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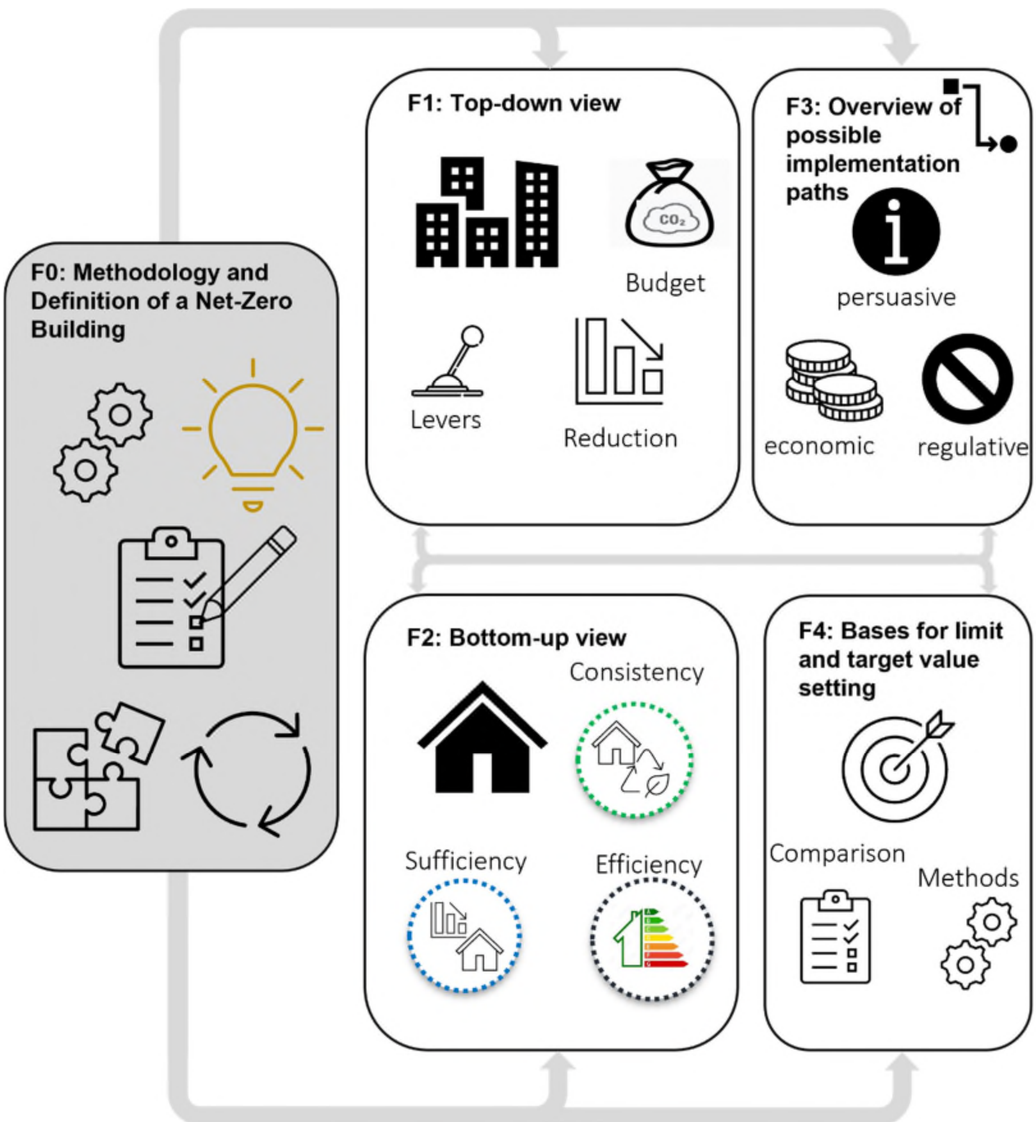
Final report from 30 November 2024

Net-zero greenhouse gas emissions in the building area (NN-THGG)

Summary Report



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Foreword

What does net-zero mean in the building area? So simple the question, so complex its answer. This research project has analysed this question from various angles and provides concrete answers.

The question of the remaining CO_2 budget to achieve the climate targets in the building area was examined in the top-down section, while possible strategies for reducing emissions in individual buildings were identified in the bottom-up section. A further part of the project shows possible policy measures and discussed their implementation. Finally, the net-zero whole life carbon method developed in this project was used to examine the extent to which current building standards and labels are suitable for assessing a net-zero building.

The sounding board played a particularly important role in this project. The representatives of the building labels, the SIA, the federal government, cantons and cities involved put their heart and soul into developing a practice-oriented and implementable calculation method for net-zero buildings. The intensive dialogue within the group and with the research teams, who for their part upheld the scientific approach, was a valuable experience for everyone involved – both in terms of content and in developing a common understanding of the sometimes very different points of view. The latter was in turn incorporated into the premise of the research work.

The most important findings of this project, which is exceptional in terms of its complexity and stakeholder involvement, can be found in the Executive Summary. This is followed by summaries of the individual sub-projects and, finally, overarching conclusions. To get straight to the point: achieving net-zero in the building area is extremely challenging, and in addition time is pressing. However, the net-zero-ready approach can be started immediately. This makes us confident that the scientifically sound findings of this research project, the practical recommendations and a jointly supported definition of net-zero buildings will enable us to contribute to achieving the climate targets in Switzerland.

I wish you an exciting and insightful read.

Andreas Eckmanns

SFOE Head of Research Buildings Division

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Abbreviations

BM	(electricity) balance model
CCS, BECSS	Carbon Capture and Storage, Bioenergy with Carbon Capture and Storage
DACCS	Direct Air Capture and Storage
EPD	Environmental Product Declaration
GE	Gross emissions
GEAK	Cantonal building certificate (Gebäude Energieausweis der Kantone)
GOO	Guarantee of origin (Herkunftsnachweis HKN)
KBOB	Coordination Group of the Construction and Property Services of Public Clients
KlG	Federal Act on Climate Protection, Innovation and Strengthening of Energy Security
LCA	Life Cycle Assessment
MinGE	Minimised Gross Emissions
NE	Negative Emissions
NET	Negative Emission Technology
NZ	Net Zero
GHG	Greenhouse Gas
WLC	Whole Life Carbon

Executive Summary

Context and objectives

Net-zero greenhouse gas emissions (NZ-GHG emissions) in buildings are seen as an indispensable means of achieving the Paris climate targets. The built environment accounts for a significant proportion of national and international emissions. It is therefore crucial to reduce both operational as well as upstream and downstream emissions, so-called "grey emissions". Operational emissions, which are mainly caused by fossil-fuelled heating systems, will decrease significantly in the near future. However, decarbonising the production and disposal of building materials to reduce grey emissions is more difficult. This research project, which was put out to tender by the Swiss Federal Office of Energy (SFOE) in 2022, has identified suitable strategies for achieving NZ-GHG emissions in the building area and proposes a calculation methodology for this. The multi-part project combines top-down and bottom-up approaches. The aim is to develop guidelines, benchmarks and recommendations for decision-makers, experts in the real estate and construction industry and stakeholders in the field of building standards and labels. The results should provide information for decisions on future regulatory frameworks and help to orientate the Swiss building area (new buildings and existing buildings) towards net-zero by 2050.

Key findings

1) Definition of a net-zero building

A building with net-zero greenhouse gas emissions ("net-zero building" for short) has minimum GHG emissions during construction and operation over its entire life cycle and reduces the remaining GHG emissions through accountable negative emissions at the level of building materials and elements. Negative emissions can be accounted for if the permanent storage of biogenic CO_2 is ensured. This option is not yet de facto available today.

2) Net-zero-ready building

A building in which temporary sinks – e.g. biogenic building materials – are used, which can be converted into permanent negative emissions (NE) at a later date. The prerequisite for net-zero-ready is an extensive reduction in gross emissions, e.g. in accordance with the additional requirement A of the SIA climate pathway. In contrast to net-zero buildings, a legally binding guarantee is not mandatory here.

3) Emission budgets and reduction paths for the building area

The cumulative emissions budget derived from the Climate and Innovation Act (KlG) for the building area (including upstream and downstream emissions) is around 510 Mt CO_2eq. According to current forecasts, the 2°C target can be achieved with this reduction pathway with a probability of 83 %. The 1.7°C target has a 50 % chance of being achieved, but the 1.5°C target will clearly be missed. The baseline scenario[1] of this project assumes a 78 % reduction in GHG emissions in the building area by 2050. This requires the complete elimination of Scope 1 emissions (from fossil fuels) and a significant reduction in Scope 2 and 3 emissions. Despite these challenging assumptions, the building area exceeds the target derived from the KlG by a factor of two in the baseline scenario. Of the calculated emissions of around 6.5 Mt CO_2eq per year in 2050, 5.4 Mt are attributable to Scope 3 emissions from construction, renovation and energy infrastructure. To achieve the target derived from the KlG of 2 Mt CO_2eq per year, additional measures are required. These include a comprehensive reduction in grey emissions from building materials, the complete elimination of fossil fuels in buildings and energy production (including energy grids) and extending the useful life of buildings.

[1] The "baseline scenario" considers greater energy efficiency in the building envelope, heating systems, technology and appliances as well as the almost complete elimination of fossil fuels by 2050. The demand for electricity for electric heating is to fall to almost zero, while heat pumps and district heating are to increase. Emission factors will be greatly reduced, and the use of materials and types of construction will play an important role. The levers of temporary sinks and negative emissions are considered separately.

4) Consideration of grey emissions

Most operational emissions can be reduced through simple measures in the area of energy efficiency and electrification (e.g. heat pumps, district heating) and the decarbonisation of the energy supply. However, grey emissions are more difficult to reduce. As operational emissions decrease over time, grey emissions are expected to account for a larger share of total emissions. The research results show the importance of reducing grey emissions through innovative construction practices, material efficiency and the use of low-emissions materials. Accordingly, it is important for the construction and real-estate industry to work together with the energy (electricity and thermal networks) and industry (production of materials and construction elements) sectors.

5) Holistic, multi-measure approach for buildings

Measures to reduce GHG emissions at building level can achieve an average GHG emissions reduction of 15 %, but this is far below the values required for net-zero. For this reason, a multi-faceted approach combining technological innovations, policy measures and behavioural changes is required. Three promising strategies have been identified to achieve net-zero buildings: Firstly, a reduction in building activity (less new construction, more refurbishment, efficient use of space), secondly, optimising building performance (energy efficiency, sufficiency-based design) and thirdly, integrating renewable and low-emissions materials and energy sources. The potential of combined measures and strategies to reduce emissions in the reference building analysed is up to 72 %. However, this is only possible under optimal conditions and at a suitable location. In the other cases, the possible reduction spectrum must be assessed individually.

6) Harmonisation of building standards and labels

To effectively achieve the net-zero targets by 2050, a harmonisation of Swiss building standards and labels, such as those of the Swiss Society of Engineers and Architects (SIA), Minergie, Ecobau, the cantonal building certificate (GEAK) and the Swiss Sustainable Building Standard (SNBS), is expedient. There are already common definitions and assumptions, but there are still certain differences in calculation methods, system boundaries and the recognition of certificates. The project defines a "net-zero whole-life-carbon (WLC) building" approach to which the standards and labels can be orientated. The method defined in the draft standard "FprSIA 390/1:2024" is coherent with the WLC approach if the calculation method with the sale of Guarantees of Origin and without the use of green electricity is used. Minergie deviates slightly from the methodology defined in the project in all versions due to the different accounting of PV systems (in terms of emissions from construction and electricity produced). On the one hand, the elimination of this methodological difference ensures coherence with the WLC_{NZ} methodology. On the other hand, it enables consistency between the instruments Minergie and SIA climate path.

