Overcome data gaps to benchmark building stocks against climate targets related to the EU taxonomy and other decarbonisation initiatives

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Overcome data gaps to benchmark building stocks against climate targets related to the EU taxonomy and other decarbonisation initiatives

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Abstract. National disclosure regulation is more and more flanked by stricter requirements of climate reporting. Industry stakeholders with more than 250 employees will for example be required to report on the share of their CAPEX and OPEX that is in line with the 2050 climate targets of the EU. Financial institutions are required to declare how much of their investment is in 2050 target compatible assets. Investment in buildings is an important part of such reporting and there is need of a robust approach and method to be used. The presented project developed such an approach. With reference to the work of the EU Technical Expert Group on Sustainable Finance and the Climate Bond Initiative (CBI), generally applicable criteria for buildings have been determined and calculated for the example of Switzerland. They are based on a best-in-class approach. While the EU Technical Taxonomy refers to the top 15% of buildings in terms of primary energy demand, CBI uses CO2-emissions as a benchmark. To compare the current state of buildings sector with these criteria, a distributional building stock model is used, which also addresses the fact that the data availability on energy efficiency and climate compatibility of the building stock is unsatisfactory in many European countries including Switzerland. To be easily applicable in practice, the criteria are mainly based on two dimensions: on the one hand, on the requirements of codes (in Switzerland the model regulations of the Cantons, MuKEn) and widely used standards and labels (Minergie, GEAK), and on the other hand, on the energy sources used for the generation of space heat and hot water. The study shows that ecologically sustainable, climate-compatible building financing can always be assumed in Switzerland if one of the following two criteria are met for new buildings: multi-family, office or other non-residential buildings according to Minergie from 1998 on, MuKEn from 2000 on or GEAK B that use heat-pumps, wood, pellets or solar energy. Or, any building with Minergie from 2009 on label, MuKEn 2014 or GEAK A that use heat pumps, wood, pellets, solar energy or district heating based on non-fossil energy. In the context of increased pressure on resources, it is important to acknowledge the climate-compatibility of older buildings as well (and to not only consider newly which would generate a bias towards resource intensive building of new houses).

1. Introduction

Around 36% of the energy consumed worldwide is currently used for the construction and operation of buildings. These cause 39% of CO2 emissions. In Switzerland, about a quarter of direct CO2 emissions are attributable to buildings. A significant increase in the energy and CO2 efficiency of buildings is therefore of central importance for the effective containment of global warming. The Swiss Heat

Initiative (WIS) and the Energy Perspectives 2050+ show ways in which decarbonization of the building sector can be achieved [1,2].

In order to achieve such decarbonization, investment and renewal decisions must be made by a large number of stakeholders. They need guidance as to which buildings and energy renewal measures are considered climate-friendly. The following groups of players are in the foreground: (1) Building owners, from single-family home owners to real estate portfolio owners, (2) Developers of buildings and sites, (3) Real estate and real estate portfolio managers and managers, (4) Investors in real estate companies and funds, and (5) Financial institutions such as banks and, increasingly, also pension funds.

Specific criteria are required to characterize construction projects, buildings and building renovations as climate-friendly. Approaches for such criteria are developed and proposed by various sides. These differ with regard to degree of concretization (action plan, legal framework, directive, regulation, initiative, label, etc.), focus (individual buildings, portfolios) and target group. The following should be mentioned, amongst others: (1) Work of the EU Technical Expert Group on Sustainable Finance, (2) Science Based Targets Initiative (SBTi), (3) Climate Bonds Initiative (CBI), (4) Partnership for Carbon Accounting Financials (PCAF), (5) Global Real Estate Sustainability Benchmark (GRESB), and (6) Paris Agreement Capital Transition Assessment (PACTA). In some cases, however, these are generic, rather general guidelines that do not contain any specific statements and criteria. Accordingly, the question arises as to how the various efforts can be concretized so that they can be applied in practice by the financial, construction and real estate sectors. This question was addressed, among others, in a study by Raiffeisen Switzerland and TEP Energy [3]. The following article summarizes the results of this study and supplements them with further elements.

