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Concept for next generation of technical energy regulations in buildings

Energy turnaround and Technical Regulation EnTeR – Final Report Phase 1

The role of technical regulations in the transformation of the building stock and its integration into the future energy system (EnTeR)

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The project "The role of technical regulations in the transformation of the building stock and its integration into the future energy system" has been structured in two parts. This final report summarises the first phase, consisting of four work packages (WP). Statements in general terms in the final report are documented in detail in the individual WP reports. The first phase was part of the National Research Programme "Energy Turnaround" (NRP 70) of the Swiss National Science Foundation (SNSF), and co-financed by the Conference of Cantonal Energy Directors (EnDK). Phase 2, which uses the results and conclusions obtained in the first phase, and is concerned with generating a specific set of technical regulations for building stock, is not a part of this project.

Executive Summary

The research project EnTeR analyses the role of technical energy regulations (TERs) in the transformation of the building stock and their integration into the future energy system. The main task was to identify effective measures which can guide stakeholders to achieve CO_2-emission targets by means of TER. Based on this, recommendations for future energy legislation are derived.

The international analysis revealed that TERs, despite their previous success in increasing the energy efficiency of the building stock, seem to be reaching their economic limits. Particularly when it concerns the decarbonisation of the building sector. The literature lists therefore the following five challenges: (i) Further increase in energy efficiency, (ii) consider "grey energy", (iii) increase the share of renewable energies, (iv) close the "performance gap", and (v) accelerate the renovation rate. Through technical and economic optimizations (Energy Hub optimization, Pareto Front), it was possible to identify solutions for the Swiss building stock which achieve specific CO_2-emissions below 10 kgCO2/m2 - typically at CO_2 avoidance costs of 200-400 CHF/tCO_2 compared to cost-optimal solutions.

In order to provide the best possible regulatory environment for the building stock to develop in the intended direction, a TER concept was developed based the three main life-cycle phases of a property (construction, operation and decommissioning):

1. The TER «Capacity Limit» is proposed for the construction phase (planning and building). The limitation of capacities (electricity, heating and cooling) forces energy-efficient buildings by reducing grid loads and providing incentives for installations of renewable production and/or storage systems.
2. For operation phase (usage), the TER «Energy Mix» is proposed. The proposed TER limits the amount of allowed CO_2-emissions during the operating phase. Enforced by Smart Meters and Digital Data Platforms.
3. For the decommissioning phase (material) the TER «Material Cycle» is proposed. The proposed TER aims to reduce this 'grey' share by imposing a deposit/pledge system on building materials.

This research project was part of the National Research Programme "Energy Turnaround" (NRP 70) of the Swiss National Science Foundation (SNSF). Further information on the National Research Programme can be found at www.nrp70.ch or on the web portal www.nrp-energy.ch.

Abstract

The EnTeR research project analyses the effects of technical energy regulations in the transformation of the building stock and its integration into the future energy system (abbreviated to TER). Based on this, recommendations for future energy legislation are derived. Objects of research are mandatory energy regulations in the building sector. The model regulations of the Swiss cantons in the energy sector (MuKEn) are used as examples in this work, however an analysis and assessment of the current MuKEn is not part of this research project.

The main task in this first of two project phases was to identify effective measures which can guide actors (house owners, building owners, investors, users, contractors, etc.) by means of TER to achieve $CO_{2,eq}$ emission targets, answering the question: "What should be regulated?". The results shall act as a basis to formulate effective and efficient regulations and their enforcement in a second phase of the project, which will answer the question: "How should regulations take place?" This phase will focus on legislation, specific contents, limit values and enforcement.

The international analysis revealed that TERs, despite previous successes in increasing the energy efficiency of the building stock, seem to be reaching their economic limits, particularly when concerning the decarbonisation of the building sector. The literature lists the following five challenges: (i) further increase in energy efficiency, (ii) consider "embodied energy", (iii) increase the share of renewable energies, (iv) close the "performance gap", and (v) accelerate the renovation rate.

MuKEn:2014 plays a key role in the transformation of the Swiss building stock into a sector that is nearly $CO_{2,eq}$-free. It is a state-of-the-art regulation and, in certain parts, also takes on a pioneering role by prescribing local electricity generation and renewable energies for heat generation. However, impact analysis confirms that even if the MuKEn:2014 is fully implemented in all cantons, the $CO_{2,eq}$ target of the Energy Strategy 2050 (ES2050) will still fall short by approximately 30%. In order to achieve the $CO_{2,eq}$ target, additional or more restrictive regulations, especially those applied to the replacement of oil and gas heating systems, must be included in a new TER. The current requirements of MuKEn:2014 on the building envelope for existing and new buildings have been judged to be adequate in this research work.

Through technical and economic optimization, it has been possible to identify solutions for the Swiss building stock which achieve specific $CO_{2,eq}$ emissions below 10 $kgCO_{2,eq}/m^2$ - typically at $CO_{2,eq}$ avoidance costs of 200-400 CHF/$tCO_{2,eq}$ compared to cost-optimal solutions. The technically and economically optimized solutions are characterized by three measures at building level: (i) partially improve the building envelope in terms of energy efficiency, (ii) replace oil and gas heating systems as far as possible with renewable heating systems and (iii) use photovoltaics and, where appropriate, install electrical storage systems.