7) Political measures

The current political measures mainly address direct emissions from building operation (Scope 1) and indirect emissions from energy consumption (Scope 2). However, Scope 3 emissions are hardly addressed at all; only public procurement criteria address these. There are no regulations for reducing emissions in the construction and waste sector (Scope 3). To achieve NZ-GHG emissions in the building area, regulatory gaps must be closed, particularly in the area of circular economy, with legal requirements for GHG emissions from buildings taking a central role. This also means that the cantons are called upon to include limit values for grey GHG emissions in their energy legislation. At the same time, low-emission construction should also be promoted from the waste side, for example by tightening disposal regulations.

New mandatory measures (obligations/prohibitions), such as limit values for grey emissions or mandatory refurbishments in the event of changes of ownership, can place greater obligations on private actors. However, they may meet with political resistance due to their impact on individual behaviour and their intervention in the market. To be able to implement stronger regulatory political measures, awareness-raising work is also required. The expansion of existing financial incentives, e.g. through the building programme, can facilitate the transition to stricter regulations (Commandments/Prohibitions). Investments in the sharing the targeted development of knowledge are also crucial. There is also potential for reducing emissions in the building area in the promotion of circular economy measures, the increased use of bio-based materials (especially wood) and the efficient use of space in residential construction.

Recommendations for decision-makers in the political and administrative domains

1) Strengthening the regulation of grey emissions: Decision-makers should close regulatory gaps, particularly in upstream and downstream emissions (Scope 3) in the construction and waste sectors. This includes the introduction of limits for grey emissions in cantonal energy regulations and the development of national guidelines on the circular economy.
2) Strengthen financial incentives and awareness-raising: Extending financial support through instruments such as the Buildings Programme and public procurement can encourage the use of low-carbon alternatives. Awareness-raising measures are an important lever to gain public support for stricter building regulations and sustainable practices.
3) Renovation instead of new replacement building: As a rule, building renovation should be preferred to demolition and new construction, with a particular attention being paid to minimising grey emissions. However, the resource of land use must also be considered here (new replacement building can also be expedient for densification).
4) Future emissions trends: Decision-makers should focus on future emissions trends, in particular the decarbonisation of the production and disposal of materials used in renovation and refurbishment measures in the construction sector.

Recommendations for building standards and labels

5) To promote the consistency of building standards and labels and strengthen their contribution to achieving the net-zero target, it is recommended to establish and implement a coordinated framework for emissions accounting and a step-by-step standardisation approach based on the principles developed in this project.
6) According to the "emissions reality" of the WLC-method, emissions should always be calculated with hourly resolution, i.e. own consumption or grid consumption is calculated per hour and aggregated to an annual balance, possibly a monthly balance. For practical implementation in verification calculation tools, corresponding standard cases can be defined.
7) Balancing grey emissions from PV systems: Minergie (or GEAK methodology) and FprSIA 390/1 for annual balancing (calculation method with non-sale of GOO) should adapt the calculation methodology to bring the results closer to the WLC-method. Separate requirements should be set for setting incentives, e.g. for larger PV systems, and clearly labelled as such.
8) Lifespan and durability of buildings: It should be examined whether extended reference lifetimes for buildings and their components could promote the use of more durable materials. Methods should also be developed for adapting lifetimes depending on building types, utilisation strategies and product declarations.
9) Balancing over the lifetime: It is recommended not only to use one or two key figures when presenting the project and requirement values, but also to show the annual progression of emissions. In this way, a distinction can be made between emissions from construction and those from replacements measures. This increases transparency and better demonstrates the possibilities for avoiding emissions over the life cycle of buildings.
10) Data on low-CO_2 -emission materials and components: It is recommended that the list of life cycle assessments of manufacturer-specific data be made available online in a consumer-friendly manner with API interfaces. This will make updates prompt and easy to use for users, in particular, for the providers of verification programmes.

Recommendations for the industry

11) Promotion of low-CO_2-emission and biogenic materials: There is a need to accelerate research and promote the use of low-grey-emissions materials (renewable energy in the production of materials and products, bio-based building materials, concrete with low-clinker cement types) in construction, installations and thermal insulation. Industry players should drive the decarbonisation of the supply chain.

12) Further development of negative emissions technologies (NET): Given the projected demand for NET, investment in research and pilot projects, including permanent storage of biogenic carbon, is required. These technologies will play a central role in balancing remaining emissions that cannot be avoided through direct mitigation strategies.

Cross-sectoral recommendations

13) Promoting cross-sectoral co-operation: Achieving net-zero requires co-operation between sectors, including energy, construction and waste management. Government, industry representatives and research organisations should coordinate their efforts to accelerate the implementation of innovative practices and technologies.

Introduction

The aim of the "Net-zero greenhouse gas emissions in the building area" project, which was initiated by the Swiss Federal Office of Energy (SFOE) in 2022, was to develop a comprehensive definition of net-zero GHG emissions (NZ-GHG emissions) in the building area in Switzerland. This definition is intended to serve as a guideline for regulatory framework conditions and support the country's long-term climate targets, particularly the achievement of net-zero emissions by 2050. The project closes existing knowledge gaps by analysing the system boundaries, reduction paths and necessary framework conditions for achieving net-zero in the building area. The thematically broad-based research project was divided into the following sub-projects for implementation:

F0: Methodology and definition of a net-zero building

F1: Top-down view

F2: Bottom-up view

F3: Overview of possible implementation paths

F4: Basis for setting limit and target values

The most important results and recommendations of the five sub-projects are summarised in the following sections.

Concepts and terminology

To support the implementation of the "net-zero greenhouse gas emissions in the building area" goal in practice, project section F4 provided an overview of possible requirement levels that are already used or could be used in practice. These are presented here as an overview:

Methodology WLC_{NZ}:

The methodology for calculating NZ-GHG buildings is called WLC_{NZ} methodology. WLC stands for Whole Life Carbon and the index NZ indicates that the methodology is able to depict net-zero (in contrast to WLC methods, which "only" depict gross emissions). Table 1 shows the adjusted methodological approaches that serve as the basis for the common definition of the method with which net-zero buildings - together with corresponding requirement values - can be defined.

Net-zero (NZ_{WLC}):

A building with net-zero greenhouse gas emissions ("net-zero building" for short) has minimum GHG emissions for its construction and operation over its entire life cycle (minimised gross $emissions_{WLC}$) and balances the remaining GHG emissions through accountable negative emissions at the level of building materials and building elements. Negative emissions can be accounted if the permanent storage of biogenic CO_2 is ensured. The GHG emissions are calculated according to the WLC_{NZ} methodological principles defined in this project (Table 1).

Net-zero-ready (NZ_{WLC}-ready):

A building with minimised gross $emissions_{WLC}$ (see separate definition), in which temporary sinks are used that are converted into permanent negative emissions (NE) at a later date if they are not actually re-emitted. These temporary sinks are to be linked to specific future measures. Examples include the use of biogenic building materials that serve as temporary sinks that can later be converted into negative emissions to balance the emissions from construction and operation. The prerequisite for NZ_{WLC} -ready is an extensive reduction in gross emissions. In contrast to the NZ_{WLC} building, a legally binding guarantee is not mandatory. When calculating the NE, it must be considered that, for practical reasons, not all temporary sinks can be converted into NE and unavoidable efficiency losses, e.g. in the case of carbon capture and storage (CCS), must be factored in.

Minimised gross emissions$_{WLC}$, 2025 ($MinGE_{WLC}$,2025):

A requirement level for minimised gross emissions$_{WLC}$, 2025 is to be defined in such a way that it can be achieved through the implementation of extensive measures (best available technology and best practice) in design, planning, construction and materialisation. Operational emissions should also be severely limited. In this way, GHG emissions can be substantially avoided over the life cycle compared to current construction methods (see sub-project F2). The additional requirement A according to the SIA climate path (calculation method that conforms to the WLC_{NZ} methodology proposed in this project) serves as a reference point for the definition of "minimised gross emissions". In this context, it is necessary to check whether and how special circumstances, e.g. slope or groundwater situations, are to be considered.

Minimised gross emissions$_{WLC}$ ($MinGE_{WLC}$, time index):

The level of the minimised gross emissions depends on the current state of the art and the building materials and elements on offer, as well as the "reasonable" or accepted emissions reduction measures. It is therefore recommended that the term "minimised gross emissions" be given a date, e.g. with the addition: "today or 2025, 2035, 2050 etc.", in the sense of a reduction path. The values should apply at the specified point in time and should be defined with reference to the state of the art and planning and construction practice in the sense of best practice, e.g. by regularly updating the legal requirements as well as requirements in labels and standards, which may also include a binding mid-term reduction path.

Reduction pathway:

The requirement levels of the minimised gross emissions$_{WLC}$ can be applied both for the current point in time (today's new construction, today's refurbishment) or for future points in time. Changes are to be expected in the coming years in both the industry sector (production of building materials and building elements) and the energy sector (supply of final energy). Therefore, a temporality should be specified for the requirement values in each case.

F0 Methodology and Definition of a Net-Zero-Building

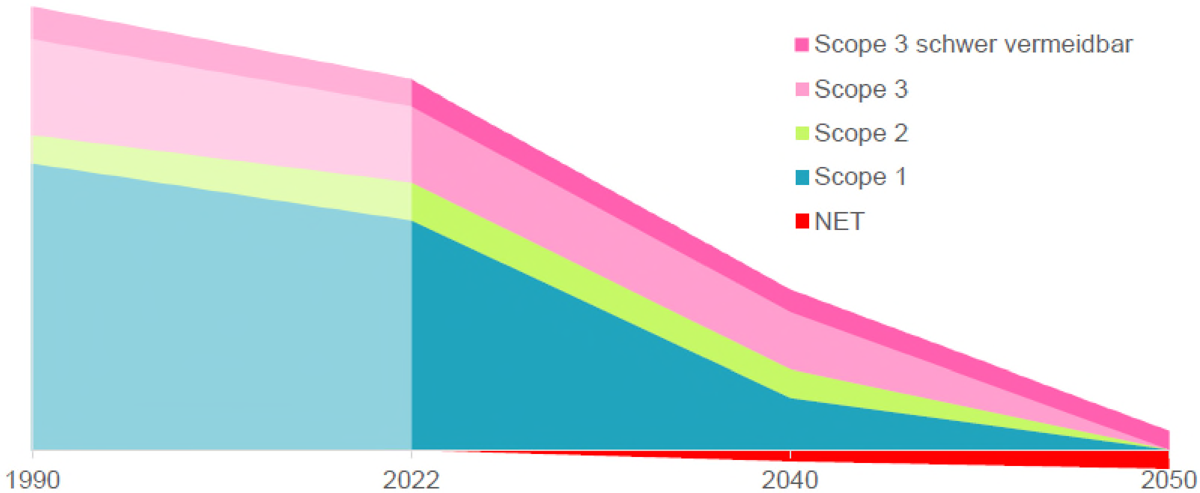

Figure 1: Schematic representation. Emissions budget of the building sector (turquoise) and the building area (all colours). Negative emission technologies (NET) are shown in red. Pastel colours: budget already consumed between 1990 and 2022. Bright colours: remaining budget until 2050. Source: TEP Energy, 2024.

Research questions and findings

Sub-project F0 documents the work on the methodological questions and serves as a basis for the sub-projects of the net-zero greenhouse gas emissions in the building area research project. The context in which the various methodological approaches are to be embedded is considered, including the incentive effects that need to be considered for different target groups. Finally, F0 analyses open methodological questions, evaluates different approaches and identifies possible solutions.

