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newTRENDs

Exploiting the potentials of circular economy and digitalization: Case studies on green public procurement and smart building policies

D6.3 Policy case study on the implementation of selected CE-action and digitalization policies

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Executive Summary

The central aim of the 2015 Paris Agreement is 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 (United Nations 2015). To reach this ambitious goal, countries have to implement the following two strategies: (i) enhancing energy efficiency and (ii) decarbonizing remaining energy supply and demand, in particular by large penetration of renewable energy sources. A comprehensive mix of policy instruments is necessary to support this transition. While countries have implemented a wide array of policies, new societal trends and emerging technologies require the development and adoption of other policies.

Many scenario-based models already consider the impact of economic policies such as carbon trading systems. However more research is necessary to consider non-economic policies for capturing system dynamics and in particular, the impact of these trends on the future energy and material demand. This is important because of its impact on greenhouse gas emissions.

To narrow the gap in existing literature, this report analyses two policy cases relevant for buildings. The first case focuses on a market pull mechanism for the industry sectors and analyzes the contribution of green public procurement to the exploitation of circular economy potentials for material demand reduction in buildings. The second case investigates technology push in the tertiary sector and analyses smart buildings policies for promoting building automation and control systems (BACS) and related energy demand reductions in buildings.

For the analysis of green public procurement, we apply a material flow model and a material intensity database for Germany (Lotz et al. NYP; Lotz et al. 2022b). This geographical scope has been chosen due to data availability. The analyses cover three green public procurement policy cases:

1. The Industrial Deep Decarbonisation Initiative pledge proposing quotas for the use of low-carbon materials (production stage);
2. Thresholds for embedded carbon in buildings (design stage);
3. Criteria for building adaptability and deconstruction (use and end-of-life stage).

The results show that green public procurement is a versatile instrument due to the different design options addressing diverse value chain stages and circular economy actions. Nevertheless, the share of public activities in the construction sector is limited. Consequently, this measure is mostly relevant in the short to medium term. On the one hand, green public procurement can create lead markets supporting production-side policies. On the other, it is possible to gather experience for the roll-out of policies that foster circular economy to the complete construction sector. Overall, it is important to align green public procurement with other policy instruments for efficiently exploiting the potentials of a circular economy for buildings.

The analysis of smart building case is based on the recent revisions of the Energy Performance of Buildings Directive (EPBD). Notably, fostering smart buildings in

both residential and non-residential buildings is an explicit policy priority. To achieve smart buildings, BACS need to be implemented. To fully understand their impact, we do a final energy demand simulation, adopted from a previous expansion of the smart building modelling in the FORECAST energy demand simulation model. Using this implementation in the smart building model, we align the diffusion parameterization of FORECAST with the EPBD and derive results for the tertiary sectors and its subsectors.

The aggregated economically feasible final energy saving potential from BACS measures in medium to larger tertiary buildings reaches over 9% in 2030. The implication is that the current EPBD will likely promote economically viable energy savings. If some measures are not viable in certain buildings, policymakers may consider additional support to reap “high-hanging” fruits.

In conclusion, both cases show exemplary results for the improved consideration of current policy cases and different mechanisms, i.e. market pull and technology push. Future research should extend the limitations of current model approaches, especially with regard to data availability.

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1. Introduction

A comprehensive mix of policy instruments is necessary to support the reduction of final energy demand and greenhouse gas (GHG) emissions in the industry and tertiary (also service) sector. On the one hand, these sectors face the challenge to maintain their competitiveness in the market. On the other, the market offers the potential to make the transition economically viable in the longer term. Consequently, it is important to support new technologies and services in the short term to ensure that these are established on the market. Therefore, a large share of current policies for the industry and tertiary sector are market-based economic instruments, e.g. the emission trading scheme (ETS).

Recent scenario-based research has largely investigated the impact of such policies. However, there are other types of instruments that can be implemented to support the transition in these sectors. These instruments either push new technologies into the market (technology push) or create a pull to the market (market pull). With new societal trends, such as circular economy and digitalization emerging, technology-push and market-pull policies become more relevant. While such policies have appeared in recent years, their effect on final energy demand and GHG emissions is not fully understood, though. This gap is narrowed in the present report by analyzing two policy case studies for buildings:

1. Exploiting the decarbonization potentials of a circular economy for buildings - Case study on green public procurement (market pull addressing the industry sector)
2. Exploiting the decarbonization potentials of digitalization in tertiary buildings- Case study on smart building policies (technology push addressing the tertiary sector)

For both cases, the political outset is introduced briefly. Afterwards the method and data sources for the analyses are outlined. Finally, the results are presented, discussed and summarized. By doing so, the research objective of improving the modelling and analysing the impact of selected circular economy and digitalization policies is obtained.

2. Exploiting the decarbonization potentials of a circular economy for buildings - Case study on green public procurement

In 2021 industry was responsible for about 22% of Europe's GHG emissions making the sector critical for the achievement of European climate goals (EEA 2021). Previous analyses have shown that for the industry sector available technologies are not sufficient for deep decarbonization (Fleiter et al. 2019). Thus, strategies grouped under the umbrella concept of circular economy (CE)are considered promising for the GHG emission reduction while maintaining economic growth (Ghisellini et al. 2016).

As a consequence, the concept of CE gains momentum in the political debate across all stakeholders. Synergies exist between the decarbonisation of the industry and the CE policy agendas. The Circular Economy Action Plan (CEAP) of the European Union (EU) is addressing several relevant topics, such as the design of sustainable products or the circularity in production processes (European Commission 2020). For instance, buildings are one of the sectors in focus due to high demand for energy- and emission-intensive basic materials and high CE potentials (European Commission 2020; Lotz et al. NYP; Lotz et al. 2022b).

Nevertheless, the current policy mix for CE in buildings is not yet sufficient to exploit these potentials. Historically grown, the policy mix currently focusses on recycling and neglects other CE strategies, such as material efficiency or use intensification. While more ambitious policies such as green public procurement (GPP) or Ecolabel criteria are available, these remain voluntary and are not aligned with the overall policy mix (Lotz et al. 2022a). However, GPP is gaining momentum for the decarbonization of the construction sector and in context of a CE (Nilsson Lewis et al. 2023; Ntsondé et al. 2021). GPP can potentially cover diverse stages of the building value chain and address various CE aspects (Lotz et al. 2022a).

Chapter 2 addresses these potentials by analysing three GPP policy cases. For this a material flow model and a material intensity database is applied for the case of Germany (Lotz et al. NYP; Lotz et al. 2022b). Section 2.1 defines the policy cases. Afterwards the method and data are summarized in section 2.2. Finally, the results are shown and discussed in section 2.3. The report closes with a summary and outlook on the policy mix for CE in buildings. Thus, this report answers one research questions: How can GPP support a circular low carbon industry?

2.1 Circular economy policies

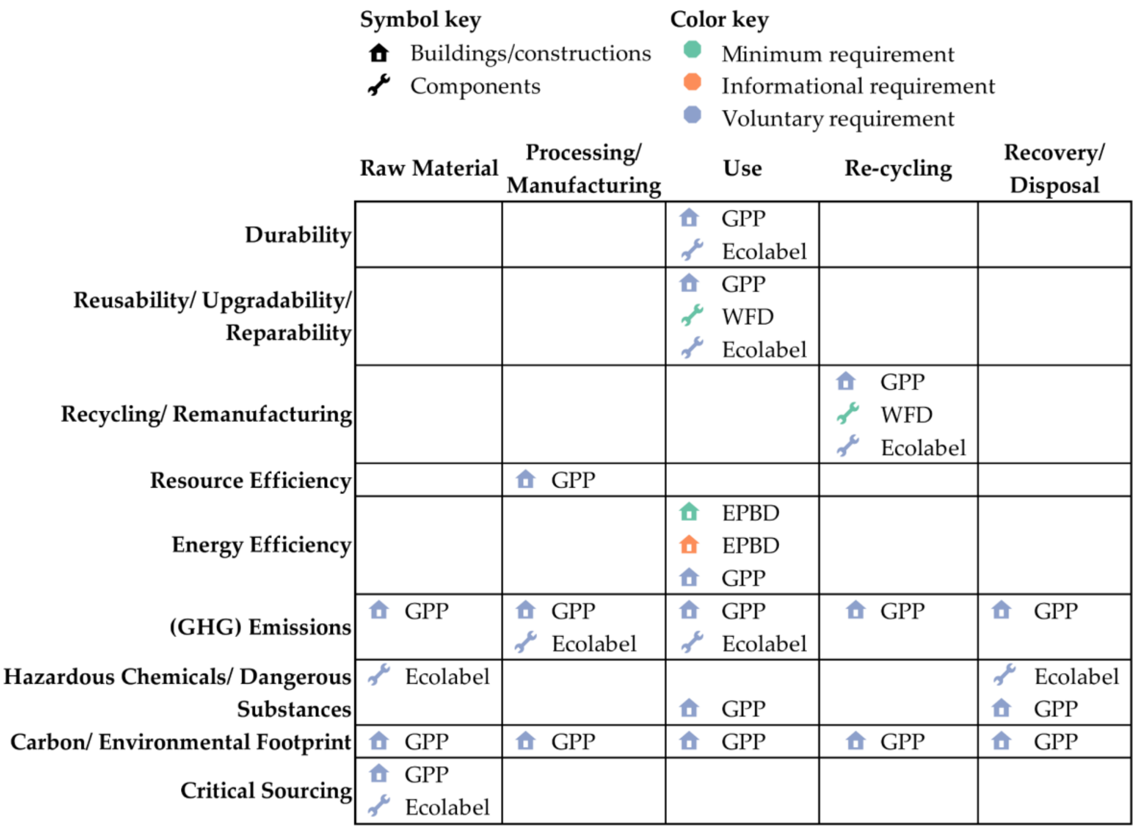
In 2020 the EU adopted the new CEAP replacing the initial plan from 2015 (European Commission 2015, 2020). CE is considered to be of major importance for achieving the climate goals within the Green Deal (European Commission

2019). In the new CEAP the focus on sustainable products within the sectors electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and building as well as food, water and nutrients is established. Of these sectors vehicles, packaging, plastics as well as construction and building can be identified as typical basic material use-sectors. They are also part of the action fields identified in the evaluation of the first CEAP from 2015. Besides this strong product focus the CEAP addresses the handling of waste (European Commission 2020).

We screened more than 90 product- or material-related EU policy documents for the CE criteria set out in the CEAP and found that the product and waste specific focus of the CEAP is reflecting the policies currently in force. This screening included regulatory instruments as the Ecodesign Directive and the Waste Framework Directive and voluntary instruments as the Circular Plastics Alliance and the guidelines for GPP (Circular Plastics Alliance 2020; Commission of the European Communities 2008; European Parliament et al. 2008, 2009). The assessed policy tools are typically addressing the final products and not basic materials and intermediates. Mostly energy related and security aspects are covered. The consideration of material aspects is typically missing or voluntary. An exception is waste-specific legislation which focusses mostly on recycling. In addition, to these regulatory and voluntary instruments, the research and development of new technologies is supported by funding programs as LIFE and Horizon Europe. The gaps mentioned are partially addressed by the proposal for Ecodesign for Sustainable Products Regulation (ESPR) (European Commission 2022).

