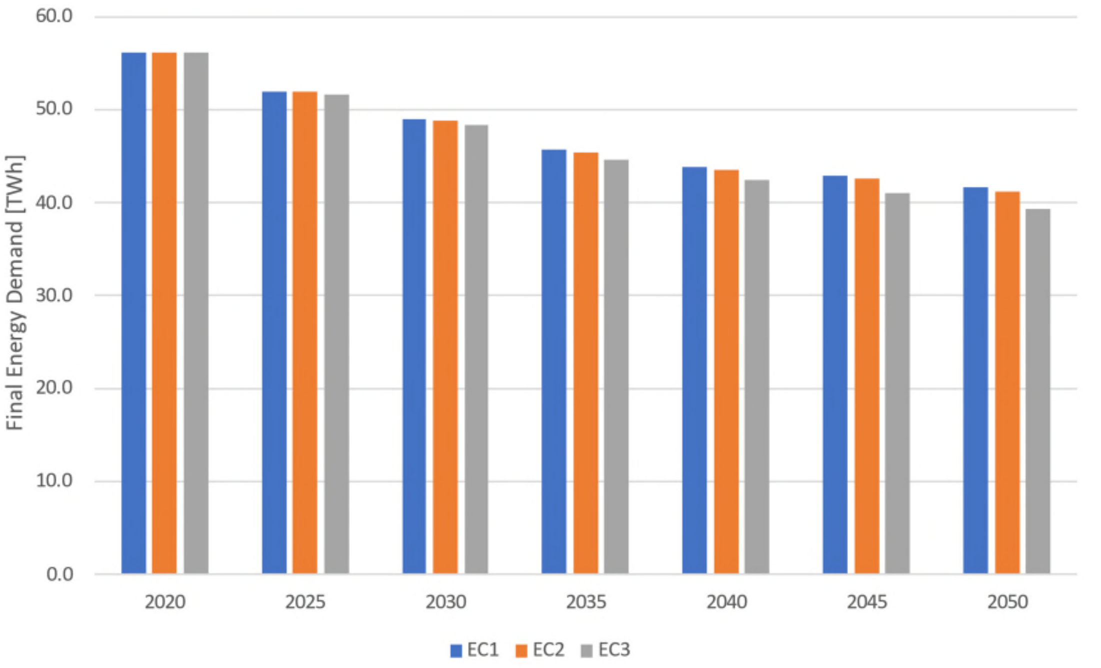
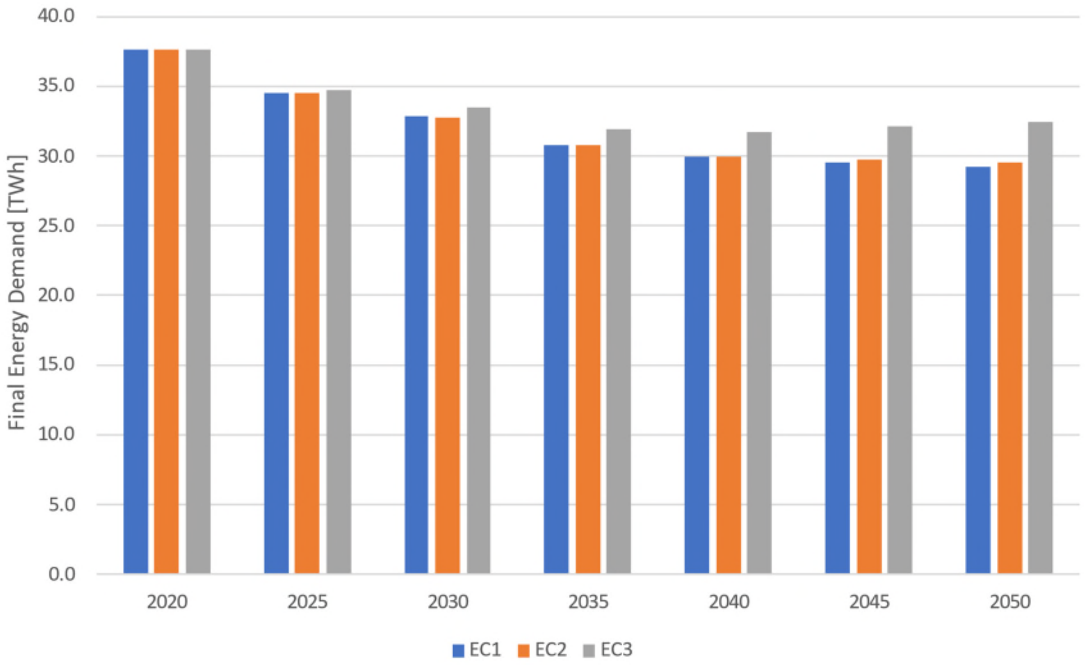