2. Overview of different approaches

2.1 Report of the EU Technical Expert Group on Sustainable Finance

When defining criteria that are decisive for the qualification of building financing as ecologically sustainable and climate-friendly, the EU Technical Expert Group (TEG) distinguished in its final report [11] pp. 369-379 between four different types of "economic activities":

1. Construction of new buildings Buying and owning buildings that were built before the end of 2020
2. Renovations of buildings
3. Individual measures and professional services
4. Acquisition and ownership

Building on this distinction, the TEG defines criteria for environmental sustainability, with the criteria being identical for cases "construction of new buildings" and "purchase and ownership of buildings built after 2021". The approach of the TEG is based mainly on the primary energy requirement of a building, which needs to be limited (e.g 20% lower than national regulation for new constructions, at least 30% of savings in case of large renovations). For the future the TEG encourages the Sustainable Finance Platform to establish a set of criteria based on GHG emissions. From 2025 the best 15% of the building stock in terms of emissions per square meter would be defined eligible [11] pp. 372-374.

2.2 The Greenhouse Gas (GHG) Protocol

The GHG Protocol is an important basis when it comes to accounting for greenhouse gas emissions from economic activities. In doing so, a distinction is made between different so-called scopes. In particular, a distinction is made between direct emissions (e.g. from companies or building owners) from indirect emissions (e.g. from tenants or from energy suppliers).

- Scope 1: Direct emissions (emissions from burning fossil fuel).
- Scope 2: Indirect emissions from the generation of district heating, electricity and any other secondary energy carrier
- Scope 3: Includes, among other things, so-called embodied energy and embodied emissions from the preparation and production of materials and energy carriers (unless already covered in Scope 2).

The development of the GHG Protocol is coordinated by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). Numerous other standards are based on the GHG protocol (including ISO 14064) or refer to it (including SBTi, PCAF, CRESB).

2.3 Science based targets (SBT)
So-called science-based targets are an important approach to achieving climate policy goals. Emission reduction targets for companies are derived from climate science requirements. The Science-Based Target Initiative (SBTi) is an initiative consisting of CDP, UNGC, WIR and WWF and shows companies a path to reducing greenhouse gas emissions towards a climate-friendly corporate strategy [4].

2.4 Partnership for Carbon Accounting Financials (PCAF)
The Partnership for Carbon Accounting Financials (PCAF) is a global industry initiative to standardize the measurement of greenhouse gas emissions for the financial sector. PCAF does not focus on individual buildings or renovation projects, but on real estate portfolios. The aim of PCAF is to measure and report on portfolio issues using a consistent and harmonized approach. Six asset classes are covered, with commercial real estate and mortgages being relevant from the perspective of the building sector, on the one hand, and (listed) bonds and equity investments (related to green bonds), on the other.
According to its own statement, PCAF has been audited by the GHG Protocol and approved as compliant with the Corporate Value Chain (Scope 3) Accounting and Reporting Standard and has the official "Built on GHG Protocol" mark.
PCAF is also incorporated into the work of other climate initiatives and is coordinated with them. These include financial sector disclosure under the Carbon Disclosure Project (CDP), the Science-Based Target Initiative (SBTi) and the Task Force on Climate-related Financial Disclosures (TCFD).

2.5 The Climate Bonds Initiative (CBI)
Another recognized example of criteria for qualifying buildings as ecologically sustainable is provided by the Climate Bond Initiative (CBI). CBI is an international organization that aims to mobilize the $100 trillion bond market for climate change solutions. It is supported by Switzerland, among others, and defines climate compatibility standards for various economic activities, including buildings [5].

2.6 Differences and similarities between the report of the EU TEG and CBI
The report of the EU TEG will be discussed in more detail below, which, among other things, can also be used as the basis for further (specified above) initiatives, and on the Carbon Bonds Initiative (CBI). A key difference between the two is the leading indicator, which is in focus in each case. In the EU report, this is based on the primary energy indicator. CBI formulates a more uniform set of criteria for qualifying buildings as "climate-friendly" and is already focusing on CO2 emissions instead of primary energy [5]. The TEG also focuses on primary energy requirements when building renovations are concerned, while CBI is taking the improvement in CO2 intensity as a benchmark. In the following, based on the approaches of the TEG and of CBI, it is analysed how criteria can be defined in a Swiss context that qualifies building financing as ecologically sustainable. The use case of individual buildings and measures is discussed below (the use case of real estate portfolios and building stocks is the subject of further work by the authors, including on the calculation of the building stocks of the Cantons and companies in the financial and real estate sector).