One of the focus sectors mentioned in CEAP are buildings due to the high material demand and the potentially significant impact of a CE. A detailed analysis of this sector performed by Lotz et al. (2022a) showed that the current policy mix is not yet sufficient to fully exploit the potentials of a CE., The current policy mix focusses on recycling and neglects other CE strategies, such as material efficiency or use intensification (see Figure 1). While more ambitious policies such as GPP or Ecolabel criteria are available, they remain voluntary and are not sufficiently aligned with the overall policy mix (Lotz et al. 2022a).

Figure 1 Mapping of policies addressing CE aspects along the building value chain from Lotz et al. (2022a)



Symbol key
🏠 Buildings/constructions
🔧 Components

Color key
🟢 Minimum requirement
🟠 Informational requirement
🔵 Voluntary requirement

	Raw Material	Processing/ Manufacturing	Use	Re-cycling	Recovery/ Disposal
Durability			🔵🏠 GPP 🔵🔧 Ecolabel		
Reusability/ Upgradability/ Reparability			🔵🏠 GPP 🟢🔧 WFD 🔵🔧 Ecolabel		
Recycling/ Remanufacturing				🔵🏠 GPP 🟢🔧 WFD 🔵🔧 Ecolabel	
Resource Efficiency		🔵🏠 GPP			
Energy Efficiency			🟢🏠 EPBD 🟠🏠 EPBD 🔵🏠 GPP		
(GHG) Emissions	🔵🏠 GPP	🔵🏠 GPP 🔵🔧 Ecolabel	🔵🏠 GPP 🔵🔧 Ecolabel	🔵🏠 GPP	🔵🏠 GPP
Hazardous Chemicals/ Dangerous Substances	🔵🔧 Ecolabel		🔵🏠 GPP		🔵🔧 Ecolabel 🔵🏠 GPP
Carbon/ Environmental Footprint	🔵🏠 GPP	🔵🏠 GPP	🔵🏠 GPP	🔵🏠 GPP	🔵🏠 GPP
Critical Sourcing	🔵🏠 GPP 🔵🔧 Ecolabel				

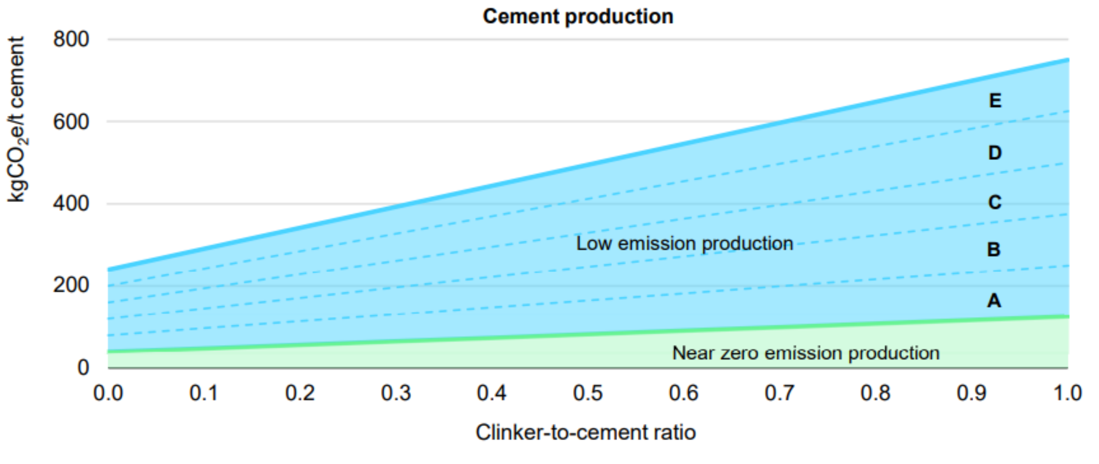
Kochanski et al. (2022) summarized the consideration of such policies in energy-demand side models from the perspective of policy makers at the European level. One of the instruments that has not yet been included in these models is GPP for buildings (Kochanski et al. 2022). However, GPP is gaining momentum for the decarbonization of the construction sector and in context of a CE (Nilsson Lewis et al. 2023; Ntsondé et al. 2021). Kochanski et al. (2022) found that the modelling of such policies should consider the interaction of mechanisms, enhance the focus on the use phase and consider the complete value chain of buildings. Fittingly, GPP can potentially include various policy mechanisms, cover diverse stages of the building value chain and address various CE aspects (Lotz et al. 2022a).

Consequently, a policy case on GPP criteria for buildings was discussed qualitatively by Miłobędzka et al. (2022). This case focusses on the use and end-of-life (EOL) stage of buildings and will be extended in this report to include model-based impact quantifications. In addition, two other cases were selected to demonstrate coverage of additional stages and to discuss possible interactions. This is on the one hand the definition of purchase quotas addressing the production stage and on the other hand the definition of thresholds for embedded carbon addressing the design stage of buildings. All three cases and their potential impact are described in the following sections.

2.1.1 GPP Case I: Quotas for exploiting CE potentials during material production

The first case analyzed regards the production stage of materials for buildings. This case covers the two main materials steel and cement, due to high, hard-to-abate GHG emissions. The Industrial Deep Decarbonisation Initiative (IDDI) of the United Nations Industrial Development Organization (UNIDO) proposed procurement targets for low carbon steel and cement (UNIDO 2022). Such quotas for low carbon steel are not relevant in context of a CE for buildings, as already mostly secondary steel is used in the construction sector. For the definition of low carbon cement, IDDI refers to the International Energy Agency (IEA) (2022). Within their publication the IEA suggest low carbon thresholds and summarizes processes to obtain them. For cement the reduction of the clinker share, the use of innovative cement types as well as carbon capture is covered. While the latter is no CE technology, the use of innovative cement types and the reduction of the clinker share are material substitution and material efficiency. Thus, both can be classified as CE strategies according to the 9R framework (Kirchherr et al. 2017). The threshold for low carbon cement is shown in the figure below. It is important to note that the IEA proposed a sliding scale for this threshold considering the clinker share. Thus, higher GHG emissions may be allocated to low carbon cement with a higher clinker share. This would prevent the incentive for reducing the clinker share. However, the IEA also allows to define a fixed carbon threshold that would set such incentives.

Figure 2 Low carbon threshold for the cement production according to the IEA (2022)



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2.1.2 GPP Case II: Carbon thresholds for exploiting CE potentials during building design

The second case considered within our analysis addresses the design stage of buildings and thereby it bridges the material production stage and the building use stage. Within this stage both structural requirements, such as floor count or use type, and sustainability criteria, such as share of secondary material, can impact the material choice and building design. A binary sustainability criterion that can affect this value chain stage could be a threshold for embedded carbon. Several EU member states have proposed and implemented such voluntary or mandatory thresholds either as emission equivalents or carbon shadow price (BPIE 2022). In contrast to the first case, there are no specific examples of implementing such thresholds in GPP yet. Also, this GPP instruments is more flexible on how the emission reduction goal is achieved. On the one hand, it is possible to substitute the conventional materials steel and cement. On the other, this criterion ensures that the materials are used most efficiently.

2.1.3 GPP Case III: Design criteria for exploiting CE potentials during and after building use

The third and final case covers the GPP criteria for buildings drafted by the Joint Research Centre (JRC) (Donatello et al. 2022). In this draft JRC suggests seven themes for GPP buildings of which one is material circularity. Within this section five criteria are proposed:

1. Inventory of building elements, technical systems, construction products and materials purchased;
2. Construction, demolition and excavation waste management;
3. Design for adaptability;
4. Design for deconstruction;
5. Operational waste management.

Thus, these criteria cover both the use and the end-of-life (EOL) stage of buildings. While the criteria 1, 2 and 5 are organizational measures that enable CE actions, the criteria 3 and 4 directly address CE actions. Consequently, these two criteria will be analyzed in more detail. Criterion 3 describes the design for adaptability defined as actions that a) facilitate changes to the internal space distribution, b) the routing or type of building services, such as heating or ventilation and c) to the building facade and structure. Hence, this criterion addresses the use stage. The 4th criterion addresses the design for deconstruction as an enabler for the reuse, recycling or recovery (Donatello et al. 2022).

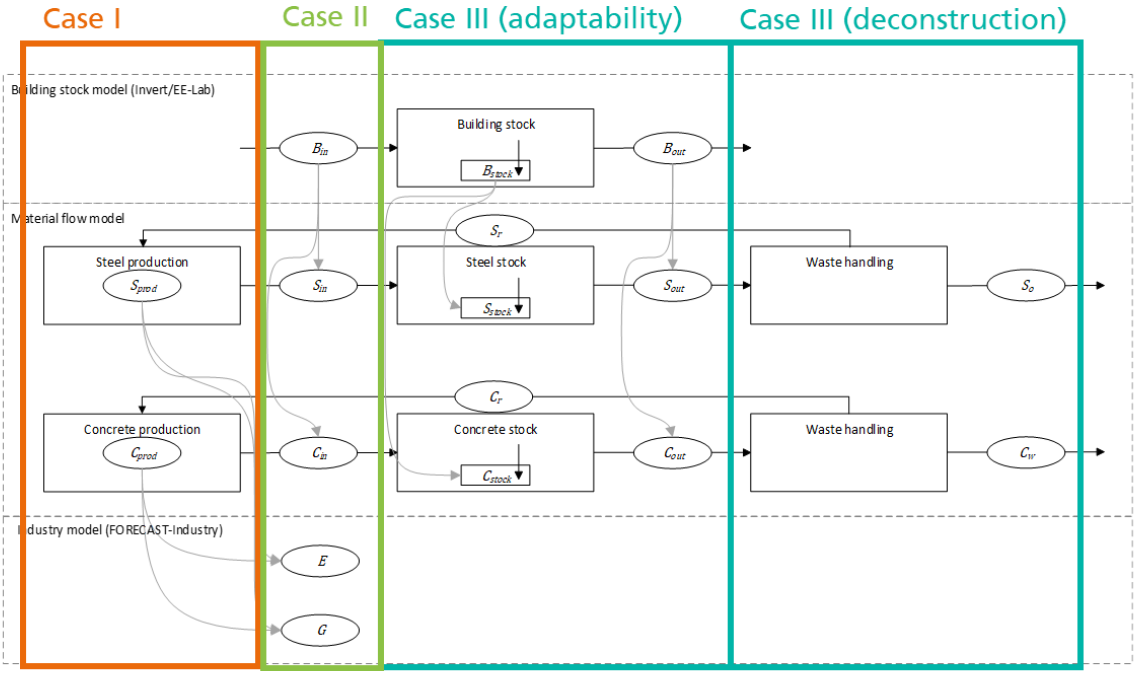
2.2 Method and data

The material flow model and material intensity database described in Lotz et al. (2022b) is applied for the analysis of the described policy cases. This approach is going to be published and is currently under revision (Lotz et al. NYP). The following sections describe the application of the method and data basis for the analysis of the policy cases. For this we considered the model recommendations for GPP stated by Miłobędzka et al. (2022).

2.2.1 Modelling approach

The modelling approach of Lotz et al (2022b) is a stock-driven material flow analysis that links the building stock model Invert/EE-Lab and the industry model FORECAST-Industry. It covers the materials steel and concrete. Concrete as such is not an emission-intensive basic material, but the downstream product of the basic material cement. Different sections of the model are relevant for the implementation of the different policy cases. Case I addresses the production stage, case II the transition from production to use phase and case III addresses both the use and the EOL stage (see Figure 3).