Definition of net-zero greenhouse gas emissions in the building area

Net-zero greenhouse gas emissions means that no more GHG emissions are released into the atmosphere than what can be absorbed by natural or technical reservoirs. To achieve this, GHG emissions must be avoided as far as possible. The remaining emissions that are difficult to avoid must be removed from the atmosphere through permanent natural emission sinks or technical measures and safely stored or disposed of in the long term (more than a thousand years). As a result of this emissions equalisation, the long-term increase in the global mean temperature is the same as if the GHG emissions had not been emitted in the first place (net-zero). From a holistic perspective, the building area also includes the necessary supply chains for the manufacture of construction products and building elements, the construction and operation of buildings and the disposal of construction products and building elements. The goal defined in this study of achieving net-zero GHG emissions in the building area is therefore based on climate physics. It is based on a whole life carbon (WLC) approach and should not be confused with the political country-level goals and its resulting sectoral targets in accordance with the Paris Agreement, which are based on a territorial and process-orientated approach.

Table 1: Overview of the methodological questions analysed, and the methodological approaches currently used, which together represent the common definition of the WLC_{NZ} methodology (consolidated recommendations of the research team and the sounding board). The abbreviations of the questions as used in the reports are given in brackets.

Topic, question	WLC_{NZ} methodology developed in this project
Lifetime and service life of buildings (temporal allocation) **(F0.2.A)**	Individual buildings, current planning practice: amortise over the service life of the building Building stocks, real estate portfolios: Recognise GHGs when they occur
Lifetime and service life of buildings (data and assumptions) **(F0.2.B)**	Standardised amortisation periods for the standard case of Norms, standards and labels concerning the planning phase
NET technologies/materials **(F0.3.A)**	There are the following NET materials: mineral, mineral-organic and organic building materials.
Temporary sinks: accountability **(F0.3.B)**	Biogenic CO_2 is "climate neutral" without ensuring permanent storage (approaches "0/0" or "-1+1" in accordance with EN 15804+A2)
Reporting NET contribution **(F0.3.C)**	The NET contribution should be recognised and reported separately. No netting at building material and building element level.
Negative emissions: accountability **(F0.3.D)**	• NE only for the balancing of building emissions. • Certificates must be purchased and retained for building materials whose NE (sink capacity) is to be credited. • Organic building materials can be considered if legally binding assurance of non-release (or permanent storage) of biogenic C.
Re-use and recycling **(F0.4. A+B)**	“Additional efforts" approach, cut-off for emissions that already happened.
PV feed-in: Allocation of embodied emissions, grid feed-in rules **(F0.4.C)**	"Split investment": Consider GHG emissions of the PV system in proportion to the share of self-consumption in generation. Electricity fed into the grid bears the environmental characteristics of PV electricity; no deduction in the operational phase.
PV feed-in: Time resolution for determining the self-consumption share **(F0.4.D)**	Determine self-consumption share with hourly resolution and aggregate to annual value.
Modelling the Swiss electricity mix: actual state, balance sheet model **(F0.6.A)**	Consumer mix = domestic production minus exports plus imports (BM3 model for building life cycle assessments according to KBOB recommendation 2009/1)
Modelling the Swiss electricity mix: temporal resolution **(F0.6.B)**	Aggregate hourly values to annual balances
Modelling of the Swiss electricity mix: Weighting of the demand profile **(F0.6.C)**	No weighting for the planning phase (use case 1 according to standard SIA 380:2022)
Modelling of the Swiss electricity mix: consideration of future developments **(F0.6.D)**	Static analysis: Current situation of electricity mix and power plants for the entire operational phase, ditto for all other energy sources.

Table 2: Overview of the methodological questions and approaches investigated that require more in-depth analysis and discussion after completion of this project or that concern the higher level

Topic, question	Methodological approaches (variants)
Calculation of the emissions budget indirect emissions for imported goods and energy imports (F0.1.A)	M1: Equal treatment (i.e. same relative reduction path abroad as in Switzerland)
	M2: Reference to current EU regulations towards net-zero GHG emissions
Calculation of embodied emissions of low-emission materials and components (F01.B)	M1: Life cycle assessments of manufacturer-specific data in accordance with "Rules for the life cycle assessment of building materials and building products in Switzerland" by KBOB, Ecobau and IPB (2024) M2: Quality requirements for the approval and conversion of (international) EPD values or comparable programmes so that they comply with recognised life cycle assessment methods and are therefore comparable. Whether and to what extent there is a need for action in this regard is to be examined as a follow-up to this project.
Recognise GHGs at the time of their occurrence or depreciate them over their time of use? (F0.2.A)	M1: Recognize GHGs at the time of their occurrence also for individual buildings. M2: Accumulate successively over the period of use for illustration and visualisation purposes.
What data and assumptions should be used regarding the service life and useful life of the buildings and facilities? (F0.2.B)	M2: Reference lifetimes that can be adjusted on a case-by-case basis (e.g. according to building type, planned utilisation concept, refurbishment strategies, life cycle assessment principles and product declaration; details and conditions to be checked).
Modelling the electricity mix in Switzerland: current status, balance model (F0.6.A)	Following this project, check whether the BM3 should also be used in the future or whether a revision is required.
Modelling the Swiss electricity mix: What weightings (heating, cooling, building types) should be applied when determining the electricity mix and GHG emissions? (F0.6.C)	M3 (new): No weighting but provide hourly values. Concerns: Use cases 2 and 3 in accordance with section 4.1.1. of the SIA 380:2022 standard
Modelling the Swiss electricity mix: considering possible future developments in the electricity mix and power plant technologies (F0.6.D)	M2: Future-oriented consideration of environmental parameters for electricity averaged between the situation today and 2050 (possibly beyond) based on a 2050 scenario compatible with the net-zero greenhouse gas emissions target (similar to the example shown in F0 report, implementation as soon as the basis for this has been established (KBOB)).

In relation to the various research questions, the following results and findings emerged from sub-project F0, which support the recommendations in Table 1.

F0.1 What CO_2 budget by 2050 is derived from the reduction path for the building sector (direct emissions) according to the KlG? What proportion of the emissions budget still available for Switzerland needs to be supplemented in a comprehensive life cycle assessment for the building area?

The CO_2 budget up to 2050 for the building sector, i.e. the budget for direct emissions from the combustion of fossil fuels in buildings (Scope 1), is the sum of emissions under the reduction path defined by the KlG: a reduction of 82 % by 2040 and 100 % by 2050, in each case compared to the base year 1990. The absolute values were determined in project section F1. As the construction and operation of buildings lead to further induced emissions, a further budget for indirect emissions (Scope 2 and 3) is allocated to the building area. These are partly domestic emissions and partly emissions that occur abroad. The emissions occurring in Switzerland (CH) therefore take up part of the domestic emissions budget of the industry sector (production of building materials and elements) and the energy and transformation sector (production of district heating, electricity, and other sources of energy).

The budgets of these sectors must therefore be divided up accordingly:

- Budget for building-related emissions for the
  - Manufacture of building materials and elements (industrial sector)
  - Generation of district heating, electricity and other energy sources (GHG inventory: industrial sector; energy statistics: transformation sector)
  - Building-related transport by road and rail (in relation to construction (including building renovation) and the supply of energy, excluding induced mobility due to building use)
- Budget for other emissions such as civil engineering, food production and other industrial products and consumer goods.

Different approaches can be taken when allocating budgets to these two areas:

- Proportional allocation
- Consider or not that the production of building materials and elements generates more "difficult to avoid" emissions than the rest of the industrial sector

The budget must also be determined for the portion of emissions generated abroad. The following different approaches are being discussed in the industrial sector (import of building materials and elements):

- M1: Equal treatment of imported products with domestic products, i.e. comparable targets and budgets must be defined for the industrial sector,
- M2: Reference to the current EU regulations towards a stronger reduction of GHG emissions and striving for the net-zero target before 2050

This open question requires further investigation, whereby the following notes are to be considered:

Equal treatment of imported goods with Swiss production would then be counterproductive if the corresponding assumption is applied in accounting norms, standards and labels, but life cycle assessment equivalence cannot be enforced for imported goods (and this is not considered in the calculations). It is therefore very important to clarify the question of which approaches should be used to measure and consider low-carbon materials and components. This should be urgently addressed as a follow-up to this project.

F0.2 How is the lifespan of a building considered in terms of grey energy/GHG emissions in a methodologically meaningful way: one-off crediting when used during the construction phase, or write off over years (in the case of the latter: how should the existing building stock be dealt with)?

The following approach was used for the accounting of GHG emissions:

- Investment principle (analogous to economics): In accordance with the CO_2 Act, the recommendation of the GHG Protocol and approaches based on this, emissions are accounted for at the time they occur. Emissions from production are therefore accounted for during the construction phase, during operation when components are replaced and at the end of the building's service life. From this perspective, the question of use time arises primarily from a portfolio and building stock perspective (accounting for new construction, renovation and demolition activities) when it comes to calculating emission paths or budgets.

F0.3 What methodologies exist to consider negative emission technologies (e.g. carbonation of concrete, biochar) or CO_2 sinks (e.g. intermediate storage of biogenic carbon)?

The following specific sub-questions were analysed and discussed in the research project:

- Which NET materials are available, and which are accountable?
  - Mineral, mineral-organic building materials and organic building materials. Can be counted as temporary sinks or negative emissions (NE)
- Accountability of temporary sinks (organic building materials)
  - Biogenic CO_2 is "climate-neutral" without ensuring permanent storage (approaches "0/0" or "-1+1" in accordance with EN 15804+A2)
- Accounting for the effect of technologies for CO_2 removal with a secured potential for long-term storage
  - NET contribution must be recognised and reported separately. No balancing at building material and building element level. At building level, balancing is appropriate in the last step, i.e. after the separate reporting of gross emissions and negative emissions, to show whether net-zero is achieved or not.
- Under what conditions may NE be recognised?
  - Only count towards balancing building-related emissions (Scopes 2 and 3).
  - NE of building materials, if certificates proving their negative emission effect are supplied and not sold to third parties.
  - Biogenic carbon content of mineral-organic and organic building materials can be considered if there is legally binding assurance of non-release (or permanent storage).

F0.4 What methodologies exist for modelling a) the reuse of building components, b) the recycling of building materials at the end of the building's service life, and c) the feeding of electricity into the grid from solar systems that are part of the building?

The following methods are preferred for modelling the reuse of building components, the recycling of building materials at the end of the building's useful life and the feed-in of electricity:

- "Additional efforts" for the reuse and recycling of building materials. Emissions that have already occurred from previously used materials and components are not to be considered (neither operational nor those from construction), only the future emissions associated with the recycling or reprocessing of reused components (plus disposal at the end of life).
- "Split investment" for feeding electricity from building-related solar installations into the grid. Production emissions are divided between the building on which the system is installed and the recipients of the PV electricity fed into the grid or sold. Determine the self-consumption share (or coverage ratio) and recognise the self-consumption share of the GHG emissions generation

of the PV system during construction or disposal. Electricity fed into the grid bears the environmental characteristics of PV electricity, no deduction in the operational phase.

F0.5 What role do the measures according to F0.4 play in relation to the development of the reduction paths and the net-zero target in the buildings area?

If materials and components coming from reuse or recycling are used, it is to be expected that the production emissions will be lower compared to new production. This improved energy and emission efficiency can be methodically considered when determining the reduction path for construction, but this can lead to increased emissions during operation.

The feed-in of electricity from building PV systems has at most an indirect impact on the reduction pathway of the entire building area. This is because such feed-in displaces, today and in the coming years, emissions in the (European) energy system and thus enables, among other things, a more climate-friendly production of building materials.