Figure 21 Final energy demand in the wholesale sector in Germany, all energy applications



4.2 Smart Buildings

4.2.1 Diffusion rates

The new ESO is deployed at a slower pace than the MEPS and AEPS of the same energy services. To demonstrate the concept, we implement two scenarios with varying diffusion rates of A-level BACS: moderate and high. In both diffusion scenarios, we assume that the new ESO is diffused at a fraction of the AEPS diffusion rates[9]. These fractions are shown in Table 21 for the Auto and Max diffusion types[10]. These assumptions result in the final diffusion curves depicted in Figure 22.

Table 21 Diffusion assumptions for new ESO. Percentages denote the fraction the ESO is diffused relative to AEPS/MEPS

Diffusion scenario	Diffusion NewESO – Auto	Diffusion NewESO – Max
Moderate	10%	30%
High	70%	90%

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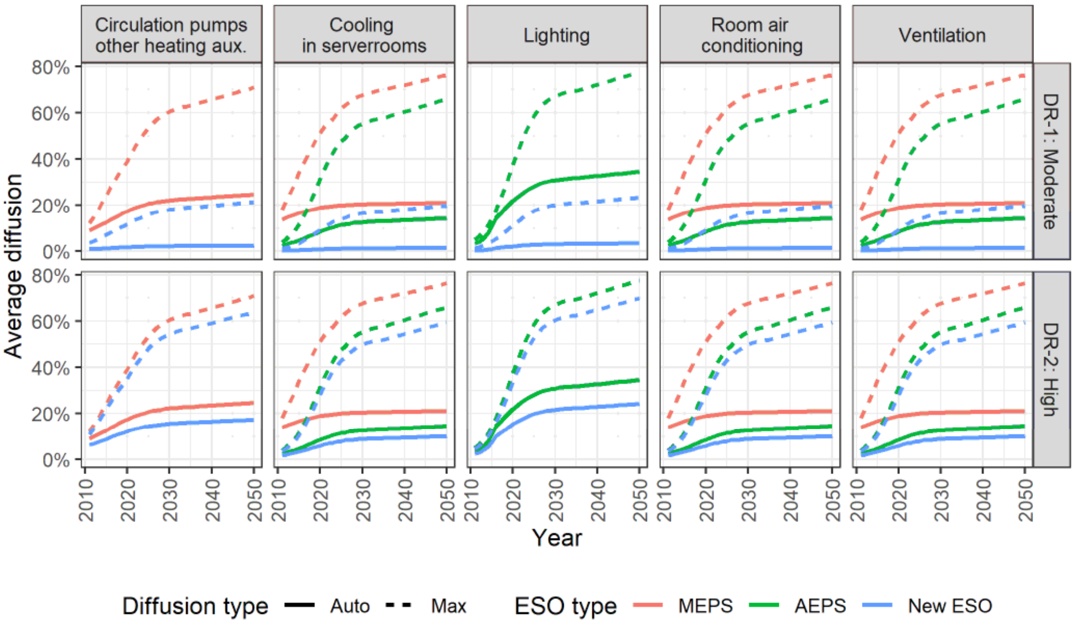
[9] Or MEPS if AEPS is unavailable.

[10] Auto and Max are not scenario but used in the decision algorithm of FORECAST.

Figure 22 Resulting diffusion curves of the BACS implementation

Solid line denotes an autonomous diffusion (Auto), and dotted line a maximum diffusion (Max) rate. Colours denote different ESO types.