Figure 3 Model structure including policy cases adapted from Lotz et al. (2022b)



For the consideration of the three described GPP cases, the model mechanisms for the respective CE actions are also derived from Lotz et al. (2022b). A summary is shown in Table 1, for the detailed model equations, please refer to the original report. Each action will be modelled individually not considering measure interactions.

Table 1 Consideration of GPP cases in the model

	CE action	Model mechanism
Case I	Reduced clinker share	Change in model input parameter (reduced clinker share)

	CE action	Model mechanism
	Low-carbon cement types	Change in model input parameter (share of different cement types)
Case II	Material substitution with timber	Change in model input parameter (adapted material intensity)
	Reducing the over-specification steel and concrete	Change in model input parameter (adapted material intensity)
Case III (adaptability)	Optimizing space use in residential and office building	Change in model input parameter building stock (less inflow)
	Repurposing cultural heritage buildings (built before 1945)	Change in model input parameter building stock (less outflow)
	Renovating existing buildings	Change in model input parameter building stock (less outflow)
Case III (deconstruction)	Reuse of prefabricated building elements	Additional flow from end-of-life to use phase
	Reuse of structural steel	Additional flow from end-of-life to use phase
	Recycling of cement	Additional flow from end-of-life to use phase

2.2.2 Parametrization

The parametrization of the GPP cases, the material intensity data base as well as the parametrization of CE actions are based on Lotz et al. (2022b). While this forms the foundation, further data is required to consider the GPP cases. On the one hand, we aimed to close the data gaps regarding industry buildings[1]. On the other hand, further information was needed on the share of public procurement in building construction. We focussed on Germany were the data requirement could be fulfilled as shown in Figure 4. Since the current targets of the German

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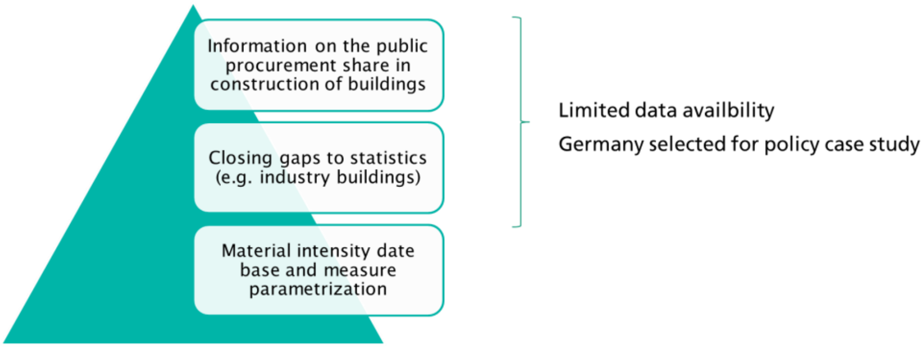
[1] The building model Invert/EE-Lab buildings, which provides the building stock development for the material flow model, does not include industry buildings as well as unheated buildings. Buildings that are only partially used throughout the year are only partly considered according to their fully-occupied- equivalent. However, industry buildings are most relevant due to the high material intensity.

government are valid until 2045 and not until 2050 as is the case at the EU level (Bundesregierung 2022), this was used as a temporal scope for the analysis.

Figure 4 Data needs for the modelling of the GPP cases



For the parametrization of the CE actions the maximum possible potential up to 2045 was selected in each case according to Lotz et al. (2022b). However, this study did not include all of the CE actions addressed by the GPP cases. Thus, the reduction of the clinker share and the use of alternative cement types has to be parametrized additionally.

The current clinker share in Germany is 0.71 and can potentially be reduced further until 2045 (Verein Deutscher Zementwerke e.V. 2020). Due to the limited availability of alternative constituents, we assume a maximum reduction to 0.6. Furthermore, new cement types are available that are related to 30%-50% less GHG emissions compared conventional cement. The production of these cement types is cost intensive. Thus, we assume a maximum market share of 5% according to the German cement industry association (Verein Deutscher Zementwerke e.V. 2020).

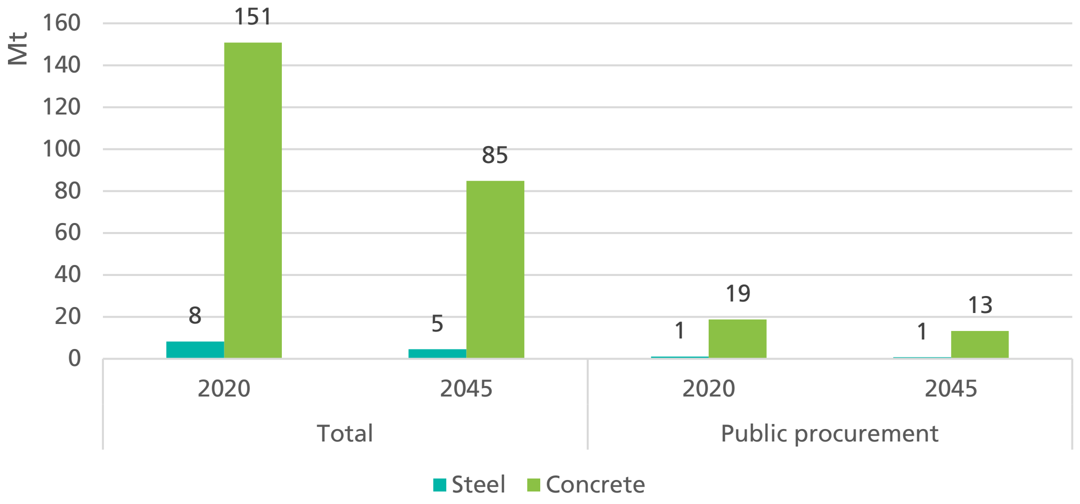
For closing the data gaps, we used an estimate on the share of industry buildings compared to all non-residential buildings as a starting point (Deutsche Energie-Agentur 2022). Afterwards we extrapolated the building stock according to the development of all non-residential buildings provided by Invert/EE-Lab. Additionally, we assumed the same distribution within the age cohorts as for 'Other' non-residential buildings. By applying that approach, the deviation between the statistics for concrete production for buildings and the modelled value is below 1%.

Data estimates on the public construction of residential and non-residential buildings were derived from the national statistics office (DESTATIS 2020). Accordingly, about 2.5% of residential and 20% of non-residential buildings are constructed under public procurement. It was assumed that these proportions do not change over time. While this may not necessarily be the case in reality, it does analyse the potential of GPP from today's perspective.

2.3 Results

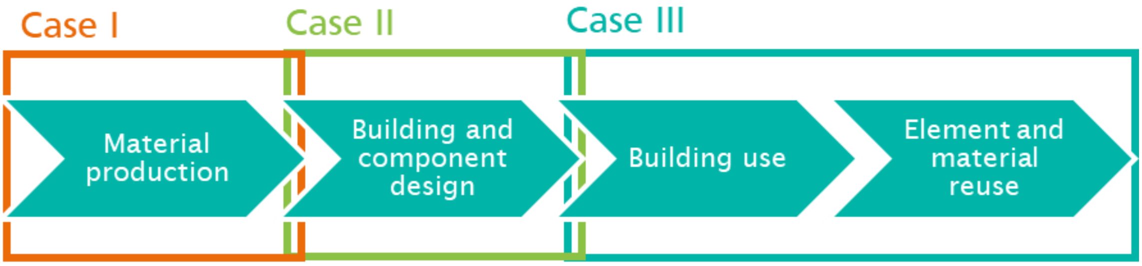
Figure 5 presents the reference development for steel and concrete demand for buildings in total and from the public sector in Germany. The overall material demand decreases between 2020 and 2045 in contrast to the EU development presented by Lotz et al. (2022b). This is caused by a saturation of the building stock in Germany. Thus, only replacement material is in demand. Such a saturation occurs, among others, due to demographic factors.

Figure 5 Reference development of steel and concrete demand in Germany



The different GPP cases can now address this material demand at different stages of the value chain as described in section **Fehler! Verweisquelle konnte nicht gefunden werden.**, see also Figure 6. Here, GPP has the potential to use different policy mechanisms.

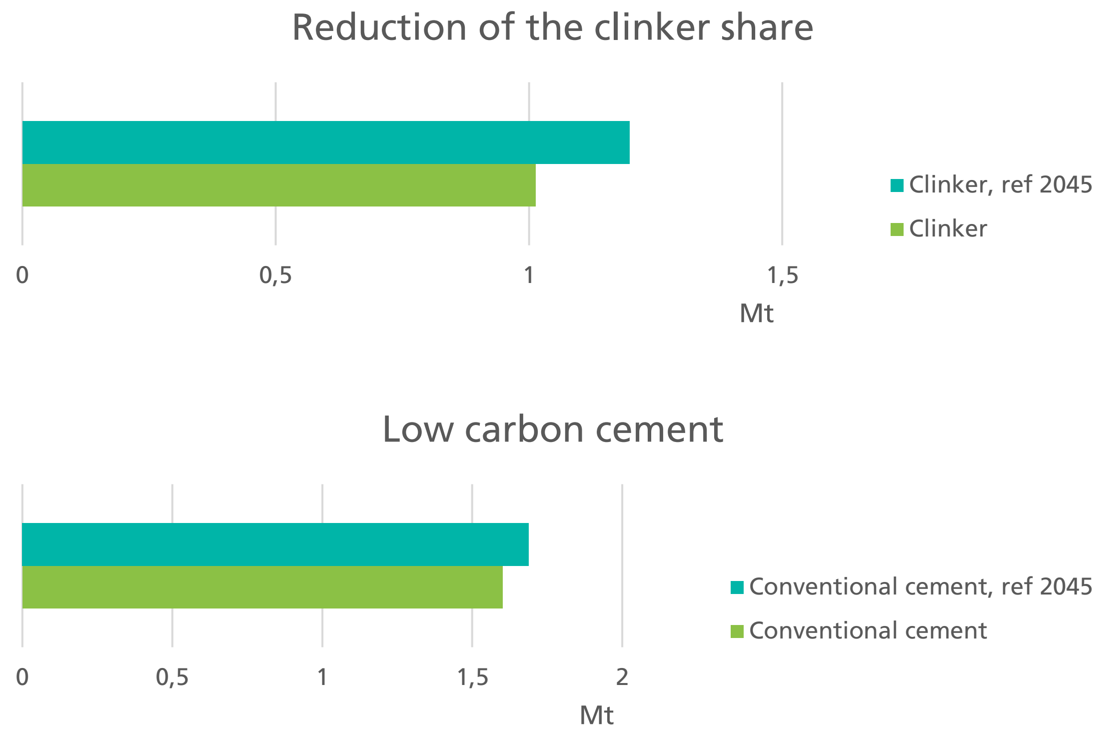
Figure 6 The different GPP cases along the building value chain



2.3.1 GPP Case I: Quotas for exploiting CE potentials during material production

The first policy case addresses the reduction of the clinker share in cement and the use of low-carbon cement types by defining quotas for low carbon material use. Thus, the material production stage is addressed. If the maximum potentials are exploited, these measures could reduce the clinker demand by up to 2.4% and the demand for conventional cement by up to 0.8% (see Figure 7).

Figure 7 Impact of the CE actions in GPP Case I on the public material demand for buildings in Germany in 2045



The prerequisite for this is that the quotas proposed by the IDDI and the definition of low carbon cement proposed by the IEA are ambitious enough to provide the incentives for this maximum diffusion. For both measures this means, that by 2045 100% of the procured cement needs to be at least low carbon cement. However, the carbon thresholds to implement this level of ambition varies. To achieve the assumed reduction of the clinker factor the maximum carbon threshold for cement has to be lower than 460 kg CO_2eq./t cement. In order to achieve a production share of 5% of low-carbon cements, the value must be below 326 kg CO_2eq./t cement. Both values are based on the assumption that all energy-related emissions are mitigated and only the process-related emissions[2] remain.