3. Applying the criteria in a Swiss context
Based on Hofer, Jakob et al. [3] the following shows in detail how criteria for determining ecologically sustainable, climate-compatible buildings in Switzerland can be derived based on the approaches of the TEG and the CBI. The two approaches are "operationalized" for the Swiss context and translated into specific requirements. In doing so, the five "economic activities" identified by the TEG are summarised as follows:
- Building stock: Buildings that were built before the end of 2020.
- Building renovation: Comprehensive retrofits or renovations and individual measures
- New building: Construction of new buildings, purchase and ownership of buildings built after 2020

3.1 Building stock
The TEG relies on a "best in class" approach to financing the purchase or ownership of a building with completion by the end of 2020. The TEG is based on the ex-ante calculated primary energy demand and qualifies the best 15% of buildings in this respect as ecologically sustainable, named the top 15% below. The procedure is very similar to the CBI approach. However, CBI takes CO_2 emissions as a benchmark

and qualifies the top 15% of buildings measured in kg CO_2-eq/m^2 as climate-friendly. In the following, it will first be explained how the top 15% benchmarks are determined for different cases. It then shows which energy efficiency and energy carrier combinations can be used to achieve these.

3.1.1 Determining the Top 15% benchmark

Primary energy and GHG emissions depend primarily on the following influencing factors:

- Energy efficiency of the building, e.g. expressed as final energy per m2 of energy reference area (ERA), depending, among other things, on useful energy and efficiency of the energy converter (namely heating and hot water systems).
- Energy carrier used to cover final energy demand.
- Primary energy and GHG emission factor of the energy carrier used.

The latter depend on the selected system boundary. With reference to the EU taxonomy and CBI, the focus is subsequently placed on total primary energy (Scope 1-3) for the energy indicator and on direct emissions (Scope 1) and the sum of direct and indirect emissions (Scope 1-3) for the emissions indicator (which includes fossil related CO2 and the other main GHG according to IPCC 2013.

In accordance with European and Swiss standards, the following energy consumption is assigned to the building in the narrower sense: Heating, hot water as well as electricity for lighting, ventilation, air conditioning (cooling and humidification/dehumidification) and related auxiliary energy (e.g. for pumps, but not for elevators which are neglected). Other energy applications in buildings, i.e. user electricity such as electrical appliances, commercial refrigeration or information and communication technologies, that consume electricity, are not taken into account. Also, embodied primary energy and emissions from construction and energy renovation (e.g. from insulation material) is not included.

GHG emissions and primary energies are calculated based on the final energy demand and primary energy factors (PEF) and GHG emission factors (GHG-EF) according to KBOB 2009:2016 [6]. In principle, these are valid values throughout Switzerland.

The actual calculation of the top 15% for primary energy, direct and total GHG emissions, is carried out using the building stock model from TEP Energy and Sinom [7]. The building stock model is a bottom-up model that simulates the energy consumption per energy carrier and thus the CO_2 emissions as well as other evaluable variables. An example of a result of such a calculation is shown in Figure 1 the sum of the GHG emissions of Scope 1-3, referred to as “Total GHG emissions”. In doing so, a distinction is made between residential buildings (RB): single-family houses (SFH), multi-family buildings (MFH), and non-residential buildings (NRB) in general and (office buildings in particular. The NRB is a weighted average of different building types based on their area shares throughout Switzerland.