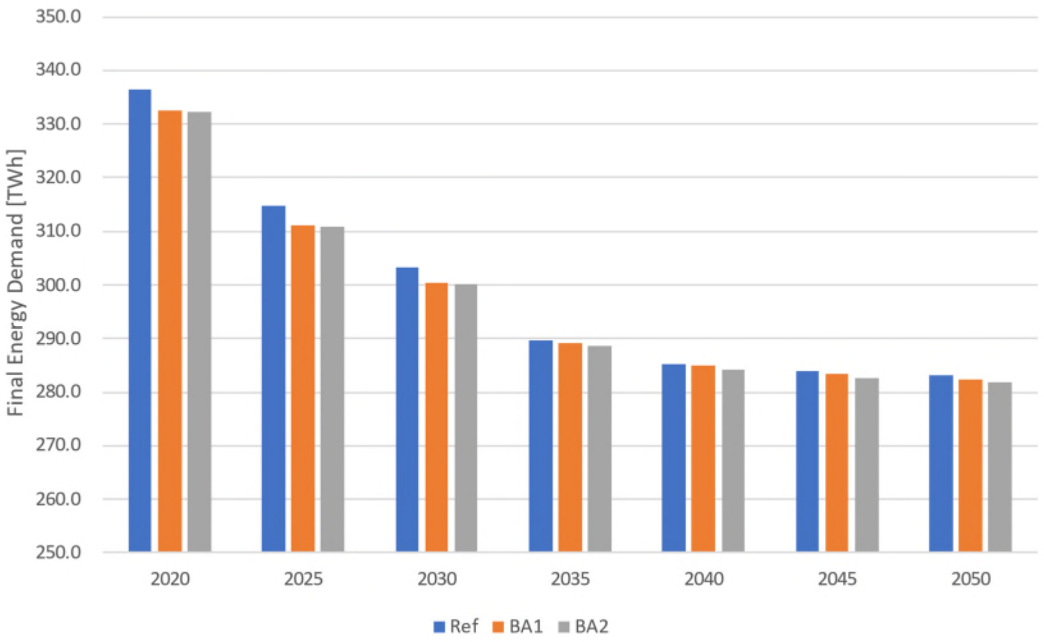
With the addition of new ESOs, we argue that the existing structure of the FORECAST simulation framework can be used to model building automation and control systems. With this extension of the underlying data set it is now possible to run different scenarios to represent the development and diffusion of smart building measures in the building stock.

4.2.2 Final energy demand

The impact of BACS is evaluated for three different scenarios (as defined Table 19). It is most significant when the final energy demand is high, particularly in the years leading up to 2030, compared to the reference scenario (Figure 23). The energy services (air conditioning, ventilation and lighting) contribute differently to this effect (Figure 24 –

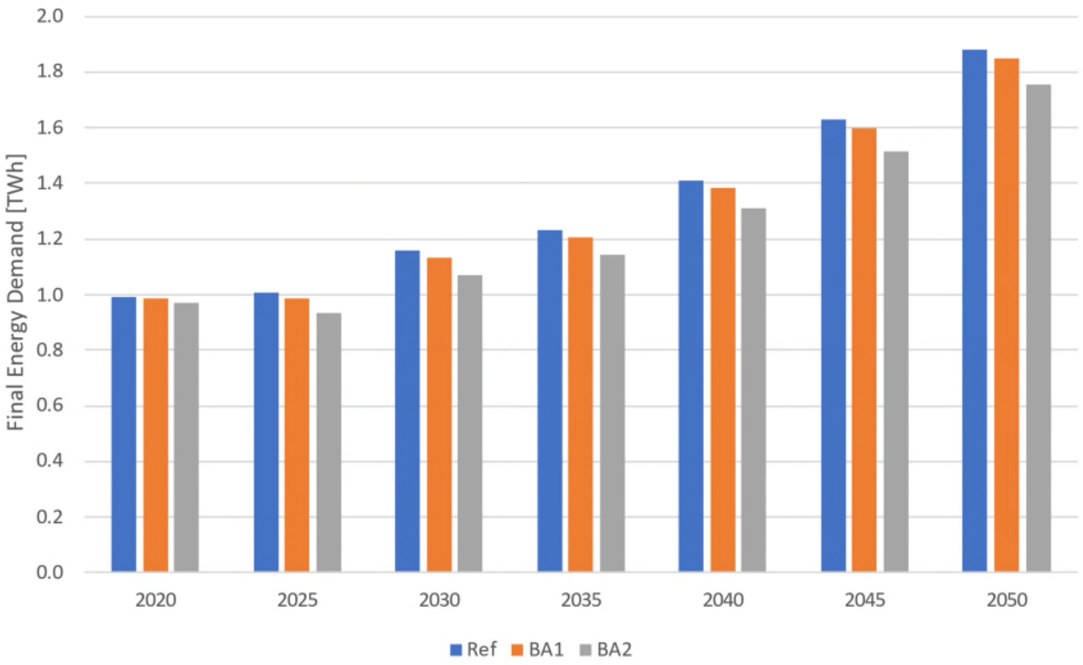
Figure 26). Considering all subsectors, the overall amounts of final energy (electricity) are highest in the lighting subsectors, followed by ventilation & building services applications. However, the effects of BASC are in the same order of magnitude, i.e., between 0.1 and 1 TWh saving, particularly in towards the years 2050. The effect of lighting differs between subsectors. Here we show the Finance sector in which the effects are most pronounced.

