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RESEARCH ARTICLE

Transition pathways for the European building sector: Comparison of environmental savings from sufficiency, consistency, and efficiency measures

Patrick Zimmermann*, [1]

Abstract • This article addresses the lack of data about the environmental savings potential of sufficiency measures in the European building sector by using the EUCalc tool. The savings potentials of different sufficiency, consistency, and efficiency measures in the impact categories greenhouse gas emissions, energy, and renewable as well as non-renewable resources are calculated. With sufficiency measures, a total of 16 % of GHG emissions can be saved compared to an EU past trends scenario. Efficiency and consistency measures save 31 % and 22 %, respectively. The most effective sufficiency measure is a reduction of living space per capita. The results vary between the impact categories studied.

***Transformationspfade für den europäischen Gebäudesektor**: Vergleich von Umwelteinsparungen durch Suffizienz-, Konsistenz- und Effizienzmaßnahmen*

Zusammenfassung • *Dieser Artikel adressiert die ökologischen Einsparpotenziale von Suffizienzmaßnahmen im europäischen Gebäudesektor. Unter Verwendung des EUCalc-Tools werden die Reduktionen verschiedener Suffizienz-, Konsistenz- und Effizienzmaßnahmen in den Wirkungskategorien Treibhausgasemissionen, Energie und erneuerbare sowie nicht erneuerbare Ressourcen berechnet. Durch Suffizienzmaßnahmen können insgesamt 16 % der THG-Emissionen im Vergleich zu einem EU Past Trends-Szenario eingespart werden. Durch Effizienz- und Konsistenzmaßnahmen lassen sich analog 31 % bzw. 22 % einsparen. Die wirksamste Suffizienzmaßnahme ist die Verringerung der Pro-Kopf-Wohnfläche. Die genauen Ergebnisse variieren zwischen den untersuchten Wirkungskategorien.*

Keywords • *sufficiency, consistency, efficiency, buildings, emissions*

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Introduction

The building and construction sector has a major impact on Europe's ecological footprint, accounting for 36 % of greenhouse gas (GHG) emissions and 40 % of energy consumption (European Commission 2020 a). Construction also contributes to almost 36 % of total waste generated (ECSOEU 2020).

To reduce these negative environmental impacts, political actions have so far relied primarily on technological approaches as can be seen, for example, in the Energy Performance of Buildings Directive (EPCEU 2021), the 'Renovation Wave' (European Commission 2020 b) and the New European Bauhaus Initiative (ECJRC 2021). All of these approaches focus on either efficiency – through thermal insulation and renovation – or consistency – through natural or circular building materials and renewable energies.

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But with the current policies alone, GHG emissions, for example from residential buildings, will decrease by only 30 % by 2050 (Kruit et al. 2020). The reasons for this include lack of ambition, mainstreaming and implementation (Staniaszek et al. 2021), but also the occurrence of rebound effects – especially as rising per capita living space counteracts square meter-related energy savings (Bierwirth and Thomas 2015) – and the failure to take sufficiency into account.

This article, therefore, aims to quantify what savings in terms of GHG emissions, energy demand, and renewable and non-renewable resource demand can be achieved with building-related sufficiency measures in Europe. For comparison purposes, the potentials for efficiency and consistency measures were also calculated. The potentials are theoretical maximum values without taking into account implementation difficulties or rebound effects.

What savings in terms of greenhouse gas emissions, energy demand, and renewable and non-renewable resource demand can be achieved with building-related sufficiency measures in Europe?

In general, sufficiency is defined as "modification of consumption patterns that help to respect the Earth's ecological limits, while aspects of consumer benefit change" (Fischer and Grießhammer 2013, p. 5). Therefore, sufficiency complements solely technical approaches to efficiency and consistency with a strong orientation towards people's basic needs (Over et al. 2021, p. 204).