In terms of the building stock as an overall system, feeding buildings with excess capacity into the grid allows other buildings with low PV potential to be supplied, e.g. due to restrictions on listed buildings.

- From the perspective of the individual building, feeding electricity into the grid is an (economic) activity that is burdened with Scope 3 emissions (emissions from the construction of the PV system). If necessary, this activity can be excluded from the system boundary of the building (in this case, the entire electricity demand with grid consumption and corresponding emissions must be measured). A "credit" in the sense of negative emissions is not possible.
- From an overall system perspective, production emissions from building PV systems represent in part emissions from the national industrial sector and partly "imported" grey emissions (e.g. from imported PV modules).

F0.6 What framework conditions are to be defined for the calculation methodology of the operation of buildings (e.g. crediting of electricity fed back into the grid, balancing period of electricity, crediting of supply contracts and certificates)?

After analysis and discussion, the following framework conditions were defined for the calculation methodology of the operation of buildings:

- F0.6.A Modelling of the Swiss electricity mix, actual state, balance model
  - Consumer mix = domestic production minus exports plus imports. Corresponds to the model for building life cycle assessments in accordance with KBOB Recommendation 2009/1.
- F0.6.B Modelling of the Swiss electricity mix, temporal resolution
  - Aggregate hourly values to annual balances. Corresponds to the procedure for building life cycle assessments in accordance with KBOB Recommendation 2009/1.
- F0.6.C Modelling of the Swiss electricity mix, weighting of demand profile
  - No weighting for the planning phase. Corresponds to procedure use case 1 in accordance with section 4.1.1. of the SIA 380:2022 standard.
- F0.6.D Modelling of the Swiss electricity mix, taking future development into account
  - Static analysis: Current situation of electricity mix and power plants for the entire operational phase, ditto for all other energy sources. Corresponds to the procedure for building life cycle assessments in accordance with KBOB Recommendation 2009/1.

The following should be noted with regard to the methodological questions and approaches that require more in-depth investigation after the completion of this project:

- F0.6.A and F0.6.C: Further basic work and research is required to make a binding recommendation for one (or more) electricity balance model (BM), as the uncertainties for all three balance models remain high despite intensive clarification. It is recommended that the corresponding work be carried out once the project has been completed. In the interests of continuity with the previous approach, it is assumed that this project will continue to use the current Swiss consumer mix until further notice.

- F0.6.B: According to the project team and feedback from the sounding board, there are indications that aggregating to monthly rather than annual values better reflect the reality of emissions.
- F0.6.D: The question of future development arises not only for electricity, but also for the district heating mix. The same approach is recommended, i.e. considering the decarbonisation strategies of local energy companies.

Conclusions and recommendations from F0

F0 comprehensively addresses the methodological challenges of defining net-zero greenhouse gas emissions in the building area. The results provide a solid framework for understanding the emissions of the entire life cycle of buildings. The development of the two definitions "net-zero building" and "net-zero-ready building" is an important step. The introduction of temporary storage to balance remaining emissions in “net-zero ready” buildings is a viable solution until secured permanent storage options are available.

F1 Top-down view

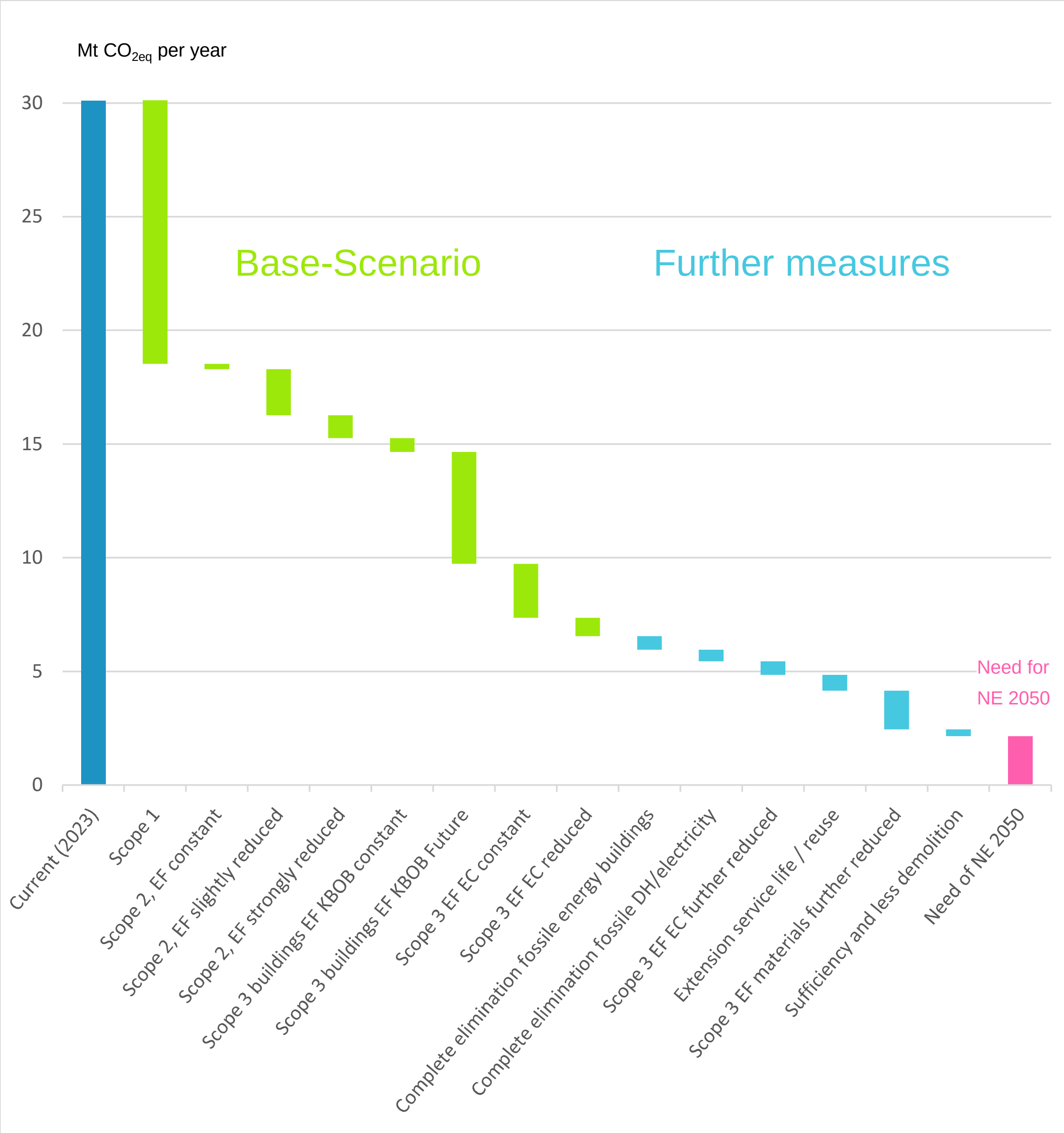

Figure 2 : GHG emissions in 2023 (Mt $CO_{2\text{-eq}}$ per year) reductions per lever until 2050 for the baseline scenario and the additional measures as well as demand for NE in 2050. Source: TEP Energy, 2024.

Research questions and findings

In sub-project F1, the building area is analysed over the entire life cycle, including the upstream and downstream GHG emissions (Scope 3) ("Whole Life Carbon" WLC approach). It therefore differs fundamentally from the observation period and perimeter of the building sector in accordance with the CO_2 Act and the Climate and Innovation Act (KIG). Except for the "exemplary function of the Confederation and cantons", only direct GHG emissions are considered; indirect emissions are addressed in their respective sectors, e.g. in the industrial sector, whereby no distinction is made between building-related and other emissions.

The objective of sub-project F1 is to show how the emissions budget defined for the building sector can be met, what additional emissions are to be expected for the building area in Switzerland and abroad and what bottom-up requirements are necessary to achieve the target. The role of technological and structural developments in the energy and industry sectors, negative emission technologies and biomass-based building materials is also highlighted.

The top-down considerations are based on model calculations with the building stock model for the period from 2023 to 2050 and on targeted top-down analyses of potentials and material flows. The following Table 3 describes the defined base scenario and the various scenario variants and sensitivities.

Table 3: Definition of the base scenario as well as scenario variants and sensitivities for the 3 scopes.

Scopes	**Base scenario**	**Variants and sensitivities**
All	Increasing operational energy efficiency in the areas of building envelopes, heating systems, building technology and appliances.	*No variants and sensitivities*
1	Virtually no fossil fuels in the building stock by 2050	*No fossil fuels at all in the building stock by 2050*
2	▪ Reduction in electricity demand for electric heating/boilers to almost 0, increase in HP, ▪ Rising demand for district heating ▪ Emission factors (EF) "greatly" reduced	*EF less strongly or not at all reduced to show the effect of this lever*
3 Buildings	▪ Lever Choice of construction types ▪ Lever Material usage ▪ With lever KBOB emission factors and emission coefficients 2050 ▪ Without lever non-technical measure ▪ Lever temporary sinks and lever NET are recognised separately	*Less or no effect of individual levers to show their effects.* *Further or additional levers to further reduce emissions compared to the baseline scenario:* • *Higher proportion of timber construction* • *Further reduction of EF components* • *Less demolition and “replacement building”* • *Less ERA growth* • *Longer utilisation times*
3 Energy sources	• Constant or falling demand • Emission factors (EF) greatly reduced	*EF less strongly or not at all reduced to show the effect of this lever*

The following results and findings emerge in relation to the various research questions.

F1.1 Target definition: What does net-zero mean in terms of GHG emissions caused by the construction and operation of the Swiss building stock by 2050, including Scope 1, 2 and 3?

This question is answered using two approaches. Firstly, for the building sector with reference to the legal framework (KlG) and secondly, the budget for the buildings area in Switzerland is broken down from a scientifically based global budget to Switzerland (method according to project part F0).

- In the first approach, a target path is defined for the calculation of the GHG emissions budget based on the target in the KlG. The different system boundaries are considered. For the buildings sector, this results in a reduction in annual GHG emissions of -30 % by 2030, -54 % by 2040 and -93 % by 2050, in each case compared to 2020. This results in a remaining share of emissions that are difficult to avoid for 2050 and therefore a requirement for negative emissions (NE) of 2.0 Mt $CO_{2\text{-eq}}$. The KlG target results in an emissions budget of around 1620 Mt $CO_{2\text{-eq.}}$ for the period 1990 to 2050, of which almost 70 % will already have been utilised by 2023. This leaves a residual budget of around 510 Mt $CO_{2\text{-eq}}$.
- In the second approach (global perspective), the budget depends on the following factors: the target set, the certainty of achieving it and the allocation approach, whereby the grandfathering principle was used here. For a 1.5°C target, the budget is 200 Mt $CO_{2\text{-eq}}$ or less. With a 1.7°C target, it is 420 Mt $CO_{2\text{-eq.}}$ or less (in each case with a probability of at least 67 %).

A comparison of the two approaches shows that the residual budget of 510 Mt $CO_{2\text{-eq.}}$ based on the KlG is a rather generous target. If the scientifically based global budget available to Switzerland is used as a guide, a significantly faster reduction in GHG emissions from buildings is required compared to the KlG.

F1.2 What GHG emissions reductions and what negative emissions are expected from construction and what GHG emissions reductions from operation to achieve net-zero in the building area in a life cycle assessment?