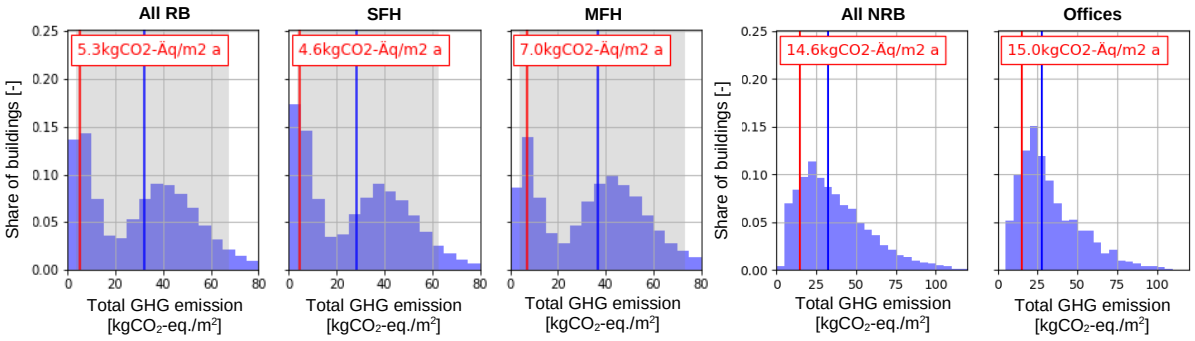

Figure 1. Top 15% limit value of the total GHG emissions for residential buildings (left) and for non-residential buildings and office buildings (right). The blue vertical line represents the median, the red, the 15% benchmark (top 15%).

Table 1. Top 15% values of primary energy demand, direct and total GHG emissions

	Primary energy [kWh/m²a]	Direct GHG-Emissions [kgCO_2-eq/m²a]	Total GHG-Emissions [kgCO_2-eq/m²a]
SFH	151	0.0	4.6
MFH	159	0.0	7.0
Offices	263	0.0	15.0
Other non-residential buildings	231	0.0	14.6

The top 15% values for total GHG emissions, which also include the upstream chains, are also shown in Table 1. The top 15% values for primary energy are also included. These are characterized by the TEG as "climate-friendly" when it comes to building financing. The top 15% figures for direct GHG emissions are now zero in Switzerland. This means that at least 15% of buildings of all buildings of the corresponding categories do not emit direct greenhouse gas emissions because they do not use fossil fuels at the building location. This is due to the frequent use of heat pumps in new buildings from the 1990s and to the use of wood and district heating in general. The evaluation of the Federal Register of Buildings and Dwellings (RBD) (focus on newer buildings built after 2000) and extensive surveys in 20 Cantons (focus on older buildings) support this finding [8].

3.1.2 Benchmarking MuKEn, Minergie and GEAK

The following is an analysis to determine which of the widely used standards, certification systems or regulations already guarantee the achievement of these top 15% values today. In this way, the corresponding values are operationalized and it is easy to identify whether buildings are in the corresponding top 15%. CBI explicitly recognizes the ability to designate appropriate "proxies" in the form of instruments such as standards, certification systems, or regulation. The NF Technical Expert Group is also addressing the issue.

The calculations are performed for a relevant selection of widely used standards, certification systems or regulations. Various versions of the energy-related model codes of the Cantons (MuKEn), various Minergie standards and the different classes of the Canton's building energy performance certificate (GEAK) of the Cantons are examined. In the calculation, a distinction is again made between single-family house, multi-family houses, offices and NRB. This is based on the "conservative assumption" of an unfavourable building envelope and a correspondingly high heat demand.

The analyses show that MuKEn, Minergie and GEAK alone do not always guarantee the achievement of the top 15% in every case: depending on the energy carrier used, even very efficient buildings can have relatively high GHG values and vice versa, low GHG values can be achieved with suitable energy carrier even in rather inefficient buildings (see Table 2). The energy carrier used for space heating and hot water therefore have a decisive influence on GHG emissions.

Because MuKEn, Minergie and GEAK alone do not sufficiently limit GHG emissions, eight cases with different energy carrier for space heating and hot water are being investigated in more detail. This approach deviates somewhat from the CBI approach and the recommendations of the TEG. These only mention standards and similar instruments in general, which need to be reviewed for their compatibility with the top 15% value. The procedure chosen here is more precise and allows the actual best buildings to be qualified as "climate-friendly" in terms of GHG emissions.

The results of the comparison of total GHG emissions according to the various MuKEn, Minergie and GEAK requirements with the 15% limit values per building category are summarized in Table 2. Appendix 2 in Hofer, Jakob et al. [3] specifies the method chosen for the calculation and the corresponding results in detail.

Since both the EU taxonomy and CBI assume a future reduction path, the assessment will also be made for the years 2025 and 2030. This is based on the simplifying assumption that a linear reduction path applies between the values of 2020 and 0 in 2050. All combinations of the Minergie, GEAK and MuKEn standards examined with the respective energy carrier, marked in Table 2 green, still fall within the top 15% in 2030.