Translated into buildings, this means "an appreciative, needs-oriented and environmentally friendly approach to the use of existing resources, that is, land, material and natural resources" (Over et al. 2021, p. 204, author's translation). Therefore, the preservation and renewal of existing buildings has to be a priority. Only if the corresponding requirements cannot be met in this way can extensions to the existing building stock be considered, and only in absolutely exceptional cases new buildings. (Deutscher Städtetag 2021, p. 6). In addition, other important sufficiency aspects that can be found in the literature are the reduction of per capita living space (e.g., through shared living concepts), low-tech construction and energy concepts, participatory planning processes, and needs-based building operation (Zimmermann 2018).

Quantifying building-related sufficiency measures in Europe

While the savings potentials of technological sustainability strategies have been quantified in many cases, calculations are still missing for sufficiency. Only a few studies consider building-related sufficiency aspects at all. They look either at the global (Grubler et al. 2018; Kuhnhenn et al. 2020), national (Association négaWatt 2018; Cordroch et al. 2021; Purr et al. 2019; Sterchele et al. 2020) or regional level (Steinbach and Deurer 2021) and are, with one exception (Purr et al. 2019), limited to GHG emissions and energy demand. Currently, there is no scenario that focuses on the building and construction sector and examines other impact categories besides GHG emissions at the European level.

Method

To quantify these potentials, a modeling approach based on the European Calculator and the corresponding web interface Transition Pathways Explorer is used (hereafter referred to as EUCalc). It aims to bridge the gap between conventional, complex, "integrated climate-energy-economy models and the practical needs of decision-makers" (Strapasson et al. 2020, p. 5). The geographical scope of EUCalc is EU27, including the UK and Switzerland. The model consists of 15 interdependent modules that represent the supply and demand side in all sectors. Users can choose between four ambition levels in different individual levers, which are divided into superordinate lever groups and topics, and thus create scenarios for which the tool models the European-wide impacts in all sectors up to the year 2050 (Climate Media Factory UG n.d.; Pestiaux et al. 2019; PIK n.d.; Strapasson et al. 2020).

In this paper, the term *building sector* refers to all levers that have an influence on the life cycle of buildings of any type of use (residential and non-residential), including its household appliances. *Key behaviors* include all levers of the lever group *homes* as well as household appliance-related levers from the lever group of *consumption*. The entire lever group *buildings* was selected from the *technology and fuels* topic. In the lever group *manufacturing*, all levers except carbon capture technologies were also included because they influence the production of building materials and thus the environmental impacts along the life cycle of buildings. Since there is a direct link to buildings through the local production of renewable energies on roofs and facades, the lever *solar* energy was also examined from the lever group *power* (Climate Media Factory UG n.d.; PIK n.d.).

It should be noted that the levers in *manufacturing* and *power* also have an impact outside of the building sector. One example is that through more renewable energies in the electricity mix the mobility sector is also decarbonized via electromobility. This circumstance cannot be avoided entirely with the EUCalc and must be taken into account when interpreting the results. Despite this disadvantage, EUCalc was selected because, on the one hand, it allows several impact categories to be cal-

Name	Lever	Lever group	Past trends values¹	Scenario values²	Explanation
S_Appl_own	Appliances owned	Homes	 1 0.7 0.45 1.1 0.8 1.4 2.5 1.5	 0.8 0.5 0.4 1 0.5 1.1 1.3 1	Number of appliances per household in 2050: Washing machines Dishwashers Dryers Fridges Freezers TVs Computers Phones (per person)
S_Appl_use	Appliance use	Homes	 0.45 1 0.45 24 24 2 4,3 24	 0.3 0.7 0.3 24 24 1 1 24	Daily use of appliances per household in hours in 2050: Washing machine Dishwasher Dryer Fridge Freezer TV Computer Phone (per person)
S_Appl_rt	Appliance retirement timing	Consumption	 96 % 93 % 93 % 96 % 96 % 83 % 90 % 90 %	 110 % 110 % 110 % 110 % 110 % 130 % 130 % 130 %	Replacement factor in % of product lifetime in 2050: Washing machine Dishwasher Dryer Fridge Freezer TV Computer Phone (per person)
S_Cool	Percentage of cooled living space	Homes	21.8 %	10.6 %	Residential living space is cooled in 2050
S_Comf	Space cooling & heating	Homes	18 °C	20 °C	Cooling comfort temperature
S_m2	Living space per person	Homes	55 m²/cap	37 m²/cap	Living space per person in 2050
E_Appl	Appliance efficiency	Buildings	B	E	Appliances with A+++ EU energy label in 2021 will be rated in 2050 as …
E_BE	Building envelope	Buildings	1 % 80 / 15 / 5 %	3 % 0 / 30 / 70 %	Renovation rate Share of new constructions and renovations with lowest/medium/highest level of efficiency (–30/40/60 % useful energy demand compared to average building stock)
E_DH	District heating share	Buildings	8.4 %	16.5 %	District heating share in 2050
E_Ene	Energy efficiency	Manufacturing	3–8 %	10–24 %	Range of increased energy efficiency across sectors
E_HC	Heating and cooling efficiency	Buildings	3 % / 5 %	18 % / 31 %	Efficiency increases for heating systems: fossil/biomass
E_Mat	Material efficiency	Manufacturing	2–8 %	10–33 %	Improvement rate ranges depending on the product and material
E_Tec	Technology efficiency	Manufacturing	No major shifts	Heavily electrified Up to 20 % 24 %	Electrification of iron and steel process Use of geopolymers in cement production Average share of secondary production routes