It should be considered, however, that a reduction in the clinker factor also alters the structural properties of the cement (EN 206-1:2001). Consequently, the inclusion of further requirements at the design level are necessary to prevent a rebound. Additionally, the quantity of alternative cement constituent, such as fly ash, are limited in future due to the omission of the emission intensive primary production processes (Verein Deutscher Zementwerke e.V. 2020). In the case of low-carbon cements the quality requirements are not a limitation, as these have been developed in particular for high quality requirements. Adversely, experience with the innovative material is lacking and the costs are relatively high (Le Den et al. 2020).

2.3.2 GPP Case II: Carbon thresholds for exploiting CE potentials during building design

The second case covers the building and component design stage by defining technology-open threshold for embedded carbon. Thus, this case has the potential to offset the previous limitations in reduction of the share of clinker. In addition, it bridges the material perspective during production and the building perspective during the use stage. Two CE actions are considered for this: timber construction in residential buildings and reduced over-specification of building components in all building types. Timber construction could reduce the demand for structural steel by 0.8% and for structural concrete by 0.6%. Increased material efficiency and reduced over-specification of building components could decrease the steel demand by 6.3% and concrete demand by 1.9% in public construction.

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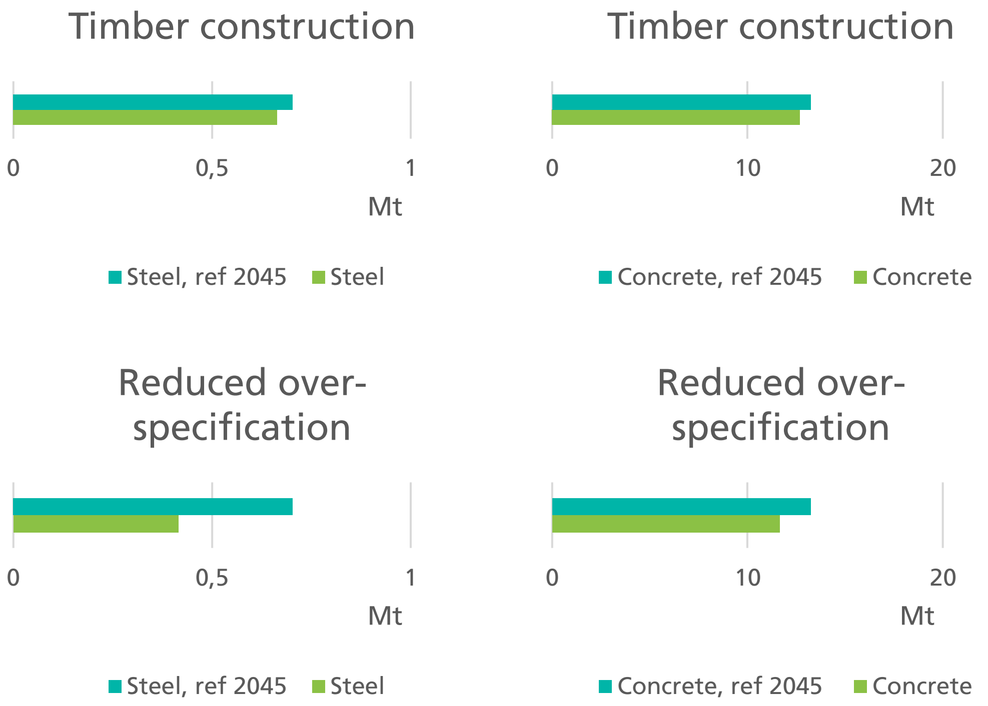
[2] Process-related emissions for the production of clinker according to EU ETS Benchmark: 766 kg CO_2eq./t clinker (European Commission 2021).

Figure 8 Impact of the CE actions in GPP Case II on the public material demand for buildings in Germany in 2045



The prerequisite for this is that the threshold is ambitious enough to provide incentives for the mentioned actions. For timber construction in wooden buildings this means that 74 kg concrete/m^2 and 5 kg steel/m^2 have to be replaced by 45 kg timber/m^2. Assuming that energy-related emissions are completely mitigated by then, the threshold has to be at least 145 kg CO_2eq./m^2 or 2.9 kg CO_2eq./m^2 and year[3]. In contrast, for the reduced over-specification the maximum threshold would only have to be 479 kg CO_2eq./m^2 or 9.6 kg CO_2eq./m^2 and year.

There are limitations to these measures as well. For timber construction, the sustainable use potential must be taken into account, as forests also act as carbon sinks. Furthermore, the costs for wooden construction have increased significantly in the last years. Safety aspects, such as earthquakes, must be taken into account when using materials more efficiently and reducing over-specification. Although this is a cost-optimal solution, it has therefore not been widely implemented to date.

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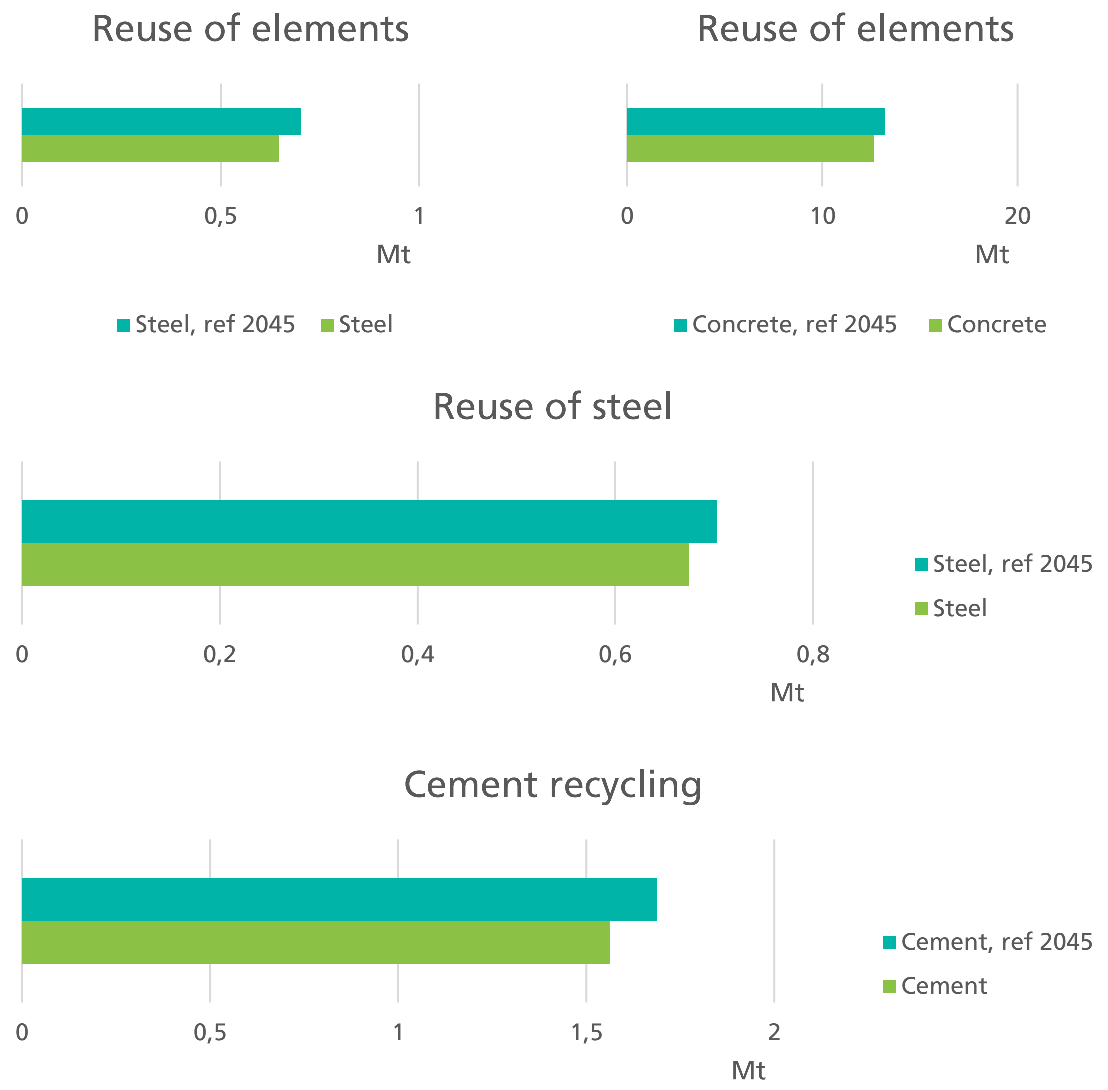
[3] Considering a lifetime of 50 years

2.3.3 GPP Case III: Design criteria for exploiting CE potentials during and after building use

The final case addresses the use and the EOL stage of buildings by defining criteria for adaptability and deconstruction of buildings. For the first criterion three CE actions are considered: the optimized space use in residential and office buildings, the protection and repurposing of cultural heritage buildings as well as the renovation and refurbishment of existing buildings. The second criterion addressed the reuse of building elements and structural steel as well as cement recycling. Optimized space use could reduce the public steel and concrete demand for buildings by up to 2.7% in 2045. In contrast the reuse of cultural heritage buildings reduces the steel demand by 0.2% and concrete demand by 2.3%. The highest impact of the actions addressing the use stage has the renovation of buildings with a reduction of 3.1% of steel and 4.9% of concrete demand in publicly built buildings. The reuse of building elements could reduce steel demand by 1.2% and concrete demand by 0.7%, while the reuse of steel only affects the steel demand with a reduction of 0.6% compared to the reference development. Cement recycling could reduce the cement demand by 1.1%.

Figure 9 Impact of the CE actions in GPP Case II (adaptability) on the public material demand for buildings in Germany in 2045

Figure 10 Impact of the CE actions in GPP Case II (deconstruction) on the public material demand for buildings in Germany in 2045



Again, the design of the criteria is crucial for their impact. However, the translation of the requirements for both criteria to the material flow model is not easily possible. Thus, we are unable to derive similar quantified recommendation as we do for the other GPP cases described before. The scoring system that underlies the criterion on adaptability is case-dependent and complex since it allows to focus on individual aspects. Consequently, it should be understood as an enabler for exploiting the mentioned material reduction potentials without being able to give a quantified estimate here. For the second criterion a reuse-share of up to 40%-60% is proposed by the JRC (Donatello et al. 2022). Based on the parameterization of CE actions from Lotz et al. (2022b), none of the actions can achieve this alone. Consequently, a combination of these is necessary for the achievement. Even then, the value of 60% seems very ambitious for reuse in buildings. Alternatively, the reuse or recycling in other sectors, e.g. road construction, would be possible and is already implemented in reality. Nevertheless, this can be classified as open loop- or down-cycling and should be minimized according to the 9R framework (Kirchherr et al. 2017). Consequently, the criterion could be improved by a requirement for equivalent reuse.