In the defined baseline scenario, the following reductions are achieved between today (2023) and 2050:

- Scope 1 emissions from the combustion of heating oil and natural gas can be reduced to almost zero.
- A large reduction is also expected in Scope 2 emissions from the generation of electricity and district heating. However, this is somewhat lower and in 2050 around 14 % of the 2023 level of emissions will remain. This is also because the demand for electricity for heat pumps and district heating is increasing and that the emission factors for these are not decreasing to zero.
- The reduction in Scope 3 emissions is even lower. Scope 3 emissions from the construction, renovation and demolition of buildings fall by just under 60 %. This is due to lower construction activity, lower-emission construction types, components and materials. Scope 3 emissions from the provision of energy sources and energy infrastructure also decline.

Between 2023 and 2050, emissions from Scopes 1 and 2 are reduced by 93 %, Scope 3 by 62 % and all three Scopes together by 78 %. Despite these significant reductions, CO_2 emissions in the base scenario still amount to around 6.5 Mt per year in 2050. These emissions come primarily from construction and renovation (around 4.1 Mt per year) and partly from the operation of buildings (around 2.4 Mt per year, of which just under 1.3 Mt comes from Scope 3 energy sources). This results in a need for negative emissions of around 6.5 Mt per year in 2050 in the base scenario. This would far exceed the quantity of 2 Mt $CO_{2\text{-eq.}}$ per year derived from the KlG. Further measures are therefore important to reduce the need for NE to an achievable level (see question F1.4).

F1.3 How great are the potentials or sustainable availability of building materials (especially biomass-based) that lead to negative emissions in the building area.

The potential of building materials in the form of durable NET solutions for building construction, such as the use of carbonated concrete, is far from sufficient to balance the remaining emissions of the baseline scenario. This is the case even if the storage of biochar is considered. The greatest contribution to potential negative emissions (NE) is made by measures that initially generate temporary sinks through the use of biogenic building materials, which can be converted into NE at a later date. This is achieved if the carbon stored in the wood used or in other biogenic building materials is stored beyond the service life of the building. Due to the large carbon stocks, this NE potential is essential for balancing the remaining emissions. In the "more wood" scenario variant, the NE need derived from the KlG for remaining emissions of around 2 Mt $CO_{2\text{-eq.}}$ per year is achieved (if the temporary sinks are already considered when the biogenic materials are installed and not only at the time of the actual transfer to NE).

F1.4 Which reduction paths in 2030/2040/2050, in compliance with the CO_2 budget for the building area according to F0.1 and differentiated according to GHG emissions and negative emissions, result from this, differentiated according to existing buildings and new buildings?

Around half of the building area's emissions of circa 30 Mt $CO_{2\text{-eq.}}$ per year in 2023 are from direct and indirect emissions (Scopes 1 and 2) and half from downstream emissions (Scope 3). The former are mainly emitted during the operational phase of the buildings (directly or through heating and power plants) and the latter occur during the construction and disposal of materials. A distinction must also be made between new and existing buildings: in 2023, emissions from the construction of new buildings amount to 4.3 Mt $CO_{2\text{-eq.}}$ per year and 5.3 Mt $CO_{2\text{-eq.}}$ per year for existing buildings. The following reduction paths are linked to the 2023 emissions:

- In Scopes 1 and 2, the reduction path is primarily based on the replacement of fossil fuels such as heating oil and natural gas with heat pumps (HP) and district heating (DH). Motivated by the aim to increase the use of wood as a building material, wood energy for heating in buildings will also be reduced by a good 30 %. Scope 2 emissions are also reduced due to the extensive decarbonisation of district heating and electricity generation. In the case of electricity, the reduced demand, made possible by efficiency gains in appliances and building technology, also plays a role.
- The following effects contribute to the reduction pathway for Scope 3 emissions:
    - A significant reduction in construction activity, partly due to the slowdown in population growth and a stagnation in the amount of space required per person. As a result, annual emissions from the construction of new buildings are already reduced by around 40 % without further measures. Due to the growing proportion of the building stock in which the building elements must be replaced due to their age, there is an increase in renovation activity. This is associated with corresponding emissions from construction, whereby less relative reduction potential is available in this area through technical measures for optimisation (compared to the new construction sector). Consequently, additional measures to extend the service life, repairability and reuse of building elements are important.
    - Measures on the building side, i.e. the choice of lower-emission construction types, building elements and materials, are particularly effective in new buildings (reduction of approx. 20 %).
    - A reduction in Scope 3 emissions can be achieved through the provision of final energy and secondary energy (mainly district heating and electricity for heat pumps). Both by reducing demand and by reducing specific emissions (e.g. from PV and wind energy systems).
    - Industry-related measures, i.e. reducing the specific emission factors of materials and building elements, reduce the emissions from construction by around two thirds, based on emission factors according to the "KBOB-Future".

Taking these reduction paths into account, the renewal of the building stock in 2050 accounts for most emissions from construction (3.3 of 4.1 Mt $CO_{2\text{-eq.}}$ per year). These are emissions from the renewal and replacement of materials, building elements and building technology as well as interior and exterior fittings. The reasons for the greater importance of existing buildings compared to new buildings are as follows: new construction activity is falling; existing buildings are growing and the reduction potential in existing buildings is lower (according to the KBOB Future basis used).

With the identified technical levers (see Table 3) in the planning, construction and operation of buildings as well as the reduction of emissions in the energy system and in the production of building materials and elements in terms of future emission factors according to the "KBOB Future", the budget of 500 Mt $CO_{2\text{-eq.}}$ derived from the KlG for the period 2023 to 2050 is met. However, the globally allocated budget of 200 Mt $CO_{2\text{-eq.}}$ is clearly exceeded. Overall, the reduction target derived from KIG for 2050 is far from being achieved in the baseline scenario: gross GHG emissions of around 6.5 Mt $CO_{2\text{-eq.}}$ per year remain. Without further measures, a large amount of NE would have to be provided. This would far exceed the amount of NE of 2 Mt $CO_{2\text{-eq.}}$ per year derived from the KlG for the building area. In addition to the measures analysed, further levers are therefore required that go beyond the base scenario. Their impact was quantified in a sensitivity analysis. The following levers were roughly quantified:

- Complete elimination of fossil fuels in buildings.
  Additional effect compared to the base scenario: approx. 0.6 Mt $CO_{2\text{-eq.}}$ per year.
- Complete elimination of fossil fuels in the generation of secondary energy sources such as district heating and electricity, e.g. using heat pumps, biomass, green hydrogen or other fossil-free or renewable energy sources.
  Additional effect compared to the base scenario: approx. 0.5 Mt $CO_{2\text{-eq.}}$ per year.
- Halving of Scope 3 emissions from the provision of energy carriers (analogue assumption as for building materials and building elements).
  Additional effect compared to the base scenario: approx. 0.6 Mt $CO_{2\text{-eq.}}$ per year.
- Extending the lifespan and useful life of buildings and components, e.g. through the careful planning of building renovations, system separation and, where possible, the reuse of components, improvements in the reparability of components, building technology and building equipment.
  Additional effect compared to the base scenario: approx. 0.85 Mt $CO_{2\text{-eq.}}$ per year.
- Further reduction of specific emissions from building materials and building elements by 50 %, i.e. beyond the assumptions of "KBOB-Future".
  Additional effect compared to the base scenario: approx. 2 Mt $CO_{2\text{-eq.}}$ per year.
- Reduction in space (sufficiency) and less demolition and “replacement building”.
  Additional effect compared to the base scenario: approx. 0.3 Mt $CO_{2\text{-eq.}}$ per year.

Taking overlay effects into account, operational emissions are reduced by around 1.7 Mt $CO_{2\text{-eq.}}$ per year and production emissions by around 2.7 Mt $CO_{2\text{-eq.}}$ per year. This means that gross emissions in 2050 amount to around 2 Mt $CO_{2\text{-eq.}}$ per year, instead of 6.5 Mt $CO_{2\text{-eq.}}$ per year as in the baseline scenario. These emissions can be balanced by NE in the building area. On the one hand, this means that the net-zero target in the building area is fundamentally achievable and, on the other, that all available levers must be utilised, as it is a ‘precision landing’ without any significant leeway.

F1.5 Quantify the impact of the reduction paths on the increase/decrease of carbon stocks in used wood and other building materials based on renewable resources.

In the baseline scenario, the proportion of timber construction in the analysed building categories increases. The resulting increase in the annual amount of wood used in the period from 2030 to 2050 is around 30 % above the baseline value of the base scenario. An increase in the use of construction timber (increase of 40 % instead of 30 %) and additional promotion of straw insulation materials is outlined with a "higher proportion of timber construction" scenario variant. This results in a 180 % to 195 % increase in the amount of wood used over the time horizon from 2023 to 2050 compared to the amount of wood removed from the building stock when demolishing and replacing building components. Over the period from 2023 to 2050, this results in a net increase of 3.9 to 5.5 Mt of stored carbon in the building stock. This corresponds to a temporary sink of 14 to 20 Mt $CO_{2\text{-eq.}}$ by 2050, or the equivalent of a sink increase of 0.5-0.7 Mt $CO_{2\text{-eq}}$ per year. As described above under F1.3, a legally binding guarantee of permanence beyond the lifetime of the buildings is a prerequisite for being recognised as a NE. It is also essential that suitable measures are taken to avoid double counting.

At the level of an overall view of the forest-building ecosystem, an increase in the use of construction timber does not necessarily mean a sharp increase in the Swiss timber harvest or an overexploitation of the forests. The increase in the use of construction timber modelled in the baseline scenario and in the "Higher proportion of timber construction" scenario variant can be offset by the reduced use of energy wood in individual buildings. A change in carbon stocks due to wood utilisation results at the forest ecosystem level depending on the total consumption of wood for buildings, furniture and other industrial applications. The utilisation does not lead to a reduction in wood stocks, but only to a slightly lower increase in stocks in forest ecosystems. Moreover, the reduction of wood use to maximise carbon stocks in the forest ecosystem makes only limited sense in view of the increasing risks of heat/drought damage and the necessary adaptation of tree species.

F1.6 What are the territorial shares of the emission targets and reduction paths (according to the Long-Term Climate Strategy, in which NET are reserved for unavoidable emissions) in a life cycle assessment of buildings or the building stock?

The GHG emissions from construction are currently in the order of 9 to 11 Mt $CO_{2\text{-eq.}}$ per year. The reduction targets of 90 % compared to 1990 for the construction industry sector in accordance with the KlG are applied equally to the territorial shares of emissions abroad in this study. This leaves a final value of difficult-to-avoid emissions of around 2 Mt $CO_{2\text{-eq.}}$ in 2050 on the construction side, with territorial shares of around 1 Mt $CO_{2\text{-eq.}}$ each from domestic production and imported goods. In the baseline scenario with building optimisation and the production of building materials with emission factors according to the KBOB future, this value is significantly exceeded: at 4.1 Mt $CO_{2\text{-eq.}}$, around twice as many GHG emissions remain for construction. Halving the final value requires further measures, see F1.4.

Conclusions and recommendations from F1

The emissions targets derived from the KlG are not achieved with the assumptions made for the baseline scenario. There are major deviations, particularly towards the end of the time horizon in the years 2040-2050. Derived from the KlG targets, the emissions that are difficult to avoid in 2050 for the building area can be estimated at 2 Mt $CO_{2\text{-eq.}}$ Even with the assumed reduction in emissions in the production of building materials in combination with a sharp decline in new construction activity, the residual emissions still remain at a level of 6.5 Mt $CO_{2\text{-eq.}}$ Negative emissions or temporary sinks to balance for this deficit exist at present and in the future but are, from today's perspective, far from sufficient to close this gap. There are also technical and regulatory hurdles. Additional measures to reduce emissions, such as those proposed in this project, are therefore expedient. Their contribution to reducing emissions should be analysed further in the follow-up, with a focus on the maintenance and renovation of existing buildings, and on upstream and downstream value chain.