Figure 23 Total final energy demand in Germany, all sub-sectors, only effects in electricity, and all energy applications (including applications without new ESOs) of the tertiary sector



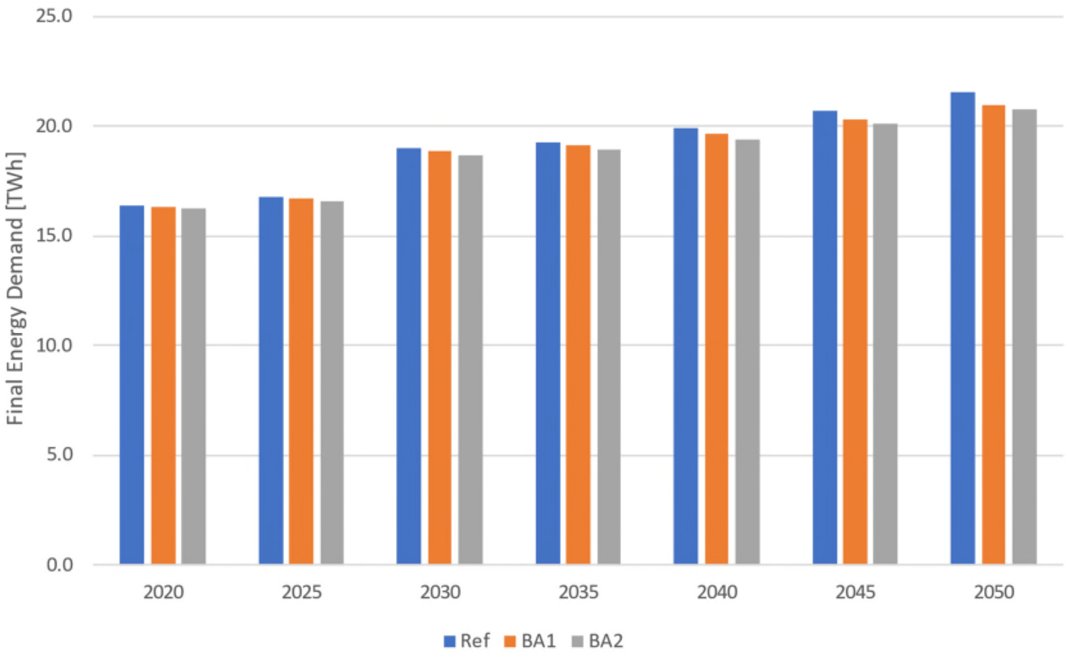
Note: Scenario description see Table 19

Figure 24 Final energy demand in Germany, all sub-sectors, air conditioning



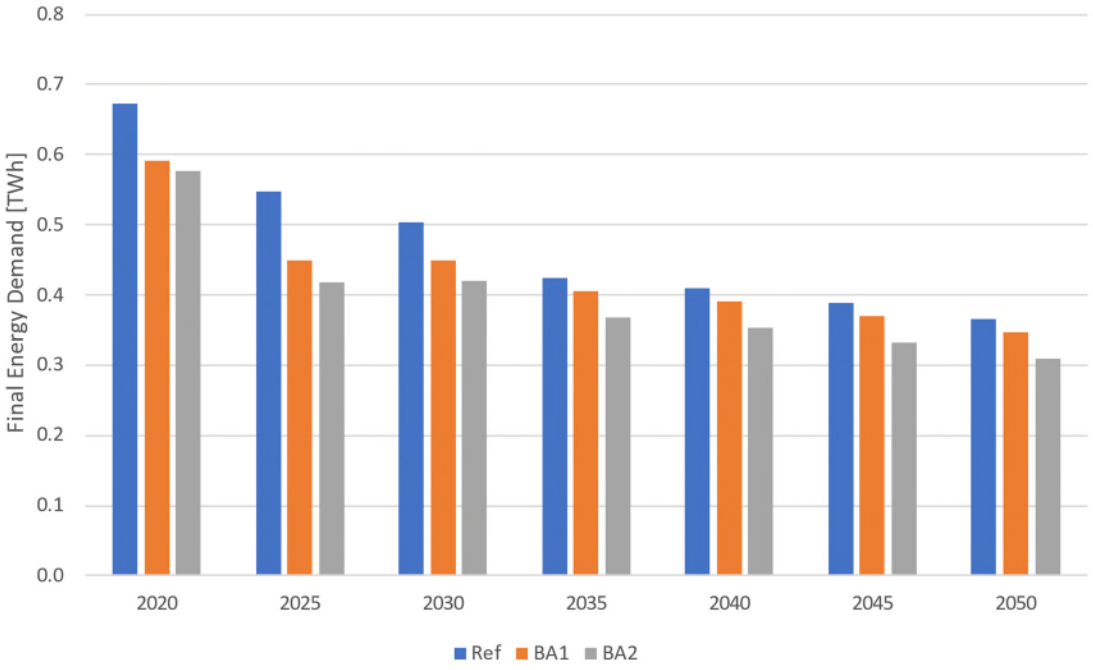
Note: Scenario description see Table 19

Figure 25 Final energy demand Germany, all sub-sectors, Ventilation & Building Services



Note: Scenario description see Table 19

Figure 26 Final energy demand Germany, Finance, Lighting



Note: Scenario description see Table 19

4.3 Data Centres

4.3.1 Final energy

As outlined in section 3.4, the model of data centres can be defined by parameters about the ICT infrastructure and the development of efficiency of the server room periphery. Figure 27 shows the simulation results of the total electricity demand in Germany for three scenarios that only vary in terms of the assumed development of ICT demand.

The reference case scenario is described by DC0. DC1 assumes a faster increase of ICT demand (factor 1.5 compared to DC0), while DC2 has an even steeper increase (factor of 1.8 compared to DC0). These factors are assumption taken for the context of proofing the concept[11]. The results show a common starting point in 2020, as the higher ICT demand (expressed as the energy service driver ICT infrastructure) rises over the course of the years. As the gradients of that driver are different, the difference across the scenarios gets bigger over the time.

Figure 27 Electric demand of ICT data centres in Germany across all sub-sectors of the tertiary sector