Again, there are limitations to implement these actions. In case of adaptability actions, these are due to behavioural factors in particular. While maintaining the building stock and reducing the floor space per capita can have a large impact, they are contrary to current trends. This may also be a reason why JRC's design of the criterion is complex and case-dependent. In contrast the reuse and recycling of building elements and materials are mostly well established. Nevertheless, we propose that this strategy should be redeveloped so that no open loop recycling takes place and new business models develop. For the reuse of components, their standardization is a major enabler, while for the reuse of steel, legislative hurdles need to be removed. For all actions, the inventory of building components is a relevant enabler, as also suggested by JRC and the proposal for a building logbook (Donatello et al. 2022; Ted eTendering 2021).

2.4 Summary

In conclusion, our analysis confirms that GPP is a versatile instrument due to the different design options addressing diverse value chain stages and CE actions. Nevertheless, it becomes clear that the total amount of material for buildings demanded by the public sector in Germany is relatively small. Thus, although the measures can significantly reduce material demand, their effectiveness is limited.

A closer look at the individual cases also reveals that each case study itself, is not sufficient to stimulate a comprehensive CE and exploit its full decarbonization potentials. In contrast, the instruments must be aligned with each other. In particular, Case II, which suggest upper limits for embedded carbon in buildings, is of special importance as a bridging instrument between the material production and building use stage. In addition, there are other relevant policy initiatives that have not been considered in detail in this report, but should be considered to create a sufficient policy mix for a CE in buildings. This is for example, the ESPR, the Construction Product Regulation or the Level(s) framework on product level as well as the Waste Framework Directive on value chain stage level. For this purpose, it would also be necessary to expand data availability beyond Germany.

Consequently, GPP is mostly relevant in the short to medium term. For instance, quota for low carbon materials can create lead markets supporting production-side policies. In addition, GPP can gather experience for the roll-out of thresholds for embedded carbon and design criteria to the complete sector. Overall, it is important to align GPP with other policy instruments for efficiently exploiting the potentials of a CE for buildings.

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3. Exploiting the decarbonization potentials of digitalization in tertiary buildings- Case study on smart building policies

In 2020, the building sector was responsible for 40% of the total energy consumption and 36% of greenhouse gas (GHG) emissions in the EU (EC, 2020). While construction and demolition activities are part of these demands and emissions, the European Commission (EC) draws particular attention to the usage of buildings as almost three-quarters of the building stock is considered to be energy inefficient (EC, 2020). To reach the EU's 2030 targets, a substantial acceleration of building renovations is thus needed (EEA, 2022).

Both *Fit-for-55* and *REPowerEU-Plan* lay the foundation to reduce energy use and GHG emissions in both retrofitted and new buildings. The main policy on the EU-level has been the *Energy Performance of Buildings Directive (EU) 2018/844* (EPBD), which promotes renewable energy and energy efficiency in buildings (EC, 2018).

One cornerstone in the EPBD is building automation and control systems (BACS). The aim of BACS is to automatically monitor and adjust the energy use of various energy services like ventilation, cooling, heating, 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.

While the potential of BACS in single buildings has been recognised and quantified in the European Standard (EN) EN ISO 52120-1:2022 (ISO, 2022)[4], and previous estimations for the building stock exist (Waide, 2019), there is a need to explore more formalised approaches to represent BACS in bottom-up models, as well as to update these numbers for the current recast of the EPBD.

The purpose of this case study is thus to propose and test a simulation framework that incorporates the effect of the EPBD on BACS in the tertiary (i.e., service) sector. Such a model can also be used to analyse the direct and indirect impact of emerging digitalisation trends on energy demand (see NewTRENDs deliverable 6.2, Steck et al., 2023).

This report is organized as follows: this section introduces the general relevance of BACS and the goals of this case study. Section 2 explores the relevant policy and the potential of BACS. Section 3 presents the model implementation. Section 4 shows results based on the policy assumptions. Finally, Section 5 concludes this report and gives an outlook for future work.

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[4] Previously EN 15232. In the remainder, EN ISO 52120-1:2022 labelled: EN ISO 52120.

3.1 Smart building policies background

This section provides a review of the relevant norms, potentials and one of the major policies regarding smart buildings, the BACS in the tertiary sector. This provides a framework to estimate the energy efficiency potentials in our modelling framework.

3.2 Current smart building policies on the EU-level

In the EU, the *Energy Performance of Buildings Directive* (EPBD) 2018/844 generally promotes smart buildings and the use of BACS in certain buildings, in particular to foster the full potential of high-level BACS (as defined in EN ISO 52120). Member states have been and will be obliged to implement this directive in their national laws. With the recasts from 2018 and the proposed recast of 2021, the EU has further tightened the requirements and strengthened the promotion for BACS (EC, 2018, 2021). In particular, with the latest (planned) recast, targets would have to be met earlier, and the scope would be expanded from non-residential to residential buildings.[5]

According to the EPBD, "BACS or 'building automation and control system' means a system comprising all products, software and engineering services that can support energy-efficient, economical and safe operation of technical building systems through automatic controls and by facilitating the manual management of those technical building systems" (EC, 2018). Ideally, such systems are capable of monitoring, benchmarking, and communicating with connected technical building systems.

In particular, the EPBD mandates the installation and retrofit of BACS in larger non-residential buildings. The implementation of BACS in the tertiary[6] sector in the EU follows several steps. First, BACS should be part of most of the larger non-residential buildings in the EU by **2025.** In particular of those buildings where the heating or combined heating and ventilation systems have a thermal output of over **290** kW. Waide (2019) states that this encompasses about 37% of non-residential buildings in the EU. With the recast of 2021, BACS will be mandatory for most non-residential building by **2030,** in particular for those which have a (combined) heating/ventilation output of over **70** kW.

These (current and future) mandatory requirements apply if the installation or retrofit of BACS is *technically and economically feasible*. The economic feasibility is of interest in the scope of our research. It describes how the upfront costs

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[5] In March 2023, the EP approved the proposed recast from the EC, and the trilogue stage was still due at the time of writing. It is likely that the provision will thus be lowered to medium and large buildings starting from 2030 (i.e., >70kW rated output).

[6] In addition, with the recast of the EPBD in 2023, BACS requirements will also apply to the residential sector. However, we will not analyse those as part of this report, as we focus on the tertiary sector.

compare to the expected benefits and to other costs borne by the investor. The EC states that this economic criterium applies to existing buildings, however, only infrequently and if payback times are large, e.g., larger than five years. In new buildings, the EC expects these measures to be economically feasible in any case. Moreover, to fulfil the EPBD, the minimum level of BACS according to EN ISO 52120 should be level B for rooms with high occupation and level C for all other rooms (EC, 2021; eu.bac, 2019).

With previous revisions of the EPBD, the EC also proposed the smart readiness indicator (SRI) to measure and evaluate the smart readiness of buildings (EC, 2021). Notably, this includes the effect of BACS. With the SRI, buildings are rated according to different criteria, resulting in an SRI-class. According to Plienaitis et al. (2023): "When referring to the smartness of a building unit, this relates to the ability of a building to document, understand and adapt the performance of the building to its user's needs. These operations are usually addressed through the performance of the building automation and control systems and are aligned to the building technical systems, rather than the building shell." Currently, research on the SRI methodology is still in its infancy (Fokaides et al., 2020; Plienaitis et al., 2023).

3.3 Levels and applications of BACS

BACS applications in various energy services (such as ventilation, heating and lighting) are listed in EN ISO 52120. These include different functions such as the automated, interconnected and occupancy-based and temperature-based regulation of HVAC systems (heating, ventilation, air-conditioning), lighting and pumps, for instance, the regulation of occupancy-based, regulation of the air volume flow rate, or the regulations of lighting according to the occupancy.

The amount of potential energy savings from BACS in individual buildings is adopted from the *BACS-factors* of EN ISO 52120. BACS-factors are based on comprehensive building simulations (Siemens, 2012) and provide an estimation of the expected energy savings from BACS. Nevertheless, the factor-based method is simplified, and does not fully account for the occupant's behaviour in very specific contexts (Van Thillo et al., 2022). The study by Van Thillo et al. further shows that other simulations arrive at different results.

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

An overview of all classes is given in Table 2. In this report, we will focus on electricity-based applications (see Section 3.2 for the model implementation.)

Table 2 Overview of BACS energy classes, incl. description (Siemens, 2012).

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 optimization.
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 modernized. New buildings must not be built with such systems: - no interconnected building automation functions - no electronic room automation - no energy monitoring

3.4 Aggregated potential of BACS

BACS can contribute to final energy savings and a reduction of greenhouse gas emission in European countries. One estimation shows that BACS In the EU may contribute to 14 % of the total primary energy savings in buildings until 2038 (Waide, 2019). Also, outside the EU, e.g., in Switzerland, the implementation of BACS could contribute to a notable share of total energy savings (Jakob et al., 2016). For example, Jakob et al. find that the potential in the energy application of cooling lies at around 5% if BACS measures and operation optimisations are implemented in Switzerland. To consider these potentials in policy planning, 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, to reach the full potential and to ensure the optimal operation of BACS systems, two prerequisites need to be fulfilled. Firstly, the simplicity of using the control and guidance systems, and secondly, trained personnel must be able to plan, commission, calibrate, monitor and, if necessary, adjust the systems.

Furthermore, energetic operational optimization is essential, in other words regular monitoring and adjustment of the BACS parameters. In particular, correctly setting the target values of such systems is necessary for achieving the highest energy efficiency. Suboptimal setpoints 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). Also, the energy needed to operate the additional appliances of BACS reduces its saving potential and cannot be neglected (Kräuchi et al., 2017). Nevertheless, the currently applicable EN ISO 52120 assumes that an increase of the BACS efficiency level provided net savings (according to the BACS-factors), given the implementation adheres to the specifications of the norm.

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 (Jakob et al., 2016).

3.5 Method and data

3.5.1 Model implementation

We adopt the smart buildings methodology from NewTRENDs’ D6.2 to simulate potential effects of the EPBD regarding BACS in the FORECAST model (Fraunhofer ISI et al., 2011; Steck et al., 2023). In summary, the installation of BACS affects the utility rate or full load hours (FLH) of the connected systems. By incorporating additional energy-saving options into the FORECAST model, it is possible to estimate the full efficiency potential of BACS.

FORECAST uses energy saving options (ESOs), which reduce specific energy demands of energy services. ESO uptake depends on diffusion, costs, and model drivers. Two types of ESOs are used: minimum energy performance standards (MEPS) and advanced energy performance standards (AEPS). To reach the full potential of BACS, which corresponds to the high energy-performance A-level in EN ISO 52120, another ESO was introduced to FORECAST.

Here, we represent the energy saving potential of BACS through the utility rate saving effect (i.e., FLH)[7] of MEPS, AEPS and A-level ESOs. In the energy services lighting, ventilation and room air conditioning, these ESOs reduce the FLHs.[8] We adopt potentials from factors in the EN ISO 52120 (ISO, 2022). Steck et al. (2023) shows that standard BACS measures were already considered in previous version of FORECAST through the effect of the utility rate.

In addition (as a novel model implementation), these three ESOs are deployed in a hierarchical order. Building on the concept of the BACS levels, we presume that building owners will likely install A-level BACS ESOs only if less expensive and advanced options represented by the MEPS and AEPS are already installed. This hierarchical implementation is also necessary for the mapping of the norm-based BACS-levels to the model (see also Section 3.3)

A full description of the model implementation, savings from BACS previously covered, assumptions (e.g., costs and factors) and the mapping process of EN ISO 52120 to FORECAST is covered in detail in D6.2 (Steck et al., 2023), as well as in Appendix A.1. of this case study.