Table 2. Summary of results: MuKEn, Minergie, GEAK with different energy carrier compared to the top 15% limit values for 4 building categories, GEAK (H) — building envelope efficiency, GEAK (G) — overall energy efficiency

	Gas				Oil				Heat pump				District heating				Wood				Wood pellets				Gas + Solar				Oil + Solar			
	SFH	MFH	ffice	NRB	SFH	MFH	Office	NRB	SFH	MFH	Office	NRB	SFH	MFH	Office	NRB	SFH	MFH	Office	NRB	SFH	MFH	Office	NRB	SFH	MFH	Office	NRB	SFH	MFH	Office	NRB
MuKEn 2008	26	23	22	24	35	30	28	31	4.1	3.8	4.9	5.5	9.6	8.4	9.2	10	4.2	3.7	5.0	5.6	4.2	3.7	5.0	5.6	25	21	21	23	32	28	27	30
MuKEn 2014	8.0	8.1	10	9	10	11	12	11	2.2	2.3	3.9	3.8	5.4	5.5	7.0	6.5	1.8	1.9	3.5	3.5	1.8	1.9	3.5	3.5	6.9	7.2	6.7	6.0	9.1	9.5	8.3	7.4
Minergie-P 2003	4.8	4.9	6	4	6	6	8	5	1.5	1.6	2.3	2.2	2.2	2.3	3.2	2.7	1.5	1.6	2.4	2.2	1.5	1.6	2.4	2.2	4.3	4.3	5.2	3.0	5.7	5.7	6.9	3.9
Minergie 2017	*	*	*	*	*	*	*	*	2.1	1.9	1.8	1.9	2.8	2.1	1.3	1.4	2.1	1.9	1.3	1.4	2.1	1.9	2.1	1.9	*	*	*	*	*	*	*	*
Minergie-P 2017	*	*	*	*	*	*	*	*	0.9	0.9	1.6	1.6	0.7	0.5	1.2	1.2	0.9	0.9	1.2	1.2	0.9	0.9	0.9	0.9	*	*	*	*	*	*	*	*
Minergie-A 2017	*	*	*	*	*	*	*	*	4.6	4.2	5.7	5.5	6.8	6.7	2.6	2.6	4.6	4.2	2.6	2.6	4.6	4.2	4.6	4.2	*	*	*	*	*	*	*	*
GEAK A (H)	15	15	14	15	20	19	17	18	2.6	2.7	4.6	4.2	5.7	5.5	6.8	6.7	2.6	2.6	4.6	4.2	2.6	2.6	4.6	4.2	14	13	13	14	19	18	18	20
GEAK A (G)	13	11	11	13	17	15	14	16	2.1	2.7	2.7	3.5	4.8	4.4	4.6	5.6	2.1	1.8	2.5	3.2	2.1	1.8	2.5	3.2	12	11	10	12	16	14	13	15
GEAK B (H)	26	23	23	24	35	30	29	31	4.1	3.8	5.8	5.5	9.6	8.4	10	10	4.2	3.7	5.8	5.6	4.2	3.7	5.8	5.6	25	21	21	23	32	29	29	33
GEAK B (G)	26	22	22	25	35	29	28	32	4.1	5.2	5.4	6.9	9.6	8.5	9.2	11	4.2	3.6	5.0	6.4	4.2	3.6	5.0	6.4	25	21	21	24	32	28	27	31
GEAK C (H)	37	31	31	34	49	41	40	44	5.6	4.9	6.9	6.8	14	11	13	14	5.7	4.9	7.1	7.0	5.7	4.9	7.1	7.0	35	29	30	33	46	39	40	45
GEAK C (G)	39	34	32	38	52	45	42	48	6.2	8	8.1	10	14	13	14	17	6.3	5.5	7.5	9.6	6.3	5.5	7.5	9.6	37	33	31	36	49	43	40	46
GEAK D (H)	48	38	40	44	63	51	52	57	7.1	5.4	8.1	8	17	14	16	17	7.3	5.5	8.4	8.4	7.3	5.5	8.4	8.4	46	36	38	42	60	48	51	57
GEAK D (G)	53	45	43	50	69	60	55	64	8	11	11	14	19	17	18	22	8.4	7.3	9.9	13	8.4	7.3	9.9	12.8	49	44	41	48	65	58	53	62

Color code

≤15% im Jahr 2030	≤15% im Jahr 2025	≤15% im Jahr 2020	>15% im Jahr 2020

* Not applicable. The limit value of Minergie-A has been 0 kWh/m²a final energy since 2011 and is therefore only possible in combination with WP. Minergie generally no longer allows fossil fuels for new buildings from 2017, nor in renovations since 2020.

green For single family houses with district heating systems in which no fossil fuels and no electric heat pumps are used, the value 2030 is also achieved here, for apartment buildings with district heating systems in which no fossil fuels and no air/water electric heat pumps are used, the value 2030 is also achieved here.