Name	Lever	Lever group	Past trends values[1]	Scenario values[2]	Explanation
C_Fuel	Fuel mix	Manufacturing	No major shifts	Full potential is exploited	Electrification of heat, use of zero-carbon hydrogen, and a switch to sustainable biomass
C_Mat	Material switch	Manufacturing	No major shifts	approximately 30 %	Substitution of carbon-intensive materials with lightweight materials
C_TFS	Technology and fuel share	Manufacturing	No major shifts	Almost complete	Fossil fuel phase-out for all fuels across Europe
C_Solar	Solar	Power	200	700	Gigawatt Photovoltaic and Concentrating Solar Power in 2050

1 Equals the lowest ambition level (1) in EUCalc.
2 Equals the highest ambition level (4) in EUCalc.

Tab. 1: Analyzed individual measure scenarios. *Source: author's own compilation based on data from Climate Media Factory UG (n.d.) and PIK (n.d.)*

culated with the same tool and thus the same framework conditions. On the other hand, behavioral changes and thus central sufficiency measures can be taken into account very well and independently through exogenous lever inputs (Costa et al. 2021).

The calculations for this paper were performed in the period April–November 2021, and results are consequently based on the EUCalc version of this period.

Scenarios

The starting point for the definition of my measures and scenarios is the past trends scenario stored in EUCalc[1] (Climate Media Factory UG n.d.). In this basic scenario, past trends in the EU are largely projected into the future. It was chosen as a starting point because it allows for a comparatively undisturbed view of the individual measures. If other baseline scenarios had been used, there would have already been assumptions in the building and other sectors, which is why the calculated savings potentials would have to be interpreted against this background. With the past trends as a baseline, on the other hand, it is easier to calculate (theoretical) maximum savings. This makes a simpler comparison between the three sustainability strategies possible. One disadvantage is that current (political) developments are not sufficiently taken into account. However, since the goal is not to develop a comprehensive and realistic emission reduction pathway, the chosen approach is adequate.

The past trends pathway forms the basis for the creation of the individual measure scenarios listed in Table 1, with each being assigned to one of the three sustainability strategies. The boundary conditions and settings on resources and land use as well as all other measures – not relevant for this study (e.g., in the lever groups travel, transport, and food) – were not varied.

An overview of the 17 single measures investigated is given in Table 1. The classification regarding efficiency (E), consistency (C), and sufficiency (S) was made independently.

1 The full scenario explanations can be accessed via the EUCalc Transition Pathways Explorer.

The individual measure scenarios were summarized for each of the three sustainability strategies (S_Sum, E_Sum, C_Sum). There are also combination pathways that combine the two technical approaches (EC_Sum) and all three – representing the best case (ECS_Sum).

Impact categories

The following impact categories were analyzed to compare the environmental performances of the scenarios and pathways. They all refer to the period from 2020 to 2050 and include all sectors, not only buildings, to assess the impact on and relevance to society and the economy as a whole. "Intra and extra EU27+2 trade dynamics" (Costa et al. 2021, p. 3), as well as trade with the rest of the world, is also taken into account via EUCalc (Clora and Yu 2020; Price et al. 2019).