3.5.2 Scenario definition and EPBD relevance

We define three diffusion scenarios for the modelling of *1-Baseline*, *2-EPBD* and *3-Top* (Table 3). The baseline scenario estimates the final energy demand if D, C, and B-level BACS remain at low levels. The *2-EPBD* scenario shows what can be expected from implementation of the EPBD. It represents a strong diffusion of B-level options (according to the EPBD), specifically the MEPS and AEPS ESOs. In the *3-Top* scenario, the full potential of A-level BACS is represented through the BACS factors (as difference between already covered hours and the maximal potential).

All scenarios only apply to electricity applications, including lighting, ventilation, and air conditioning. In addition to the EPBD-inspired diffusion rates (see next Section), we assume a high policy compliance of 90%.

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[7] The effect of MEPS and AEPS in the previous FORECAST model affected both installed power and utility rate (FLH). On average, 35% of the difference can be aFttributed to the effect of the utility rate (Fraunhofer ISI et al., 2011).

[8] In lighting, MEPS only affects installed power.

Table 3 Scenario overview, diffusion assumptions and EPBD compliance regarding the covered applications

Scenario	Description	Diffusion	EPBD-compliance
1-Baseline	Inefficient BACS-measures. Only level D, C and B, but at low diffusion.	ESOs (MEPS/AEPS) related to standard BACS have low diffusion. A-level BACS have no diffusion.	No
2-EPBD	EPBD compliance. More similar to C and B levels. In some instances, also higher.	AEPS, which correspond to efficient B-levels, are diffused according to the EPBD targets. A-level BACS ESOs are not implemented.	Yes
3-Top	Very efficient BACS systems. Highest potentials.	High diffusion of A-Level BACS, which bridges “gap” between already covered FLH savings of MEPS / AEPS and the full potential (according to EN ISO 52120).	Exceeded

3.5.3 Diffusion of Energy Saving Options

3.5.3.1 Model implementation

One of the key-determinants of the BACS adoption in buildings is their diffusion. The diffusion parameters in FORECAST determine the levels with which an ESO is deployed in a specific subsector (Fraunhofer ISI et al., 2011). For this, two boundaries, the autonomous (Auto) and maximal (Max) diffusions, limit the realised diffusion. The calculation of the realised diffusion in each year is determined by the ESOs’ economic viability.

The lower boundary, the Auto diffusion, represents a diffusion that will be reached in any case. In this report, we chose the Auto diffusion levels to represent the areas affected by the EPBD requirements. The higher boundary, the Max diffusion, can only be reached if the economic viability is high. This is particularly the case if the annualised costs are lower than the energy costs, as for instance, if energy prices are high.

Because the Max diffusion could be much higher than the Auto diffusion, there is a risk for a sudden and strong diffusion in a single year, for instance if energy prices rise rapidly. However, such a strong adoption of single ESOs is likely unfeasible in practice, e.g. due to supply chain constraints or the shortage of skilled labour. To achieve more realistic results, we have limited sudden strong diffusion increases using an s-curve function (instead of a step function with sudden shifts from the Auto to the Max levels).

3.5.3.2 Definition of parameters

For the definition of the Auto and Max diffusion levels of the MEPS, AEPS and A-level ESOSs, we updated previous assumptions (Fraunhofer ISI et al., 2011) to incorporate the requirements of the EPBD. To estimate energy saving effects of the current and upcoming recast of the EPBD in the tertiary sector (EC, 2018, 2021), the diffusion of ESOs must reflect the obligations to implement BACS. The stringency of these obligations depends on the target year, the building types, and has been broadened in the expected recast of the EPBD from 2021.

In the recast of 2018, non-residential buildings with a rated output of more than 290 kW are obliged to implement BACS by 2025. In 2023, at the time of writing, the European Parliament has accepted the EC's proposal for the EPBD recast (EC, 2021), albeit it has not reached legally binding status. Nevertheless, we expect that the recast will be adopted and that the recent obligations will be strengthened. Notably, non-residential buildings with a rated output of more than 70 kW will likely be obliged to implement BACS by 2030.[9]

For the implementation in FORECAST, we need to estimate the shares of tertiary buildings which operate at the power levels of above 290kW, from 70kW to 290kW and below.[10] For this, we rely both on literature and a ballpark figure based on a Swiss building stock model. This estimate based on Switzerland provides a reasonable estimate for countries with a well-developed tertiary sector, which arguable most countries in the EU correspond to.

In the literature, Waide (2019) estimates that the obligation for 290kW applies to around 37% of the tertiary building floor area in the EU. With the Swiss building stock estimation, we derive at a share of 44% for these large areas. Additionally, Waide suggests that the adoption of the EPBD equated the B-level BACS.

To reflect this approximation in the FORECAST model, we assume that the Auto diffusion rate of AEPS reaches 38% in 2025. This figure also considers a policy compliance rate which is below 90%. For the 70kW obligation, no estimation from the literature is available. Figures based on Switzerland suggest that overall, 30.8% of buildings fall into this category. Considering the policy compliance, we assume a cumulative Auto diffusion of AEPS of ~57% in 2030 (see Table 4 and Table 5).

Given that the EPBD prescribes a high diffusion of B-level BACS, we assume that MEPS have an even higher adoption rate in 2025 and 2030. In contrast, the diffusion of A-level BACS will likely be lower than the one of AEPS, mainly due to the high technical prerequisites and lower profitability. Therefore, in the

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[9] In addition, residential buildings will be covered, but are out of scope of our policy case study.

[10] This method is necessary as there are not building representatives in FORECAST.

scenario with the *3-Top* scenario, we assume that the A-level BACS will only be deployed at half the AEPS diffusion levels (Table 5).

Finally, in all scenarios, the maximum diffusion levels are higher to enable a stronger diffusion if it is economically viable. Overall simplifications include that subsectors and countries are not differentiated, and that we apply the same diffusion curves for the three ESOs in focus.

Table 4 Diffusion assumptions for BACS-related ESOs in the scenario *2-EPBD*. Policy compliance is considered. Examples are based on figures for Ventilation.

	Autonomous diffusion		**Maximal diffusion**	
ESO	**2025**	**2030**	**2025**	**2030**
MEPS	64%	90%	84%	99%
AEPS	38%	57%	49%	74%
A-level BACS	4%	6%	5%	7%

Table 5 Diffusion assumptions for BACS-related ESOs in the scenario *3-Top*. Policy compliance is considered. Examples are based on figures for Ventilation.

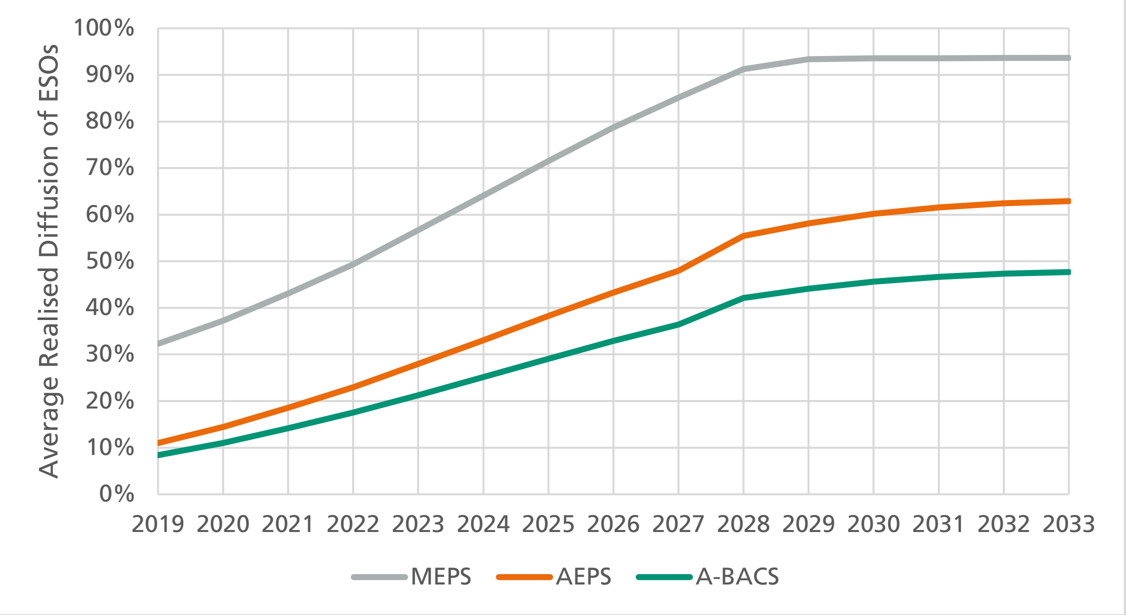
	Autonomous diffusion		**Maximal diffusion**	
ESO	**2025**	**2030**	**2025**	**2030**
MEPS	64%	90%	84%	99%
AEPS	38%	57%	49%	74%
A-level BACS	26%	40%	34%	52%

3.5.3.3 Realised Diffusion

Based on the economic viability of the saving options, the model selects either the Auto, Max or a diffusion level, which lies in between those two (based on the s-curve function). Figure 11 shows the realised diffusion of the three ESOs for one example in scenario 3-Top. Regarding the EPBD compliance, AEPS follows the considerably high policy-driven Auto diffusion assumptions. In contrast, the MEPS in the same scenario approaches the maximum diffusion due to very high economic viability. The A-level ESO, as assumed, have a lower realized diffusion.

In summary, the AEPS enforces the minimum as prescribed by the EPBD policy, while the full BACS potential can be reached by A-level BACS. Additional potentials, notably to reach the defined Max diffusion levels, may be feasible in the presence of financial support or more ambitious goals (see Section 3.7.1.).

Figure 11 Realised diffusion of the Ventilation ESOs in scenario 3-Top, including MEPS, AEPS, A-level ESOs. Average over all countries and subsectors.



3.6 Results

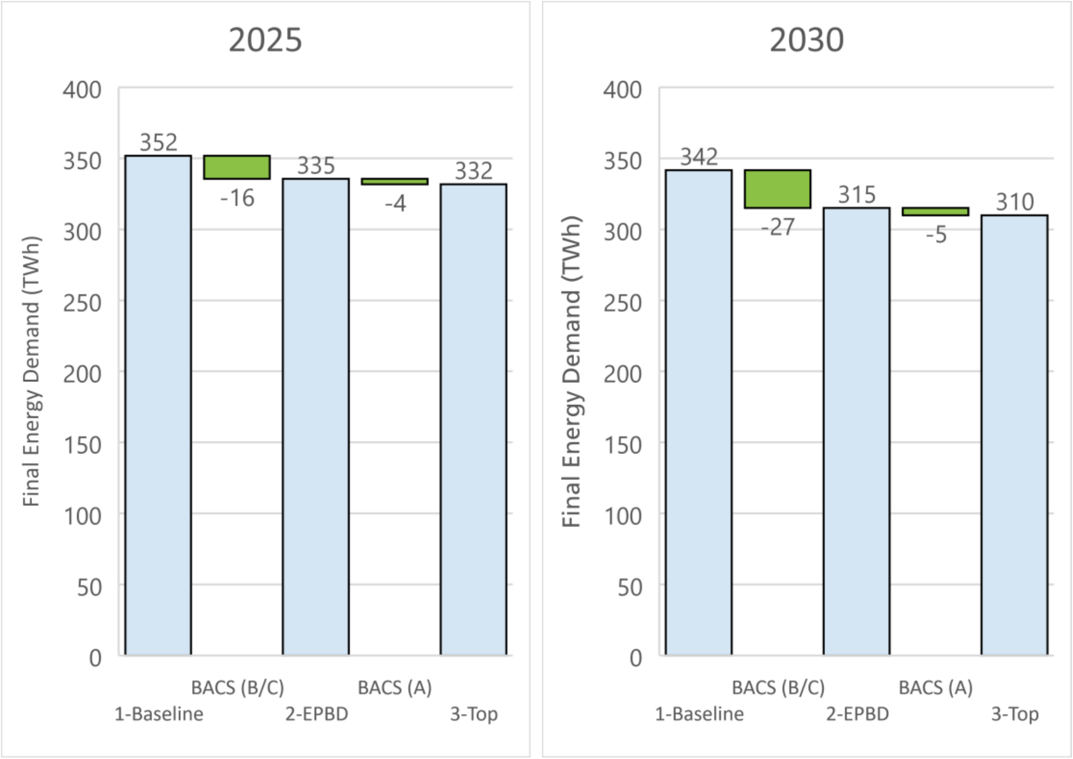
In this section, we show final energy demand results for the scenarios defined in Section 3.5.2. With this, we expand the scope of NewTRENDs' D6.2. (Steck et al., 2023), to the entire EU-27 and the EU's implementation of the EPBD policy. These results illustrate how the BACSs' energy saving potential translates to national energy saving potentials. We report them as aggregated yearly developments (see Section 3.6.1) and for the tertiary subsectors in two relevant years (see Section 3.6.2). In Section 3.6.3, we provide more context regarding the self-consumption of BACS, and in Section 3.6.4, we explore potential limitations and compare results to the literature.