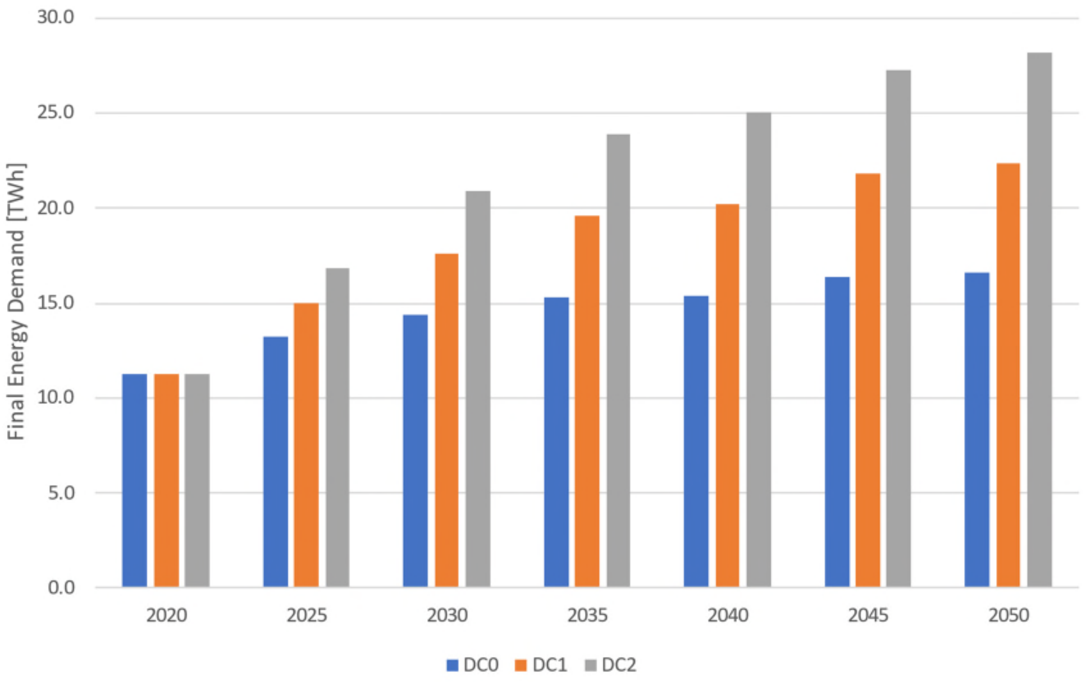


Figure 28 shows the demand of ICT applications in offices for comparison. It can be seen that the definition of an increasing ICT data centre demand works in the model as intended, as the office ICT applications were not affected by the settings about the data centres. These results also show that, compared to the

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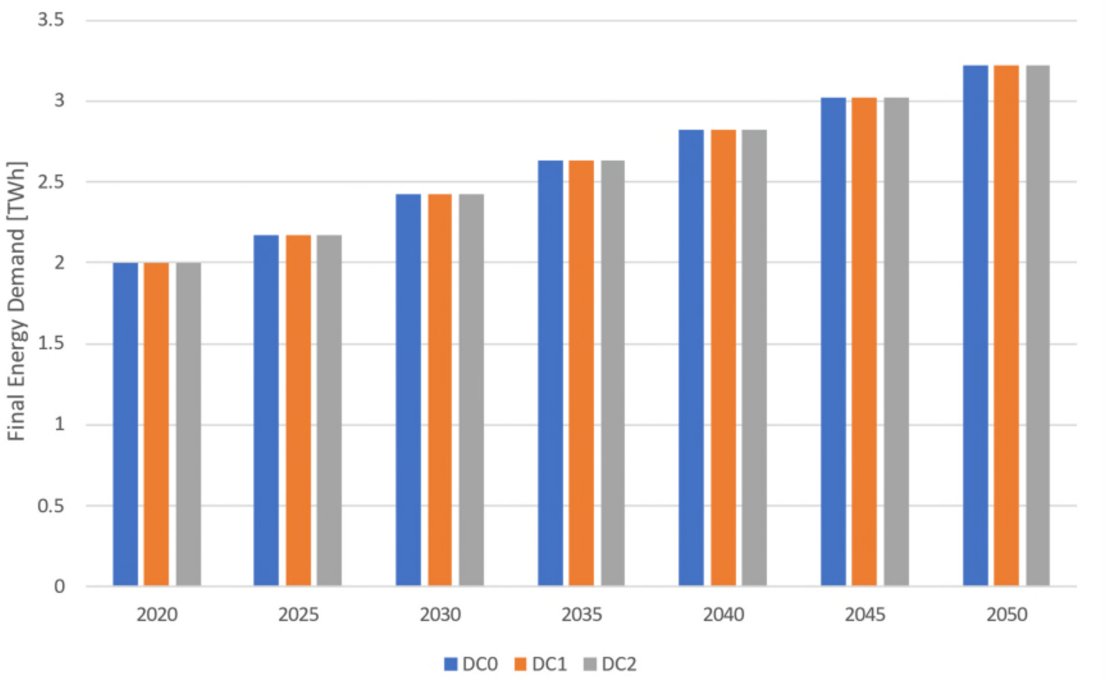
[11] There is a lack of comprehensive literature review about the ICT demand.

total power demand in data centres, the final energy demand of ICT applications in offices is significantly lower.

Figure 28 Final energy demand, caused by ICT applications in offices, EU 27, all energy carriers



Furthermore, the comparison of energy consumption in data centres and servers and office devices show that the first is dominating by a factor of 5.

This example model of data centre scenarios show that the existing model can be used to simulate different development trajectories of ICT demand. Comprehensive energy efficiency scenarios, which are in line with the newTRENDs project, will be modelled as part of WP3.

5. Conclusions from the Focus Study Report

The aim of this report is to document the model enhancement of the FORECAST simulation framework in order to better model new (societal) trends. This report covers the tertiary module of the framework. It describes the improvements to the code and/or to the data structure and content (chapter 3). For testing the enhancement, small and simple scenarios are defined that are suitable to perform plausibility checks in the relevant parts of the model (chapter 4).