F2 Bottom-up view

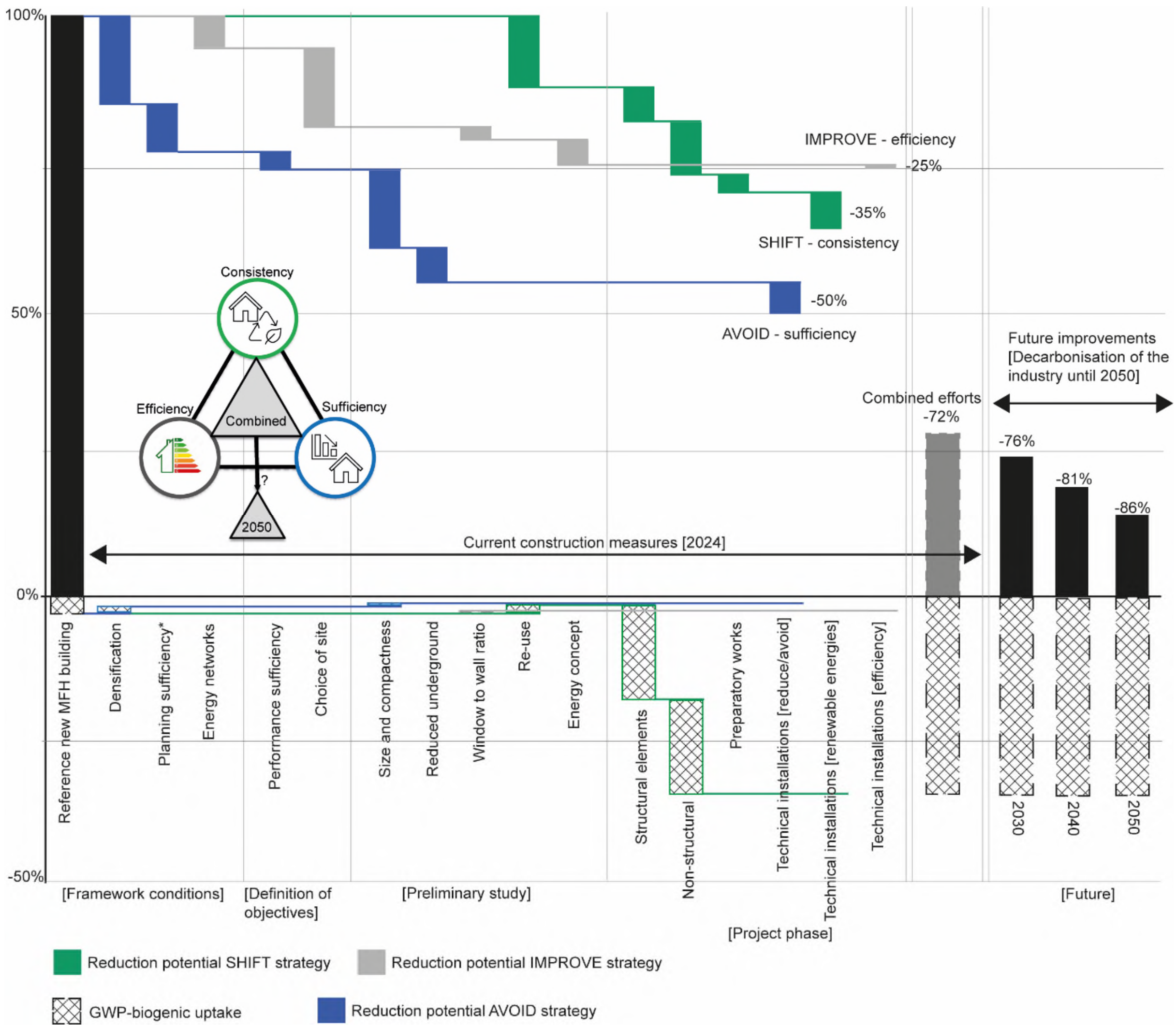

Figure 3 : Relative GHG emissions reduction potential and GWP-biogenic uptake potential of the proposed measures and strategies for a reference MFH building 100 % represents 20kgCO_{2eq}/m^2.year. Figure taken from F2 report.

Research questions and findings

Research question F2 aims to define net-zero GHG emissions strategies, establish benchmarks and support stakeholders in the implementation of net-zero practices at the building level. The objectives of sub-project F2 include the identification of measures to reduce GHG emissions from construction and operation at building level, the formulation of strategies to achieve net-zero GHG emissions by 2050, the evaluation of these strategies from a social, economic and technical perspective, and the classification of building standards in relation to net-zero targets. A systematic approach involving literature reviews, logical groupings and data collection is used to answer the research questions. The results in the report are based on a life cycle approach. The measures are assessed in terms of their relevance for emissions at building level and the limitations associated with the data situation and the practical implementation of the individual measures. Recommendations are then made for each measure, providing a detailed overview of the challenges and opportunities for implementing net-zero building practices. The measures are then evaluated with feasibility indicators in economic, social and technical terms. Finally, the measures are combined into strategies according to the results of the feasibility study. In parallel to the evaluation of the measures and strategies, the building standards and labels available in Switzerland are analysed to identify possible deviations from the net-zero targets.

The following results and findings emerge in relation to the various research questions.

F2.1 What technical and non-technical measures to reduce GHG emissions from construction and operation exist at the level of individual buildings, differentiated by new construction and existing buildings (incl. refurbishment)? The measures can concern the building itself and/or their supply chains (specially building material manufacturers).

The following measures are discussed in terms of their overall potential for GHG emissions reduction, considering the limitations of individual projects and contextual conditions.

For new buildings :

- Technical measures: The use of low-emission materials, including biogenic materials (e.g. wood, straw), can significantly reduce grey emissions. In addition, compact construction and the avoidance of underground constructions (e.g., underground floors, parking) reduce material requirements and further reduce emissions. Other measures include increasing energy efficiency, using renewable energy sources and optimising the load-bearing structure.
- Non-technical measures: The promotion of densification instead of new construction, the promotion of sufficiency measures (e.g. smaller area per resident) and a focus on the durability and flexibility of materials and buildings are crucial to minimising emissions.

For existing buildings (refurbishments):

- Technical measures: Renovating existing buildings instead of building new ones offers considerable potential for minimising emissions in the building area. Retrofitting buildings with energy-efficient technologies as well as using low-emissions and reused materials and installations also makes a significant contribution to reducing emissions.
- Non-technical measures: Extending the lifespan of buildings and reducing the scope of renovations can also help to reduce emissions.

F2.2 Which strategies (combination of measures) are suitable for achieving net-zero for individual buildings by 2050?

The measures identified in section F2.1 are grouped into the following three strategies:

- AVOID: This strategy focuses on sufficiency measures, such as reducing the living space per person, avoiding new buildings and reducing the energy consumption of buildings. This strategy could reduce GHG emissions by up to 50 % in a reference multi-family house but faces challenges in terms of acceptance and economic feasibility.
- SHIFT: This strategy aims to replace conventional materials and systems with low-emissions and/or reused materials and the use of renewable energy. The strategy has a high level of social acceptance and brings additional ecological benefits, but also poses technical and cost-related challenges.
- IMPROVE: This strategy focuses on increasing the efficiency of existing practices, such as improving the energy efficiency of buildings, optimising energy networks and increasing the efficiency of systems. The effectiveness of this strategy is heavily dependent on infrastructure and policy reforms, such as the expansion of renewable energy infrastructure.

F2.3 How are these strategies assessed from a constructional and economic point of view?

For all strategies, there are obstacles, particularly regarding the framework conditions of a project, especially the costs for the expansion of energy networks and the decarbonisation of the industry, public acceptance of planning sufficiency measures and the technical simplicity of industrial decarbonisation. Technical indicators suggest that measures can be scaled up quickly and easily in early planning phases (e.g. compactness, window-to-wall ratio, avoidance of undergrounds). Measures in the project phase, such as the selection and dimensioning of construction elements and technical installations, are technically feasible, but are of medium to low simplicity in terms of implementation and are often associated with higher costs. Overall, the feasibility assessment shows that most measures are ready for implementation. However, measures in early planning phases generally have more favourable conditions. While measures at the framework conditions level encounter more obstacles for all the indicators analysed (economic, social, technical).

F2.4 How should the various building standards and labels (MuKEn 2014, GEAK, Minergie, SNBS, as well as the SIA efficiency path) be classified in relation to the net-zero target and what are the methodological differences between them?

The building standards and technical bulletins SIA 2032, 2040 and FprSIA 390/1:2024 are consistent with each other in terms of scope, indicators, data used and GHG emissions limits. They all enable the assessment of a building based on the full life cycle approach with limit and target values to be complied with in relation to GHG emissions.

The other building standards and labels analysed do not follow a complete life cycle approach and their requirements differ. This can be explained by the scope of application of the respective label or building standard. For example, a GEAK is currently not intended to map a complete life cycle analysis (LCA), but rather to inform the building owner about the energy efficiency of the building and the associated GHG emissions. To improve comparability, there should be harmonisation between LCA-based building standards (SIA standards) and the labels (e.g. Minergie) regarding specific rules such as the allocation of PV electricity between the building and the grid.

Considering the measures available, the labels require or promote practical measures - from urban planning and target definition to the selection of suppliers for tenders. Some measures listed in the SIA standards and technical bulletins, which are indirectly necessary to fulfil the requirements, are not explicitly promoted in the labels. These include the optimisation of building size and compactness, the minimisation of basement structures, ensuring an optimal ratio of window to wall area and the implementation of a simple load-bearing structure with adapted spans (i.e. optimal dimensioning of the structure). Measures for carbon storage or NET are not promoted.

F2.5 To what extent do the limits and targets of these standards meet the net-zero target for individual buildings?

Only the FprSIA 390/1:2024 has a reduction pathway that is compatible with the net-zero goal for 2050, but only with an informative annex. Existing labels, particularly the more environmentally orientated ones such as Minergie-ECO and SNBS, could be more closely aligned with net-zero targets by adopting standardised GHG emissions limits on a life cycle basis in the coming years, based on the national carbon budget for buildings. In the case of the SNBS, the broader sustainability approach reduces the relevance of net-zero compatible measures. To bring the label in line with the net-zero targets, the certification rules should be stricter in this respect. The integration of criteria that explicitly promote the missing measures (size and compactness, minimisation of basements, optimal window-to-wall ratio and simple load-bearing structures) could raise awareness among practitioners of these key emission reduction levers and thus facilitate the construction/conversion of low-emission buildings and ultimately the achievement of net-zero targets. Overall, the combination of the lack of GHG emissions reduction requirements for construction and operation and the lack of carbon storage or NET measures shows that the labels analysed are not yet fully in line with net-zero targets.

F2.6 Quantification on concrete examples on different building categories.

The identification and evaluation of GHG emissions reduction measures at building level highlighted the wide range of reduction options available to stakeholders in the construction and renovation activities. Projects are always closely linked to specific site conditions, the regulatory framework, preferences of owners and users, building typology and contextual conditions. These factors always limit the full potential of the identified measures. Nevertheless, each measure offers approaches to reducing emissions that can be implemented despite case-specific limitations. It is crucial that these approaches are prioritised by all stakeholders in the area of building planning and the creation of the relevant framework conditions.