3.6.1 Final energy saving potential in the EU

We quantified the final energy demand savings in electricity-based applications including lighting, ventilation, and air conditioning. In 2025 in the EU, BACS already provide a saving potential of 20.1 TWh (in the three applications, see Figure 12). From a baseline of 352 TWh, this corresponds to a 5.7% decrease. These savings entail 16.4 TWh from the 1-Baseline to the 2-EPBD scenario, which is mostly the shift to C and B-level BACS as mandated by the EPBD. In shifting to very efficient BACS-systems, another 3.8 TWh could be reaped. In 2030, even though general efficiency improvements contribute to a lower baseline level, the stricter EPBD leads to additional final energy demand savings. Namely, 27 TWh could be saved by C/B-level BACS, while very efficient A-level BACS contribute 5 TWh. From a baseline of 342 TWh, this corresponds to a 9.3% decrease.

Given the implementation in FORECAST, these potentials are all economically feasible or required by the EPBD. Nevertheless, further potential might be possible at higher energy prices, as the economic feasibility increases.

Figure 12 Aggregated final energy demand in the EU **in 2025 and 2030**, **all** tertiary sub-sectors. Only air conditioning, ventilation & building services and lighting applications, all energy carriers.



3.6.2 Sectoral results

The simulated effects of BACS differ between the six subsectors[11], both in 2025 and 2030 (Figure 13 & Figure 14). The adoption of C/B-level and A-level BACS provide energy saving potentials of up to 12.1% in the Finance sector, while less can be reaped in the public offices, wholesale and retail sectors, relatively (see Table 6). These differences are partly explained by the dominance of individual energy applications in these sectors, higher full load hours, and the mapping of

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[11] In this policy case study, the subsectors “other services” and “traffic and data transmission” are out of scope. See limitations in Section 3.6.3.

building types, and thus BACS-factors, to the subsectors (see NewTRENDs D6.2., Steck et al., 2023). Qualitatively, sectoral differences between the year 2025 and 2030 do not deviate much.

Figure 13 Final energy demand in the EU in **2025** per tertiary sub-sector for electricity applications (air conditioning, ventilation & building services, and lighting) and three BACS scenarios.

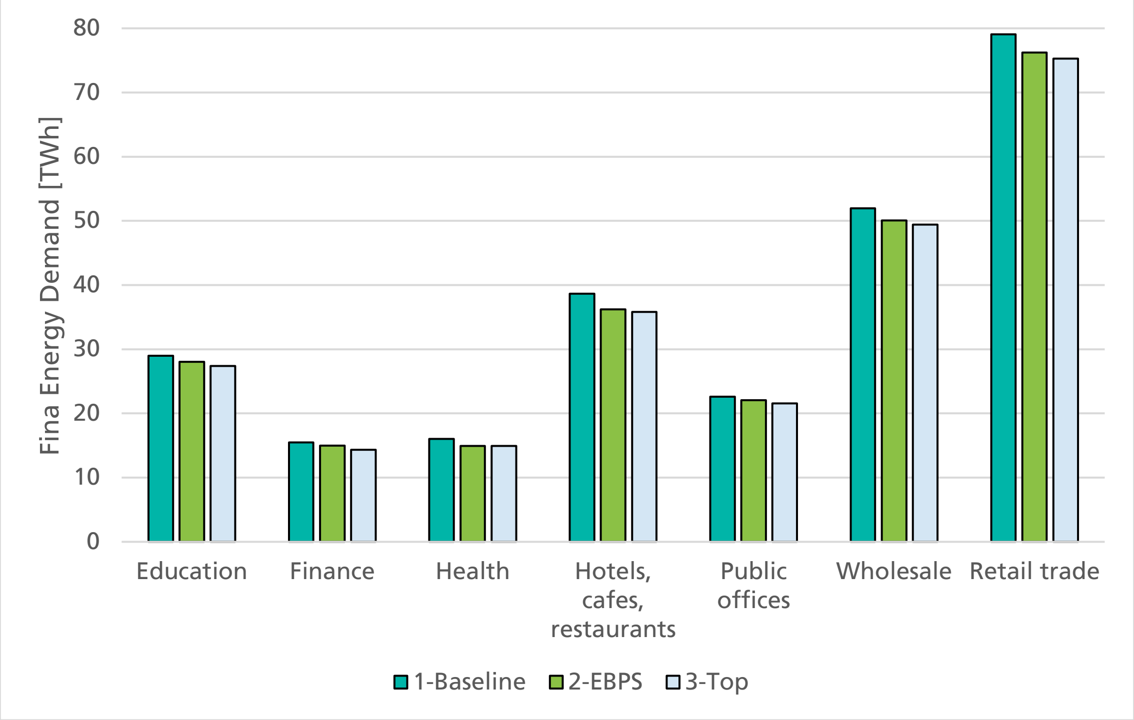

Figure 14 Final energy demand in the EU in 2030 per tertiary sub-sector for electricity applications (air conditioning, ventilation & building services, and lighting) and three BACS scenarios.

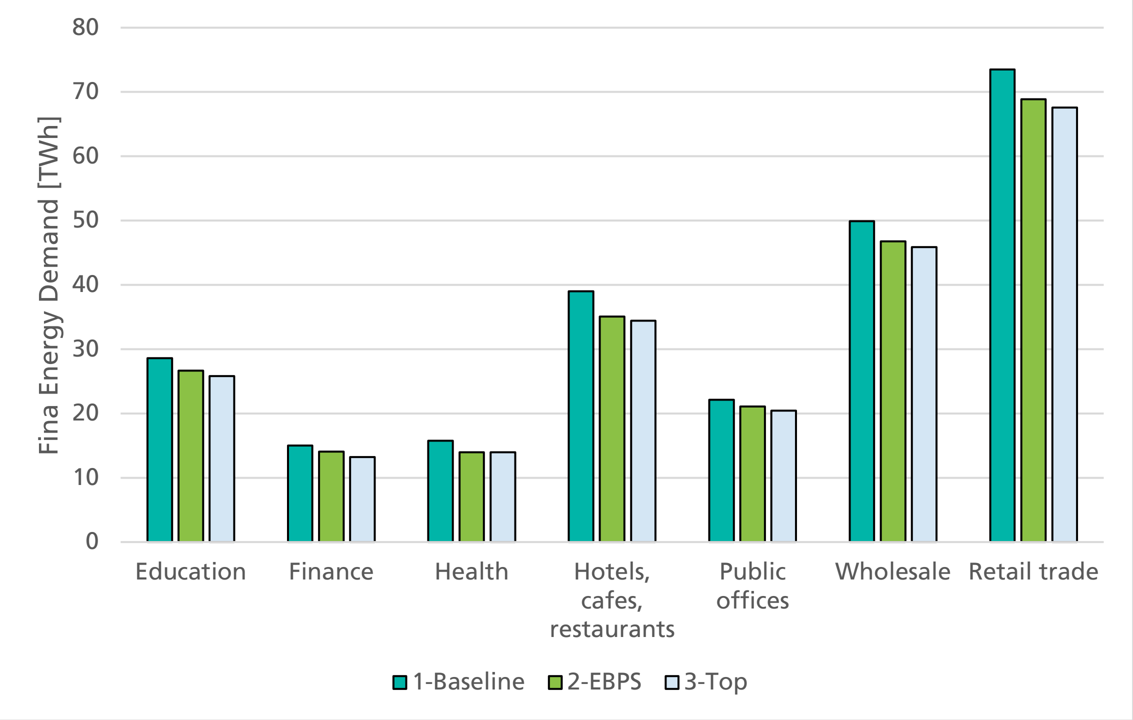

Table 6 Effects of Standard and A-level BACS. Relative differences between final energy demand in the EU **in 2025 and 2030** per tertiary sub-sector for electricity applications (air conditioning, ventilation & building services, and lighting).

Subsector	**2025**		**2030**	
	2-EPBD	3-Top	2-EPBD	3-Top
Education	-3.2%	-5.4%	-6.8%	-9.8%
Finance	-3.3%	-7.5%	-6.3%	-12.1%
Health	-7.0%	-7.0%	-11.3%	-11.3%
Hotels, cafes, rest.	-6.4%	-7.4%	-10.1%	-11.7%
Public offices	-2.5%	-4.6%	-4.7%	-7.6%
Wholesale	-3.6%	-4.8%	-6.3%	-8.1%
Retail trade	-3.6%	-4.8%	-6.3%	-8.1%

3.6.3 Specific final energy demand saving

There is evidence that energy self-consumption of BACS cannot be neglected. For instance, Kräuchi et al., (2017) suggest that the energy demand of BACS lies between 2-5kWh/m^2. Our simulations suggest an average saving potential of ~6-9 kWh/m^2 on average, i.e., it is in the same order of magnitude.[12]

Our results are based on the adopted methodology, i.e. are partly due to BACS-factors (EN ISO 52120). Unfortunately, the norm does not specify the extent to which self-consumption of energy is considered, as well as the overall impact of self-consumption on the potential of BACS. Future studies should hence assess the EU-wide potential with particular attention to these counteracting energy demands.

3.6.4 Comparison and limitations

Our policy case study provides an assumption-driven and data-based estimate of the impact of the EPBD policies on the adoption of BACS in non-residential buildings up to 2030. There are differences between our study and existing research, as well as some limitations that provide opportunities for future research.

We quantified that the final energy saving potential of BACS lies between 6% and 9% in 2025 and 2030, respectively. According to a study by Waide (2019), the adoption of BACS following the EPBD obligations (2018 recast) could result in primary energy savings of up to 14% in 2028. The guidelines by an industry association (eu.bac, 2019) even estimate a potential of over 20%. While their estimates are larger compared to our findings of 2030, the results are in the same order of magnitude.