- *GHG emissions:* Following the GHG budget approach (WBGU 2009), the sum of all GHG emissions in all sectors from 2020 up until 2050 is calculated in gigatons [Gt]. As the EUCalc model only provides values in five-year steps, linear interpolation was performed to calculate the total emissions.
- *Energy demand:* The final energy demand across all sectors in 2050 in TWh/a was calculated and compared.
- *Non-renewable resource demand:* Is defined as the sum of sand demand for cement and glass production plus iron demand for steel production that is used in buildings, infrastructure, and household appliances. It is calculated as the sum from 2020 to 2050 megatons [Mt].
- *Renewable resource demand:* Summarizes wood demand as building material and for bioenergy. Interpolation and summation are analogous to GHG emissions. The unit is megatons [Mt].

Results

The results of the calculations are compared below, sorted by the various impact categories. The achievable savings in brackets are a comparison with the past scenario. The results in each case

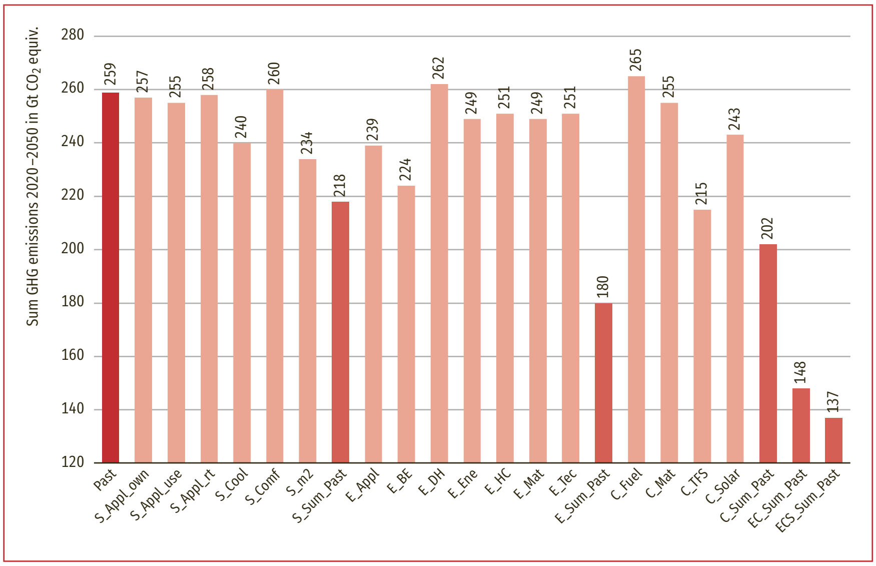

Fig. 1: Sum of European greenhouse gas emissions in all sectors from 2020 to 2050 by scenario.
Source: author's own compilation based on EUCalc results

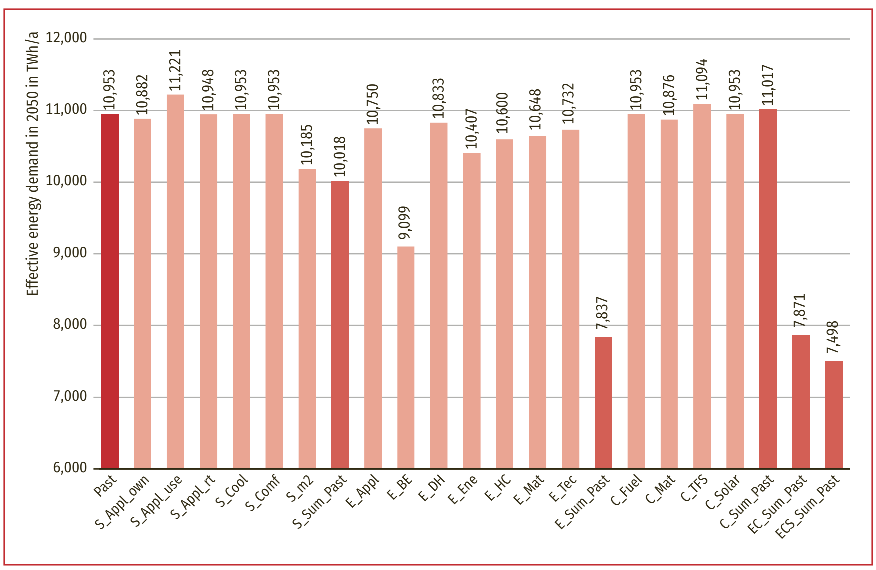

Fig. 2: Effective energy demand in 2050 by scenario.
Source: author's own compilation based on EUCalc results