In summary, these three trends were implemented in the model:

- Increase of E-commerce
- Larger diffusion of Smart building
- Higher demand of ICT in Data centres

The adjustments to the model source code are substantial, as the employees need to be differentiated by their activity in conventional or e-commerce trading. Furthermore, the formerly combined sub-sector of wholesale and retail trading is now split up into its two trading forms. These changes require extensive alterations to the code as all calculations have to consider both the added employee activity and the two trading forms.

Model improvements in the field of smart building/building automation are mainly achieved by adjustments to the input data (structure and content). The model already allows to add new energy saving options (ESOs) without changes to the model code. The task here is to add ESOs that are aligned with the existing options. In that case, the new ESOs are defined according to standards of the building and automation control systems. To avoid overlapping effects, the existing ESOs need to be adjusted as well.

Data centres are already modelled in a suitable way. By simulating scenarios of different development of ICT demand that affects data centres, the existing approach could be checked and validated.

Furthermore, the impact of teleworking could be added to the model. As this part is already used in a different focus study report of the newTRENDs project, the code enhancements are described in that report[12].

With these new modules, the tertiary module of the FORECAST simulation framework could be improved significantly and is ready to model the new trends and their impact on the energy demand of buildings.

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[12] Deliverable 7.2: Focus Study report on sharing economy in the tertiary sector

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A.1 Appendix

A.1.1 Definitions of digitalisation

Besides the definition by Gartner Glossary (2023) which is used in Chapter 1, Other definitions of digitalisation are used in the papers of our literature review (Table 22).

Table 22 Definitions of digitalisation in literature

Reference	Definition
Gartner Glossary, 2023	Digitalisation is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business
Gobble, 2018	Digitization is the straightforward process of converting analogy information to digital. Digitalisation refers to the use of digital technology, and probably digitized information, to create and harvest value in new ways
Rachinger et al., 2019	Digitalisation is the innovation of business models and processes that exploit digital opportunities
Business Dictonary, 2023	Integration of digital technologies into everyday life by the digitization of everything that can be digitized
Rachinger et al., 2019	Digitization (i.e., the process of converting analogue data into digital data sets) is the framework for digitalisation, which is defined as the exploitation of digital opportunities. Digitalisation by means of combining different technologies (e.g., cloud technologies, sensors, big data, 3D printing) opens unforeseen possibilities and offers the potential to create radically new products, services, and BM

A.1.2 Summary of Energy Consumption

Deep dive into the sighted studies of Chapter 2.3

Table 23 Summary of the studies analysing energy consumption

Author, year	ICT Service	Scope
Moberg et al., 2010	e-news	The impact of digitalisation on publication (e-publication)
Horner et al., 2016	Literature review	Cover most of the e-materialisation
Asgari & Jin, 2018	Transportation	Impact of ICT on transportation

Author, year	ICT Service	Scope
Achachlouei & Moberg, 2015	e-publication	The impact of digitalisation and the scope effect (Direct effect, indirect effect and rebounded effect)
Achachlouei & Moberg, 2015	Substitution (defined as the partial or complete substitution of material products with electronic equivalents)	The impact of digitalisation and the scope effect (Direct effect, indirect effect and rebounded effect)
Moberg et al., 2011	e-book	The impact of digitalisation
Hochschorner et al., 2015	E-materialisation	The impact of digitalisation and the scope effect (Direct effect, indirect effect and rebounded effect)
Subramanian & Yung, 2017	E-materialisation	The impact of digitalisation and the scope effect (Direct effect, indirect effect and rebounded effect)
Talamo et al., 2019	ICT application	Smart cities
Pacheco Sánchez et al., 2019	e-business	Impact of ICT on business
Meza & Garciá, 2018	E-materialisation	Impact of ICT on education sector
Moberg et al., 2010	E-materialisation	The impact of digitalisation on publication
Magazzino et al., 2021	Digitalisation	Electricity consumption, ICT, and carbon footprint
IEA, 2017	ICT application	Overview of all related topics
Asgari & Jin, 2018	Transportation	ICT on transportation
Horner et al., 2016	E-materialisation	Review of all the ICT goods (e-matiralization)
Malmodin & Lundén, 2018	E-materialisation	Energy and carbon footprint
Belkhir & Elmeligi, 2018	E-materialisation	ICT, energy consumption and footprint

A.1.3 Effect on digitalisation in education and e-health

A.1.3.1 Education

Digitalisation has a massive impact on education sector, and that due to the integrate of ICT devices in the education sub-sector. E-learning, online education, and remote education are aspects of this impact. E-library as well is an impact of digitalisation on this sub-sector.