We attribute these deviations to methodology, diffusion rate assumptions and the scope of the studies, namely the energy applications considered (see Appendix A.1). Here, we only consider three electricity applications (room air conditioning, ventilation and lighting applications). However, heating is also a relevant and energy-intensive energy service. For instance, Jakob et al. (2016) find that in Switzerland, the potential of BACS in heating applications lies above 20%, hence even surpassing the energy saving potential of BACS of electricity-based applications. Future studies should thus expand the scope to heat applications. With this, the aggregated impact of BACS will likely be higher.

Furthermore, the underlying factors from EN ISO 52120 should be scrutinised. Some argue that this factor-based method may not be a reliable estimate of savings (Van Thillo et al., 2022). Others show that self-consumption of BACS should be considered (Kräuchi et al., 2017).

Moreover, many studies (including ours) rely on simulations. While simulations may be very detailed, there is an apparent lack of empirical evidence about the

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[12] If 57% of the floor area will be equipped with BACS, see also Section 3.5.3.2.

real-world effects of BACS. We, therefore, suggest collecting more detailed data about the operation of BACS in practice (see also Section 3.7.3). Furtermore, our representation of the EPBD using FORECAST is simplified, as the model is not built around distinct building representatives. We can only indirectly establish a relationship between installed power and diffusion of ESOs. Although we have circumvented this issue by estimating the affected share of the total area using empiric data, a more granular analysis might improve results.

Finally, future work should consider further subsectors, particularly traffic and data transmission and other services. For this, the mapping of dominant building types and BACS-factors to subsectors needs to be more detailed (see also Appendix). Despite these limitations, the current report provides an estimate of the effect of current policy. Furter recommendations follow in the next section.

3.7 Policy recommendations

The purpose of this case study is to estimate the impact of EU policy related to automation and control systems (BACS). Our focus lies on the *Energy Performance of Buildings Directive (EPBD)*, which fosters smart buildings and BACS. To estimate the final energy demand savings, we represent the requirements of the EPBD using a previously developed modelling approach.

The resulting energy savings illustrate what can be expected if the EPBD is implemented in every member state. If highly efficient smart building systems are deployed for ventilation, room air conditioning and lighting in larger and medium-sized non-residential buildings, we estimate that energy savings in 2030 reach over 9%.

We conclude that the directives and national regulations, which are already implemented, have a measurable effect. More energy savings might be achievable if economically less feasible options are supported (see next Section).

It is noteworthy that the potential in single subsectors and building types differs. This suggest that single sectors could be supported by targeted information campaigns (Section 3.7.2). In Section 3.7.3, we recommend collecting more detailed data provision for future empirical studies to eliminate methodological uncertainties, e.g., related to self-consumption.

3.7.1 Support to increase potential

The average investment costs for a full-fledged BACS system (i.e., level-A BACS) lie between 200-275 €/m2 (see Appendix 4.A.1.4). Although industry associations highlight the cost-effectiveness of smart building systems (Martin, 2021), the financial feasibility is not necessarily granted as it depends on the specific circumstances, capital and O&M costs, as well as energy prices. The EC estimates that BACS may not be feasible in some of the existing building stock (EC, 2021; eu.bac, 2019). In such cases, the EPBD directive does not require the installation of BACS. Policymakers could argue that these are missed energy efficiency opportunities.

While the share of existing buildings in which BACS lead to high upfront costs may be comparably small, they might still contribute to overall energy savings and contribute to (climate and energy) policy goals. Therefore, to increase diffusion rates beyond what we have assumed, and to reap any high-hanging fruits, national policymakers might encourage building owners to tap into the full energy saving potentials by providing financial support.

Several countries already have support policies for BACS measures in place, e.g., Germany and Italy (Martin, 2021). These support programs entail tax breaks, low-interest loans, or grants. Their purpose is to reach high BACS levels in buildings. Based on the experiences of these countries, we suggest that policymakers in other countries critically evaluate the policy trade-offs between fostering energy efficiency through smart buildings and BACS and other goals such as building renovations or the deployment of renewable energy sources.

To assess the need for additional support, future research needs to simulate the maximal energy saving potential of BACS, beyond the economic feasibility. Potential methods would be to not consider costs as a limiting factor, increase diffusion rates or to implement more advanced policy modules. The latter, e.g., using FORECAST, could assist in assessing the need for support policies in specific national contexts.

3.7.2 Differences between subsectors

Our results suggest that the effect of BACS, and hence the application of smart building applications, differs between tertiary subsectors. This result is due to the different full load hours in different sectors, as the diffusion assumptions of BACS ESOs are assumed to be the same in all sectors. Such differences are evident considering the heterogeneity of different subsectors, e.g., cooking in restaurants versus office work in finance, or air conditioning demand in the retail sector.

Previous studies have highlighted the need to adapt the smart readiness indicators and methodology to different building types (Fokaides et al., 2020; Plienaitis et al., 2023). Our results illustrate the need to consider the different subsectors, as well. As subsectors like trading or finance offer large energy saving potentials if they adopt highly efficient BACS, policymakers could focus on such sectors. Through targeted information campaigns, actors in the subsectors, or their associations, could be made aware of the potentials and support policies to adopt efficient measures.

3.7.3 Monitoring and data expansion are essential

Energy monitoring is a prerequisite to qualify as BACS systems of level A or B. Periodical monitoring and energetic operational optimisation are indeed preconditions to reap any energy saving potentials of BACS (Jakob et al., 2016). In badly adjusted or operated system, Jakob et al. argue that BACS might even have a negative impact on energy saving efforts (see Section 3.4). Furthermore, monitoring generates valuable data to empirically investigate the real-world effects of BACS, which we recognise as gap in the current literature (Section 3.6.4).

The EPBD mandates the monitoring of the building stock, stating that digital tools will facilitate the integration of data in the EU Building Stock Observatory. Currently, aggregated energy data is collected. With the EU-wide adoption of BACS, policymakers should consider expanding data collection to the performance of individual BAC systems. Such data provides the means to research the energy saving potentials of BACS more accurately, thereby overcoming current gaps about the real-world effects of these systems.

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4. Conclusion

This report aimed to evaluate the impact of two distinct policies in the industry and tertiary sector of the EU. Even though the related literature has already modelled sectoral scenarios with a strong focus on economic instruments, this report expanded the analysis to non-economic instruments against the backdrop of new societal trends. This was done by analyzing two policy cases for buildings. The first case analyzed green public procurement (GPP) creating a market pull for circularity in buildings, affecting the material demand in the industry sector. The second case evaluated a technology push for building automation and control systems (BACS), affecting final energy demand in the tertiary sector.

Firstly, GPP is a versatile instrument due to the different design options addressing diverse value chain stages and circular economy actions. Nevertheless, the share of public activities in the construction sector is small compared to the other contractors. Consequently, GPP is only relevant in the short to medium term for the two following reasons. On the one hand, GPP can create lead markets for products that are deployed via technology-push policies. On the other, GPP enables policymakers to gather experience for the roll-out of policies that foster circular economy in the entire construction sector. Overall, it is important to align GPP with other policy instruments, e.g. product standards and waste legislation, for efficiently exploiting the potentials of a circular economy for buildings.

Secondly, the obligation to expand BACS in large non-residential buildings, and medium-size buildings, representing almost 60% tertiary floor area (considering lower policy compliance), leads to considerable and economically viable energy savings. More energy saving potential might be reached through highly efficient BACS. However, the economic viability of such systems is not given in every building, therefore, policymakers may consider additional support if they need to fulfill ambitious energy goals. Such support policies are already implemented in a few countries and act as role model on how to reap the expensive "high-hanging" fruits in smart buildings. Furthermore, these policies may have to be differentiated by the heterogeneous subsectors.

Both cases show that non-economic instruments play a relevant role when exploiting the potentials of new societal trends, such as circular economy and digitalization. The mentioned trends can contribute significantly to reduce final energy demand and GHG emissions. The cases highlight that both mechanisms, technology-push and market-pull, are necessary for comprehensive target achievement. Consequently, such policies should be considered by policy makers and aligned with the overall policy mix addressing climate neutrality. Future research should extend the limitations of current model approaches, especially regarding data availability.

A.1 Appendix: Modelling of potentials (from D6.2)

The following chapter is based on report of D6.2 (Steck et al., 2023) and describes the method and how we derive potentials for BACS in the policy case study

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.

A.1.1 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 automation norm (EN 15232).[13] 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 7). 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

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[13] From 2023 onwards, only 52120 is the applicable norm. In this version of D6.2., the previous version, which has the same BACS-factors, was used.

heating or office ICT energy services mainly save energy by reducing the installed power[14].

Table 7 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 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.

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[14] Installed power is not strongly affected by BACS.

Table 8 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).

A.1.2 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 A.1.1). 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 9 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; Jakob et al., 2012; Wietschel et al., 2011)

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 9). Existing ESOs with effects on FLHs already contain some BACS functions and have already considered some energy savings from BACS (Table 10). 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.[15]

A.1.3 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[16], 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, 2016; Ott et al., 2009; Wietschel et al., 2011), interviews, norms and standards about thermal energy (SIA 380/1).

We compare BACS coverage in previous FORECAST models in Table 10. If the average savings in Table 10 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 additional energy saving options (see next Section). For the ESOs which exceed 100%, A-level BACS will not lead to additional energy savings in the modelling.

Table 10 Average savings over all countries form existing MEPS and AEPS in FORECAST. 100% denotes the savings achievable by A-level BACS.

Sub-sector	Circu-lation pumps / heating aux.	Cooling in Server-rooms	Lighting	Room Air Condition ing	Ven-tilation	Average BACS coverage
Education	63%	53%	49%	53%	86%	61%
Finance	53%	31%	43%	31%	53%	43%
Health	157%	NA	150%	NA	143%	150%

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[15] For the subsectors, “other services” and “traffic and data transmission”, no building types are mapped. These subsectors are out of scope.

[16] In some subsectors and applications even the full BACS-potential, see Table 10. For these sectors, no additional A-level BACS are assumed.

Sub-sector	Circulation pumps / heating aux.	Cooling in Server-rooms	Lighting	Room Air Conditioning	Ventilation	Average BACS coverage
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%

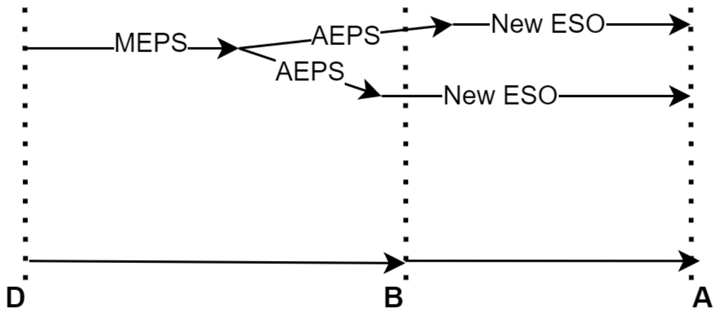
Source: Based on a comparison of full load hour savings from A-level BACS and MEPS/AEPS of the 4th version of FORECAST

A.1.4 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 15).

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 **Fehler! Verweisquelle konnte nicht gefunden werden.**).

Figure 15 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 (GRYPS, 2023; Rüesch, 2014). These indicate that investment costs per square meter floor area are very heterogenous but, on average, range from under 100 € to over 200 € per m² 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 11. Applying this ballpark figure, costs reach 200-300 € per m², 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 11 Aggregated investment costs of existing and new ESOs in € per driver (€/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	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 12 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.

Imprint

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