represent totals across all sectors. It needs to be mentioned again that due to the definition of the scope of this study, the efficiency and consistency scenarios related to the lever groups *manufacturing* and *power* also have impacts on other sectors than buildings and therefore have higher reduction potentials. This must be taken into account when interpreting the results.

Greenhouse gas emissions

As can be seen in Fig. 1, the two most effective sufficiency measures are S_m2 (–10 %) and S_cool (–7 %), which are both below the top five of the individual measures. The highest reductions are achieved in C_TFS (–17 %) and E_BE (–14 %). Some measures also lead to higher emissions than the past scenario. One example is E_DH. Due to the individual adjustments of the individual measures, in this case the sole conversion to district heating without a simultaneous switch to renewable energies (C_TSF) does not lead to savings. In sum, all the sufficiency measures combined lead to a 16 % reduction of the GHG emissions and are thus clearly behind those of efficiency (–31 %) and consistency (–22 %). The sum of all measures examined leads to a reduction in total GHG emissions of 47 %.

Energy

Fig. 2 shows that the only sufficiency scenario reaching noticeable energy savings is S_m2 (–7 %). E_BE saves the highest amount of energy (–17 %). In principle, it is primarily the efficiency measures that achieve savings. Consistency measures, except for C_Mat (–1 %), do not achieve any savings, but even lead to additional demands (C_TFS: +1 %). That is also the case for the summarizing consistency pathway (C_Sum: +1 %). The sufficiency measures can save 9 %, the efficiency measures 28 %, and the summarizing pathway 32 % in energy demand.

Non-renewable resource demand

Also, in this impact category – the results are shown in Fig. 3 – S_m2 achieves the highest reduction from the sufficiency scenarios (–9 %) while the others can be neglected. In sum, all the sufficiency measures lead to savings of 10 % (S_Sum). The highest overall savings are reached with E_Mat (–10 %). But in the efficiency sum scenario, this is compensated by E_BE, which increases the non-renewable resource demand through the high number of new constructions (+13 %). Therefore, the E_Sum pathway leads to higher consumption (+2 %). From the consistency measures, only C_Mat shows a significant reduction potential (–3 %), which is the same result as for C_Sum.

Renewable resource demand

The only sufficiency measure achieving reductions here (Fig. 4) is S_m2. With 61 % savings, it is by far the most effective scenario of all. Most of the other measures – especially efficiency and consistency – only reduce the wood demand by about 1 %.

In contrast, E_BE and C_Mat lead to an increase in renewable resource demand by 9 % and 43 %, respectively. The reason for this increase is the huge amount of demolition and new construction (E_BE) as well as the ambitious switch from building materials like concrete to wood (C_Mat). It is the same for the sum scenarios. Even here, S_m2 is more successful in reducing the demand than the maximum pathways ECS_Sum (–16 %). In this impact category it can also be seen that the combination of the two technological sustainability strategies has a positive interaction as the difference between EC_sum_Past and C_sum_Past is higher than the difference between E_sum_past and Past.

Fig. 3: Sum of European non-renewable resource demand in all sectors from 2020 to 2050 by scenario.
Source: author's own compilation based on EUCalc results

Comparison with other basic scenarios

The previous results all refer to the past trends scenario as the basis. Table 2 shows the reduction potentials of the sum pathways compared to other basic scenarios from EUCalc. Detailed descriptions of those basic scenarios can be found in the EUCalc documentation (Climate Media Factory UG n.d.; PIK n.d.).