3.2 Criteria for buildings built after 2020

For new buildings and for the purchase and ownership of buildings constructed after 2020, the TEG requires buildings to be 20% more efficient in terms of primary energy consumption than the minimum required by law in the respective EU Member State. Outside the EU, standards, the certification system or regulations can be used as criteria if they are equivalent to the 20% criterion of the EU [9, 10]. If one takes the comparatively strict MuKEn 2014 in Switzerland as the basis for the legally required minimum (in 14 Cantons the MuKEn implementation in 2014 has been decided or has already taken place (as of the end of 2021)), the Minergie-P standard from 2017 and the more demanding Minergie-A standard (for residential buildings) would be guaranteed in any case that the legally required minimum for primary energy requirements is exceeded by at least 20%.

With regard to GHG emissions, the “legally prescribed minimum” can be determined less clearly because MuKEn 2014 does not set any relevant requirements. The GHG emissions of today's new buildings are therefore determined as described below.

Final energy, greenhouse gas emissions and primary energy are determined specifically for new buildings in accordance with the explanations in chapter 3.1.1. With regard to energy efficiency, the MuKEn 2014 is assumed, and with regard to the market share of energy carrier, evaluations of the RBD and the above-mentioned survey in 20 Cantons. Based on the emission factors of KBOB, so-called emission coefficients (typically kg CO_2 /m² heated floor area) can be calculated, differentiated according to building class, for example.

It turns out that direct emissions are higher in residential buildings than those of office buildings due to the higher consumption of space heating and hot water. This is vice-versa for total emission coefficients: Office buildings have lower room heating and hot water consumption compared to residential buildings, but significantly increased electricity consumption (especially for lighting, cooling and ventilation), which leads to higher total emissions. The level of total GHG emissions ranges from 6 kg CO2 -eq / m2 ERA (SFH) to just under 8 kg CO2 eq / m2 ERA (office). These emission coefficients can be used as a starting point, for example to compare project values with the benchmark of new buildings. On the basis of the TEG, for example, all buildings whose values are at least 20% lower could be described as climate-friendly. For residential buildings, this is approx. 5 kg CO2 /m2 ERA and for office buildings approx. 6.5 CO2 /m2 ERA. For comparison: These figures are similar to the top 15% of the total building stock for residential buildings, but significantly lower for office buildings (compare with Table 1). From Table 2, it can be seen from which efficiency and energy carrier combinations achieve these new construction benchmarks.

3.3 Renovation

3.3.1 Renovation packages

According to the TEG, the financing of a renovation can be qualified as "green" if the renovation achieves a reduction in primary energy of at least 30% compared to the primary energy of the building before the renovation. CBI also relies on GHG efficiency when it comes to building renovation and at the same time goes somewhat further in terms of requirements than the TEG. According to the CBI, the reduction achieved by a renewal must be higher if the financing is long-term. Only in the case of financing (or with the term of a bond, as CBI focuses on bonds) for 5 years, 30% is sufficient. At 10 years, CBI requires an improvement of 34%.

The 34% improvement in primary energy efficiency, which is comparatively easy to implement, can be well operationalized in Switzerland based on the GEAK system. Based on the GEAK classification criteria, it is calculated which improvement in this system can in any case be equated with an increase in primary energy efficiency of at least 34%.

Table 3 shows which improvements in the GEAK rating — while maintaining the same energy carrier — with regard to the efficiency of the building envelope and primary energy, an increase in energy efficiency of at least 34% can be achieved in each case (Appendix 3 by Hofer, Jakob et al. [3] explains the calculations in detail).