The impact of digitalisation on this sub-sector came to the surface in the studies after the lock-down, and the consequence conditions align with the closure.

Most of the studies have come across the European policy concerning remote education. (Zancajo et al., 2022) have analysed the impact of digitalisation and the educational policy concerning remote education and teachers and provided a table with clear concept (see Table 24).

Table 24 Policy response included in the national recovery plans and the digitalisation impact

Country	Digitalisation of education	Perform gap and education inequality	Teacher working condition and well-being
Belgium	Technological resourcing of schools (hardware devices, software, and infrastructure) Development of digital skills/competences for teachers and students.	Personalised education and targeted compensatory policies	Teachers' training and development on digital skills
Cyprus	Technological resourcing of schools (hardware devices, software, and infrastructure) Development of digital skills/competences for teachers and students	Expansion of early childhood services	Teacher and school evaluation system
Denmark, France	Technological resourcing of schools (hardware, software, and infrastructure) Development of digital skills/competences for teachers and students		Teachers' training and development on digital skills
Germany	Technological resourcing of schools (hardware, software, and infrastructure) Development of digital skills/competences for teachers and students Provision of digital devices for teachers and students	Expansion of early childhood services	Teachers' training and development on digital skills • Teachers' access to mobile digital devices

Country	Digitalisation of education	Perform gap and education inequality	Teacher working condition and well-being
Greece	Technological resourcing of schools (hardware, software, and infrastructure) Development of digital skills/competences for teachers and students	Expansion of early childhood services	Teachers' training and development on digital skills
Italy	Technological resourcing of schools (hardware, software, and infrastructure) Development of digital skills/competences for teachers and students	Expansion of early childhood services Personalised education and targeted compensatory policies	Teachers' training and development on digital skills Teachers' training on STEM skills and pedagogic innovation • Career progression system linked to professional development
Portugal	Technological resourcing of schools (hardware, software, and infrastructure) Development of digital skills/competences for teachers and students Provision of digital devices for students	Improvement and strength of vocational education and training	Teachers' training and development on digital skills Teachers' access to mobile digital devices
Spain	Technological resourcing of schools (hardware, software, and infrastructure) Development of digital skills/competences—teachers and students Provision of digital devices for students	Expansion of early childhood services Personalised education and targeted compensatory policies Improvement and strength of vocational education and training	Teachers' training and development on digital skills

(Bozkurt & Sharma, 2020) show that the rapid shift to the digital sphere during school closure periods highlighted major differences in access to digital technologies, depending on countries' level of income, but also about the different social groups within countries. The stark digital divide added to and amplified the social divide, increasing inequality and directly impacting the distribution of learning losses among social groups during school closures. However, the sudden shift to online teaching, without careful prior preparation, also affected both the impact on learning and teachers' and students' perceptions of online education, with educators and students having to familiarise themselves with new types of technologies in record time and having to deal with uncertainties regarding Internet access or connectivity.

A.1.3.2 E-health

The impact of digitalisation increased and spread rapidly to cover most of the life aspects including the health sector. On the one hand, Telemedicine can be defined as impact of ICT development on the health sector. On the other hand, medical robots can be counted as impact of digitalisation on the health sector.

The scope of this sector is widely spread and the study that has been conducted covers various aspects. In Coeckelbergh et al. (2016) drive result medication delivery framework and medical service scheduling. Moreover, electronic health record information can broadly support the robotisation of answering public health organisations about things to tell—persistent diseases and conditions.

To understand this concept well, it is necessary to define digital health, which is framed as the “the convergence of the digital and genomic revolutions with health, health care, living, and society” by ((Paul Sonnier, 2017)). Another definition is: Digital health, as a concept, can refer to a technology, a user experience, a service, a product, a process, an ecological system of itself, and part of the ecological system of health services.

The impact of digitalisation has been tackled in the health area and the development of medical robots, systems to collect and analysis medical data, schooling and training, telemedicine, and hospital equipment. However, there is a lack of studies concerning the impact of this development on energy consumption and the floor area of the health sector. The review by Ernawati et al. (2022) provides a good image of the scopes mentioned above and discusses the advantages of using digital applications in public health services in the era of automation.

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