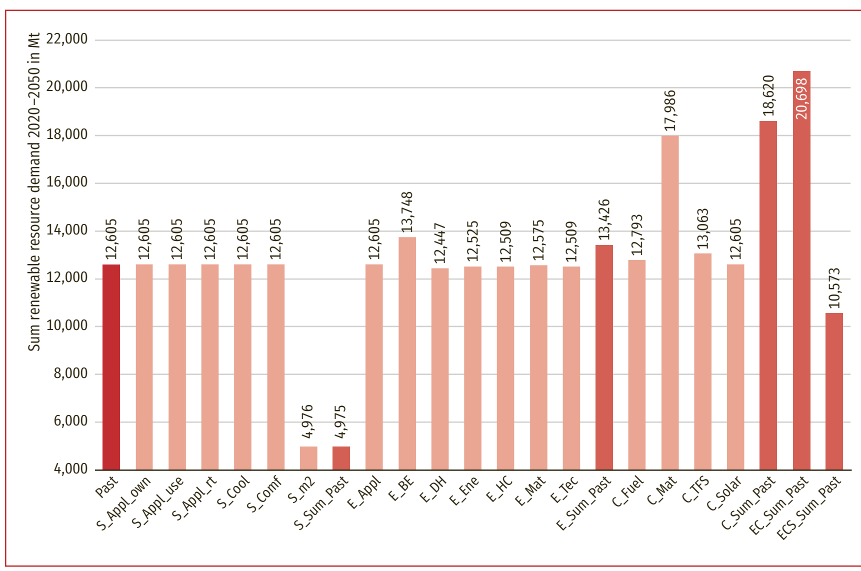

Fig. 4: Sum of European renewable resource demand in all sectors from 2020 to 2050 by scenario.
Source: author's own compilation based on EUCalc results

- *EU reference* (EU_ref) is based on a modeling of a European reference scenario commissioned by the EU Commission, which meets the GHG and renewable targets for 2020 and implements other agreed climate protection measures (Capros et al. 2016).
- *LTS baseline* (LTS_base) is based on the simulations conducted as part of the scenario development for the 'European strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy' (European Commission 2018).
- *Ambitious*: Here, an unprecedented transformation is assumed. Very ambitious efforts are made to reduce emissions, both in terms of behavioral changes and technology.

Conclusion

The results show significant savings through sufficiency across all impact categories. It achieves the highest savings in renewable and non-renewable demand where the technological strategies can lead to overconsumption, even though savings from efficiency and consistency tend to be overestimated due to the selected method. For greenhouse gas emissions, on the other hand, efficiency and consistency are ahead of sufficiency. In terms of energy consumption, efficiency achieves the greatest savings, followed by sufficiency, while consistency results in increased demand. The most effective sufficiency measure in all impact categories is the reduction of living space per capita. The most effective efficiency and consistency measures vary between the impact categories. A combination of all three sustainability strategies shows the highest savings across all impact categories examined, with the exception of renewable resource demand.

Scenario	GHG emissions	Effective energy demand	Non-renewable resource demand	Renewable resource demand
S_Sum	−10 %	−9 %	−10 %	−61 %
E_Sum	−32 %	−28 %	+2 %	+7 %
C_Sum	−22 %	+1 %	−3 %	+48 %
EC_Sum	−43 %	−28 %	−3 %	+64 %
ECS_Sum	−47 %	−32 %	−10 %	−16 %
EU_ref	−20 %	−18 %	−4 %	+39 %
LTS_base	−41 %	−26 %	−4 %	+9 %
Ambitious	−91 %	−69 %	−31 %	+2 %

Tab. 2: Comparison of sum pathways with different basic scenarios. Numerical values given refer to percentage reductions compared to the past trends scenario.
Source: author's own compilation based on EUCalc results

Given its significant savings potentials, sufficiency measures must be increasingly considered in further European modeling to make the results more reliable. Sufficiency also needs to be addressed with policy instruments so that the theoretical savings can actually be realized. Special attention or additional studies should be devoted to rebound effects, which have not been investigated in this work. Additionally, it is particularly important to consider equity and justice aspects in order to ensure the acceptance of necessary (major) behavioral changes.

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