The average reduction potential of an individual measure is around 15 %, whereby no individual measure is able to reduce emissions by more than 30 %. One exception is renovating instead of building new buildings, as this completely avoids the construction of a new building, thereby eliminating its emissions altogether. However, this shifts the emissions burden to the area of refurbishment, which on average has lower emissions than a new building, but not zero. Continuous decarbonisation of industry by 2050 has the greatest potential as an individual measure, although this is associated with considerable uncertainties and methodological challenges. Building size and compactness show high potential as individual measures and achieve a reduction of almost 20 % compared to the reference case.

Overall, the AVOID strategy can potentially reduce the GHG emissions of a reference multi-family house by 50 % and a reference single-family house by 27 %. The second strategy, based on the consistency principle or "shifting" concept, combines measures that provide a consistent use of low-emissions and fossil-free options such as bio-based materials and a higher proportion of renewable energies. This strategy achieves a 35 % reduction for both reference cases and potentially increases the biogenic temporary storage by up to 32 % of the original GHG emissions of the reference multi-family house and 50 % of the reference single-family house. The third strategy focuses on efficiency principles or the "improve" concept by combining measures that improve existing practices and increase the efficiency of the systems used. This strategy achieves a reduction of 25 % for a reference multi-family house and 12 % for a reference single-family house with current technologies (without future decarbonisation of the industry).

When all measures are combined, a reduction of 72 % can be achieved for a reference multi-family house and 50 % for a single-family house, with biogenic carbon storage reaching the emissions' level when permanent storage with legally binding agreements is considered. The same reference building with combined measures built in 2050 (assuming a reduction in supply chain emissions) could reduce its emissions by a further 50 %.

Conclusions and recommendations from F2

The results of the F2 report (bottom-up approach) show that a combination of technical and non-technical measures is crucial to achieving the net-zero targets. A key finding is that no single measure is sufficient to achieve net-zero at building level; rather, a holistic approach is required that considers both grey and operational emissions.

For new buildings, the use of low-emissions materials such as biogenic alternatives, the optimisation of structural design and the reduction of building size and basement levels are crucial. For existing buildings, refurbishments combined with energy efficiency, the expansion of renewable energies and the reuse of building materials can significantly reduce GHG emissions.

The most effective strategies include the "AVOID" approach, which focuses on sufficiency measures, and the "SHIFT" approach, which emphasises the use of renewable materials and energy sources. A combination of strategies, as applied to a reference multi-family house in this project, showed a possible reduction of the original life cycle GHG emissions by 72 %. This results in life cycle GHG emissions of 5.4 kg $CO_{2\text{-eq.}}$ /m² and year and an equivalent or higher amount of temporary biogenic carbon storage.

F3 Overview of possible implementation paths

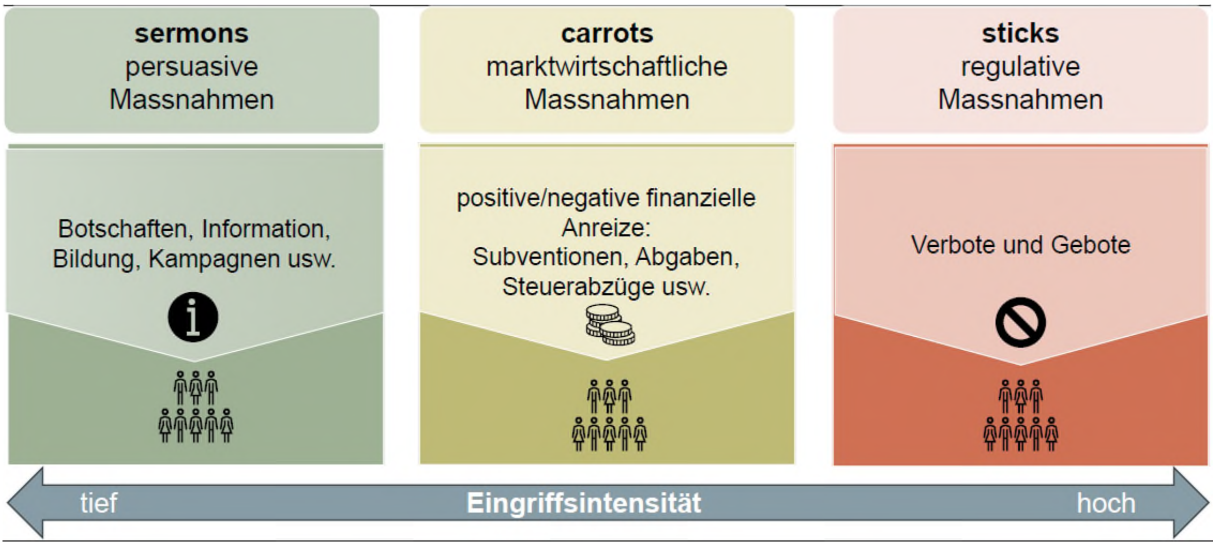

Figure 4 : Policy instruments. Illustration of Interface, based on Verdung 2010; Sager et al. 2017.

Research questions and findings

Sub-project F3 has two main objectives: (1) to provide an overview of the existing policy framework and instruments for the "net-zero greenhouse gas emissions in the building area" goal and (2) to demonstrate the development of policy measures based on the three strategies from sub-project F2 (avoid, shift, improve). The opportunities and risks of these measures are analysed qualitatively from a political science perspective and recommendations are made for future policy design. The analysis is based on existing literature, the knowledge of the project team and feedback from the sounding board. It is important to note that this is a qualitative study that provides an overview of existing policy measures and includes ideas for possible further government regulation. The recommendations are prospective in nature, as the regulatory environment develops dynamically.

The following results and findings emerge in relation to the various research questions.

F3.1 What are the current political framework conditions (outline)?

The overview shows that there is already a broad mix of measures that are being implemented by various actors (federal and cantonal, and in some cases also municipal). From a building perspective, this is a cross-sectional policy that is primarily anchored in energy, climate and sustainability, and environmental policies. The competence (responsibility) for the design and implementation of the central measures and instruments in the area of GHG emissions lies with both the federal government and the cantons or municipalities. In addition, many aspects of both the construction of buildings and the utilisation of living space are fundamentally a matter of the private sector. The public sector therefore currently only influences some of the relevant framework conditions for NZ-GHG emissions in the building area.

F3.2 What policy measures (regulations, incentives) could in principle be used to achieve the objective defined in question 1.1?

Various policy measures could be used to achieve NZ-GHG emissions in the building area. These include regulatory measures such as binding regulations for the reduction of emissions and limit values for CO_2 emissions of buildings. Incentives could be financial support programmes for the energy-efficient refurbishment of buildings and the use of renewable energies, as already implemented in the Buildings Programme or envisioned in the KlG (impulse programme). Persuasive measures such as information campaigns, knowledge building or the further development of building standards and labels to promote sustainable building materials also play an important role. Finally, strengthening the circular economy in the construction sector can make a significant contribution in reducing Scope 3 emissions.

F3.3 Which existing policy measures fall short when taking a life cycle approach, i.e. when considering Scope 1, 2 and 3?

The current policy measures and framework conditions are primarily aimed at direct emissions during operation (Scope 1) and indirect emissions from the purchase of electricity, district and local heating or cooling (Scope 2). Indirect emissions from Scope 3, i.e. from the production of building materials and components and their installation (upstream) as well as dismantling, waste treatment and disposal (downstream) are only directly addressed in the award criteria for public procurement. The legislation for the construction and waste sector does not currently contain any measures to reduce Scope 3 emissions for the building area. With a view to achieve NZ-GHG emissions, there are therefore gaps, particularly in the area of circular economy. The (ongoing) revision of environmental protection legislation can provide an important concrete basis for closing this regulatory gap. Subsequently, the cantons will be required to include limit values for grey emissions in their energy legislation.

F3.4 How should the strategies from question 2.2 be assessed in terms of implementation opportunities and risks in the periods 2030/2040/2050?

Regarding the implementation of the three strategies for NZ-GHG emissions in the building area, it can be stated that subsidies (incentives) for the substitution of fossil heating systems and for energy-efficient refurbishments are already established. New binding measures (Commandments/Prohibitions), such as limit values for grey energy/grey emissions, a tightening of building permit practice or refurbishment obligations for changes of ownership, can place greater obligations on private actors. However, such measures are highly controversial politically due to the intensity with which they interfere with individual behaviour and the market. Potentially effective political measures to achieve NZ-GHG emissions in the building area are: a) requirements to promote circular economy and the use of low-emissions materials such as wood, b) expansion of financial incentives for the energy-efficient refurbishment of buildings, c) stricter building regulations to reduce emissions in new buildings and d) promotion of sufficiency in housing construction and per capita living space consumption. The introduction of corresponding political measures is challenging for social and political reasons. It is therefore important for the development and implementation of "new" and scalable policy measures that there is a continuous dialogue between the stakeholders involved and the transfer of knowledge between government levels, the private sector and the scientific community.

Conclusions and recommendations from F3

The project provides an overview of possible policy measures to achieve net-zero in the building area. The central conclusion is that a multi-layered approach of regulation, incentives and knowledge building is necessary to achieve NZ-GHG emissions. While current policies address direct emissions (Scope 1) and energy-related emissions (Scope 2), there is a significant gap in the consideration of life cycle emissions along the entire supply chain (Scope 3). An expansion of regulations, particularly in the area of recycling management, offers potential, with a focus on legal requirements for greenhouse gas emissions from buildings. This also requires the cantons to include limit values for grey GHG emissions in their energy laws. At the same time, low-emission construction should also be promoted from the waste side.

In general, cooperation and the exchange of knowledge between government levels and experts are decisive factors for the development of new policy instruments and measures. Finally, the effects of increased state intervention on future construction activity and approval practices should be analysed in depth. It is also important to clarify who can and should make what contribution to NZ-GHG emissions in the building area.

F4 Bases for limit and target value setting

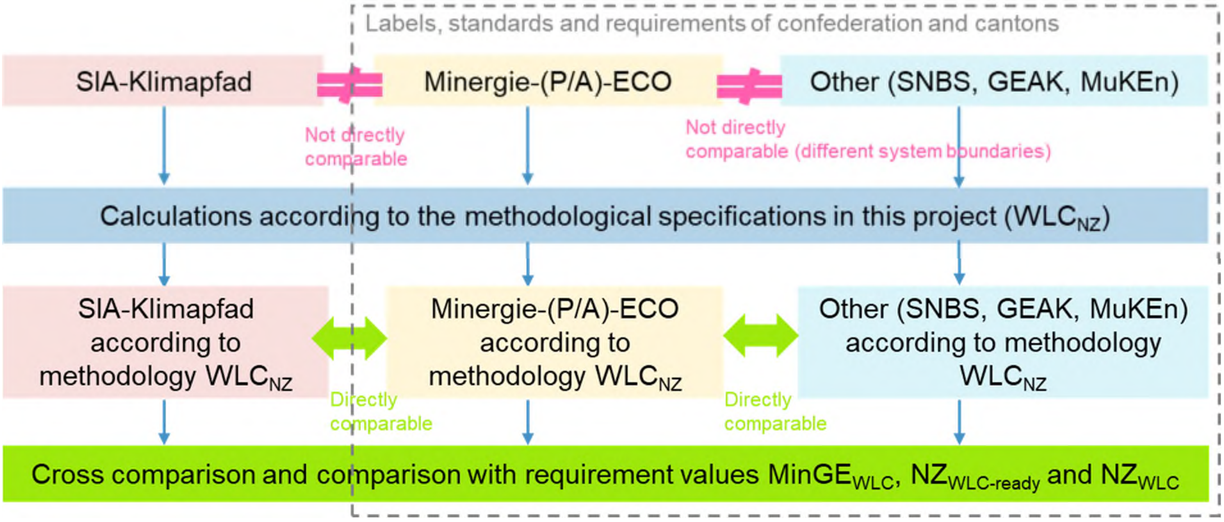

Figure 5 : Establishment of comparability between different building standards and labels by transferring them to a common basis, the WLC_{NZ} methodology. Source: TEP Energy.