For single family houses that reach GEAK class C before a renewal, an improvement by two classes to A is necessary (although it should be noted that this is hardly achieved in practice). For GEAK classes D, E and F, a three-rate improvement is required for single family houses and an improvement of four classes for class G. For multi family buildings, an improvement of three classes to A and B is required for GEAK classes D and E, and an improvement of four classes is required for classes F and G.
Offices and other NRBs require a three-tier upgrade for Class D, four-tier improvements for E, F, and G.

Table 3. Improving primary energy efficiency by at least 34% in the GEAK system (overall efficiency and hull efficiency)

	Improve GEAK by 2 classes	**Improve GEAK by 2 classes**	**Improve GEAK by 4 classes**
SFH	C*	D, E, F	G
MFH		D, E**	F, G
Office + other NWG		D	E, F, G

It is not possible to develop generally applicable criteria for improvements in GHG efficiency of 34%, as required by CBI. There is no directly applicable system for classifying buildings according to GHG efficiency. How high the GHG efficiency achieved with a renewal must be calculated on a case-by-case basis. The calculation of various scenarios in order to determine generally valid criteria for a corresponding efficiency gain would be too complex. However, in order to better meet the GHG

efficiency criterion, it is proposed in addition to the GEAK improvements above: After the building has been renovated, no fossil energy shall be used to generate heat.

3.3.2 Individual measures

The Technical Expert Group NF also mentions various individual measures that can be used to increase energy and greenhouse gas efficiency in buildings as further cases of ecologically sustainable financing. These include insulation of walls and roofs, installation of energy-efficient windows, installation of LED lighting systems, charging stations for electric vehicles or photovoltaics. Such individual measures should, in principle, be part of a comprehensive renewal plan, but allow general conclusions to be drawn as to whether a 30% improvement will be achieved.

According to analyses by Hofer, Jakob et al. [3], only the replacement of a fossil heating system with one with energy carrier that always guarantee the top 15% - wood, pellets, heat pump - represents a reliable and effective individual measure to curb GHG emissions. This is true even if the energy efficiency of the building is not significantly improved when replaced.

4. Discussion and conclusion

This article explains how international efforts to characterize the climate compatibility of buildings can be concretized for Switzerland. On the one hand, specific criteria for primary energy and greenhouse gas emissions are quantified for different building categories. On the other hand, it shows which combinations of energy efficiency and energy carrier meet these criteria. As such it overcomes a serious shortcoming

A directly applicable metric is created by including various forms of legal regulations, particularly energy-related building codes (MuKEn), Minergie labels and the Canton's building energy performance certificate (GEAK). This allows actors in the real estate and financial sectors (building owners, developers, managers, investors, financing institutions such as banks and pension funds) to identify climate-friendly buildings. This provides them with guidance on new construction and renovation projects as well as in the selection of appropriate buildings and thus also for the design of related financial products. The latter include, for example, green bonds, mortgages or investment funds.

Finally, we ask what impact could the criteria developed here have? Three aspects are in the foreground:

First, if the derived criteria are observed, only buildings are identified that are compatible with the goal of achieving “net zero” GHG emissions in the Swiss building stock by 2050 at the latest and reducing climate change to well below 2°C — as stipulated by the Paris Climate Agreement and the Federal Energy Strategy 2050+ specify. The corresponding buildings are significantly more climate-friendly than the average: For single-family homes that meet the above criteria, total CO2 emissions are at least 84% lower than the average value of all single-family homes in the Swiss building stock in 2030. For apartment buildings, the figure is 81%, for office buildings 44% and for other non-residential buildings 53%. In the case of energy renovations of buildings that are classified here as “ecologically sustainable”, the primary energy requirement is in turn always improved by at least 34%. GHG emissions are also reduced by at least as much or more.

Secondly, the criteria derived here support the phasing out of fossil fuels in the building sector. This is crucial from a climate protection perspective.

Thirdly, the discussion and application of the criteria in conjunction with financing decisions can sensitize existing or future owners of buildings to what needs to be taken into account in relation to sustainability and climate protection considerations in connection with a building. For example, when it comes to renovations, the GEAK should be improved by three or four classes and fossil fuels should be dispensed with.

In addition, buildings that meet the developed criteria are likely to retain their value even if climate policy measures are tightened up. Due to the climate compatibility that already exists today, they are likely to be less affected by such measures.

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