Research questions and findings

F4 analyses the similarities and differences in definitions, calculation methods, databases and assumptions for net-zero buildings in the building standards and labels.

The following results and findings emerge in relation to the various research questions.

F4.1 Where are there uniform definitions and assumptions, where are the differences? How can the different evaluation systems of the energy supplied be dealt with?

Both the SIA climate pathway (FprSIA 390/1: draft norm SIA 390/1, as of February 2024) and Minergie-(P/A)-ECO include a comprehensive emissions balance over the life cycle of a building. There are certain differences in the individual methodological approaches and the requirement values. Other building standards and labels, such as SNBS, refer to the SIA climate path or Minergie or, conversely, provide a basis for them. Mention should be made, in this regard, of the GEAK, which defines the emissions calculation for the operational phase but does not cover the construction phase.

The most important similarities between the SIA climate path (FprSIA 390/1) and Minergie-(P/A)-ECO are as follows:

- Use of basic definitions, assumptions and calculation routines, especially as these refer in part to each other or to common principles (e.g. SIA 380, SIA 380/1, SIA 2032, KBOB life cycle assessment data).
- Both Minergie and the SIA climate path recognise that neither useful, final nor primary energy efficiency are good indicators for low or even zero GHG emissions.
- Because Minergie has included production GHG emissions in its label since 2023 and reports operational emissions for information purposes in accordance with the GEAK methodology, Minergie and the SIA climate path cover the areas relevant to net-zero. However, there are methodological differences.
- Both Minergie-(P/A)-ECO and the SIA climate path only recognise measures that are related to the building. Separate approaches, such as certificates for green electricity or negative emissions, are generally not recognised (except for the SIA climate path, which recognises electricity from new ecological systems to provide incentives for larger PV systems).

The following methodological differences exist between Minergie-(P/A)-ECO and the SIA climate path (FprSIA 390/1):

- Accounting for the electricity produced by PV systems and the associated pro rata emissions during construction: With Minergie, the self-consumption share of the PV system in the building is determined on an hourly basis. In addition, 40 % of the production emissions that would be attributable to the electricity fed into the grid on a pro rata basis are allocated to the building. This calculation method is not WLC-compliant. With the SIA climate path, the self-consumption share is determined on an hourly basis in accordance with the WLC if the Guarantees of Origin (GOO) are issued to third parties. To incentivise larger PV systems, the self-consumption share can be determined on an annual basis for the SIA climate path (in this case, the Guarantees of Origin are not sold). This results in different production GHG emissions to be considered between Minergie and the SIA climate path for the same system size in the same situation. These differences are significant in the assessment of photovoltaic systems per se but make little difference in the assessment of entire buildings.
- To set incentives, the SIA climate path recognises certain green electricity-GOO or certificates, provided they originate from new plants and meet minimum requirements for ecological quality (e.g., as with nature made star), but Minergie does not. However, Minergie does not set any requirements for which this would be relevant. In particular, the emissions from operation are only shown for information purposes and are not subject to any limit values (yet they are constraint indirectly, see below). Both the SIA climate path and Minergie calculation methods mentioned do not conform to the WLC approach developed in this project.
- In the case of district heating, the SIA climate path calculates with the actual emissions of the district heating product. Minergie, on the other hand, uses project-specific weighting factors depending on the fossil share of the individually purchased district heating.

The following differences between Minergie and the SIA climate path are noted when setting requirements and incentives:

- The SIA climate path includes the emissions of the entire life cycle in the GHG emissions requirements. Minergie only sets explicit requirements for emissions during construction, but not for emissions during operation. The latter are limited indirectly: On the one hand, Minergie sets requirements on the energy side by means of the Minergie coefficient. On the other hand, the use of fossil fuels is restricted: fossil fuels are excluded from building heating systems (with exceptions, e.g. for peak coverage) and the proportion of fossil fuels is also limited when using district heating.
- FprSIA 390/1 sets systemic requirements for both building phases (construction and operation) in the form of limit and target values (specifically so-called additional requirements for these two phases) and proposes separate guide values for the two phases. In contrast, Minergie sets separate requirements for each of the two building phases, whereby these are partly project-dependent to take project-specific conditions into account (e.g. increased limit values for PV systems, geothermal probes, solar collectors).
- Incentives to install large or roof-filling PV systems: When determining the system size required on the project side to achieve compliance, relatively small PV systems may already be sufficient in practice. Minergie and the SIA climate path take different approaches to incentivise larger PV systems: Minergie requires a minimum size (as a % of the usable roof area) and the SIA climate path optionally allows the calculation of the self-consumption share on an annual basis if the GOO is not sold, which results in incentives for larger PV systems.

F4.2 What approaches are there to include a common net-zero definition based on the different methodological approaches in the various planning and implementation instruments of SIA, Ecobau, SNBS, GEAK and Minergie?

Finding solutions for a common net-zero definition implies that the various planning and implementation instruments of SIA, Ecobau, SNBS, GEAK and Minergie are able to map emissions of all relevant phases and scopes. A common definition is therefore possible if areas that are not covered by one instrument (or its calculation method) are completed by another instrument.

For a net-zero definition based on the different methodological approaches to be labelled "common", it must fulfil the following points:

- be similarly complete: By definition, net-zero does not allow any residual emissions within the system boundary of the building area. Residual emissions may remain outside the system boundary of the building area, e.g. in agriculture or the transport sector.
- standardise important principles and methodological principles.
- be transparent and comprehensible.
- enable transferability between the different calculation methods or the simplest possible comparability, e.g. by converting to a common basis such as the WLC_{NZ} methodology.
- strive for harmonisation in concrete terms (methodology)

F4.3 How can the limit and target values based on different methodological approaches be set so that they are aligned?

There are several ways of defining the limit and target values based on different methodological approaches in such a way that they are harmonised in terms of content and material, i.e. regarding their intended incentive effect. The following three variants were identified in the project:

- Subsidiarity: The various information and planning instruments are related to each other. This means that the limit and target values for a specific area or indicator (e.g. scope 1, 2 or 3 emissions) are only calculated and assessed in one place or in one instrument (standard or label). For example, one body (the SIA, the SFOE) could have the methodological basis developed and the building standards and labels refer to it. In such an approach, areas not covered or other methodological approaches (e.g. depreciation or investment principle) would be defined subsidiarily in the relevant instrument where they are to be used.
- Harmonisation: The various information and planning instruments are harmonised as far as possible. On the one hand regarding the calculation methods and the observation perimeter, and on the other hand in concrete terms. This would mean that certain methodological and content-related adjustments would be necessary and would require a coordinating body (e.g. a commission consisting of representatives of the various stakeholder groups)
- Conversion: Maintain the different calculation methods and assumptions between the various instruments and convert the limit and target values so that they are physically comparable (i.e. in terms of the stringency of the requirements). Certain differences in the areas covered could be considered on an ad hoc basis using correction factors. However, to the best of our knowledge, we have identified a need to adjust the areas to be covered and the key indicator, GHG emissions, for most instruments, meaning that this option may not be feasible.

Conclusions and recommendations from F4

The work in the various sub-projects and the literature consulted show that net-zero WLC is currently a very challenging requirement and can only be achieved with a large number of far-reaching measures given the current state of the art and the available building materials and elements. A significant reduction in emissions during the construction phase compared to today's standard new construction methods and the avoidance of emissions during the operation phase are a prerequisite for being able to offset remaining emissions with negative emissions. As the technical and legal requirements for negative emissions are not yet met to a sufficient extent, we propose the concept of net-zero ready (NZ_{WLC}-ready).

In the case of net-zero ready, temporary sinks are used, which are converted into negative emissions at a later date if they are not actually re-emitted, i.e. if they are secured and stored, i.e. permanently kept out of the atmosphere. The temporary sinks are to be linked to specific measures. Examples include the use of biogenic building and construction materials due to their long life-times. The prerequisite for NZ_{WLC}-ready is a distinct reduction in gross emissions. In contrast to NZ_{WLC} buildings, a legally binding guarantee is not mandatory for NZ_{WLC}-ready

The following additional findings and recommendations result from the analyses of sub-project F4:

- It is important to further develop the various instruments in the direction of GHG emissions reduction and to consistently include the GHG emissions of the construction and operation phases (all three scopes), at least at the informational level. The operational phase and therefore energy efficiency are still important. Energy efficiency should also be addressed from a top-down perspective, e.g. with energy source-specific approaches for electricity efficiency, winter electricity share, controllability of electricity production, utilisation and storage.
- One of the most important levers of GHG emissions reduction in construction are the measures taken by the industry in the production of building materials and components. To record the reductions achieved by the relevant suppliers, manufacturer-specific life cycle assessment data and regular updates are required. A standardised system, such as that offered by KBOB with its life cycle assessment rules, is essential for the comparability of data from different manufacturers.
- New technologies such as BECCS, CCS and NET in the area of building materials produced are necessary to achieve net-zero. The use of CCS and NET leads to new questions, for example regarding double counting, with the sale of NE certificates already underway. The conditions for balancing BECCS, CCS and NET in buildings must be defined with the trading of certificates. What exactly this should look like and what the possibilities are should be analysed in greater depth as a follow-up to this project.
- When calculating the NE, it must be considered that, for practical reasons, it may not be possible to convert the entire quantity of temporary sinks into NE. Unavoidable efficiency losses, e.g. with CCS, must also be factored in.

Overall Conclusions

The research project shows that achieving net-zero greenhouse gas emissions in the building area is an essential prerequisite for achieving Switzerland's climate targets. The comprehensive approach of this project underlines that both operational and grey emissions need to be addressed across the entire life cycle of buildings. While operational emissions can be significantly reduced through energy efficiency the use of renewable energy sources, and electrification, embodied emissions from materials, construction and disposal pose a greater challenge.

By 2050, the already ambitious baseline scenario achieves an overall reduction in emissions of 78 %, which at 6.5 Mt of CO_2 per year in 2050 is significantly higher than the target of 2 Mt derived from the KlG. To balance the remaining emissions at this magnitude, considerable use of negative emission technologies (NET) would be required. Despite progress in this field, there is a gap between the current possibilities and the statutory target for 2050, which makes additional measures to reduce dependence on NETs necessary.

Reducing grey emissions requires the conversion of manufacturing processes to renewable energies and electricity, as well as carbon capture and storage (CCS) on the one hand and innovative solutions and practices in the circular economy on the other. Both social acceptance and the political will (appropriate framework conditions) are needed to ensure that such solutions are supported and competitive. If this does not succeed, we run the risk that the remaining residual emissions in the building area could be too high to be balanced with NET (namely through the use of biogenic materials combined with BECCS). This would jeopardise the achievement of Switzerland's long-term climate targets.

The key to achieve the climate targets therefore lies in the initiative from the business community and in the accelerated implementation of measures in the areas of regulation, incentives and knowledge building. In particular, a more extensive reduction in grey emissions from building materials, the complete abandonment of fossil fuels in buildings, energy production (including energy grids) and in the manufacture of materials and components, the extension of the useful life of buildings and the reparability of building components, as well as the introduction of CCS in waste disposal must be addressed as a matter of urgency.

Necessary steps include expanding the regulatory framework to promote the use of renewable and low-emission building materials, realising net-zero-ready buildings and ensuring that these initiatives are supported by clear political guidelines. In addition, specific further research needs are also identified in the various parts of the project.

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