Further results indicate that in cities, a district solution with thermal networks would be appropriate for 50-80% and in more densely populated or industrialized agglomerations for up to 50% of the neighbourhoods. The investment costs of such district solutions are between 20 and 25% lower than standalone building solutions.

By scaling the technically and economically optimal solutions to the entire building stock, $CO_{2,eq}$ emissions could be reduced by up to 80%. This shows that it is technically and economically feasible to achieve the ES2050 target for the Swiss building stock.

In order to provide the best possible regulatory environment for encouraging building stock to develop in the intended direction, a TER concept has been developed based on life-cycle thinking. The life-cycle perspective has made it possible to formulate effective measures in the three main phases (construction, operation and decommissioning) of a property. This separation allows a TER to be specifically aligned to the phase-specific relevant actors:

The «**Capacity Limit**» TER is proposed for the construction phase (planning and building). The evaluation of the building energy calculations showed that the maximum system capacity represents the energy efficiency of a building in a marginally worse way only than the assessment of the annual energy demand. However, with a TER regulation “Capacity Limit”, the certification can be simplified and the impact extended: (i) Simplification: The calculation of the system capacity is based exclusively on the chosen construction and the selection of materials and equipment. Operational assumptions such as solar gains, internal loads, room temperatures etc. can be neglected. Implementation can be carried out in a similar way to the previous procedure of verifying compliance with a limit value during planning or (more simply) during construction by checking the capacity data of the installed systems. (ii) Expansion: The switch to renewable energy sources in the energy system is a particular challenge for the electricity, gas and heat infrastructures and the corresponding capacity of supply and distribution. By limiting the capacity of a building, it is possible to directly influence infrastructure requirements by reducing network and reserve capacities and increasing storage capacities.

For the operation phase (usage), the «**Energy Mix**» TER is proposed. Energy consumption and greenhouse gas emissions are significantly influenced during the use of a building. The proposed TER limits the amount of allowed $CO_{2,eq}$ emissions during the operating phase. In order to take into account the quality of the used energy, the resulting $CO_{2,eq}$ emissions should be assessed. The actor can comply with the $CO_{2,eq}$ limits by reducing his consumption, choosing low $CO_{2,eq}$ or $CO_{2,eq}$-free energy products and/or increasing his own energy production (e.g. photovoltaics, combined heat and power generation, etc.).

For the demolition and decommissioning phase (material) the «**Material Cycle**» TER is proposed. The indirect, 'embodied' share of energy consumption and greenhouse gas emissions is caused by the building materials used. The share of these non-operating emissions can account for up to 40% of total emissions over the lifetime of a building. The proposed TER aims to reduce this 'embodied' share by imposing a recycling fee on building materials. By imposing such a fee on building materials the owner will be motivated to return his materials and the industry will develop recycling processes, which are fully decarbonized in the future (see «Energy Mix» TER).

The presented work (Phase 1, The role of technical regulations in the transformation of the building stock and its integration into the future energy system) is focused on energy regulations. Further policy instruments, e.g. spatial planning, subsidies and taxes, are not considered in this work. The coordination of such instruments with the future TERs is essential to achieve the greatest possible impact. Furthermore, the determination of the tax effects of the various regulatory instruments should also be examined and, if necessary, coordinated. This will establish holistic conditions for achieving the objectives of the ES2050 in an economically efficient and effective manner from a regulatory point of view. These further topics can be addressed in the subsequent phase 2.

Contents

1 Current Situation and Project Definition

Energy regulations today represent an essential driver for increasing energy efficiency and reducing $CO_{2,eq}$ emissions[1] in various economic sectors, including the building construction field. However, the further development of these regulations is essential in order that future systems, concepts and components are capable of being implemented. Such further development smoothen the way for the application and use of innovative technologies and concepts from the research sector, such as the NRP 70 Project "Economic assessment of multi-energy-hub systems integration at neighbourhood scale IMES-ECO". Furthermore, the new regulations should ensure that yet-to-be-developed technologies, systems and concepts are governed by regulations which aid and encourage their implementation, rather than hindering them.

The EnTeR research project is investigating the effect of technical energy regulations (TERs[2]) in the transformation of the building stock and its integration into the future energy system. Based on the results proposals for future adjustment in energy legislation will be derived. Compulsory energy regulations in the building sector will be used as the object of research. Supplementary and/or complimentary regulations and measures such as e.g. spatial planning, energy planning, subsidies etc. will not be considered in this work. On the other hand, the interfaces to these types of regulations will be indicated and, when appropriate, synergistic potentials mentioned which could influence the effect of a TER. The cantonal model regulation in the energy sector (MuKEn) are used in an exemplary manner in this work. However, a detailed analysis and assessment of the existing MuKEn does not form part of this research project.

The overarching research question is: Which combination of TERs support and encourage the achievement of the goals of the Energy Strategy 2050 in the most effective and efficient manner? At the same time new methods, concepts and elements in the field of energy regulations which might find place in future TERs should also be investigated. One of the basic principles of this work is that the suggested proposals should be considered separately from existing regulations. Only at the end of this work the proposals will be compared to the current TER (MuKEn 2014).

This work is intended to provide the basis for drafting the subsequent MuKEn:20XX, and encompasses the first of two project phases. The first phase presented here, deals with the TER concept and is based on the scientific facts. The main task to be considered is to identify effective factors determining energy consumption and $CO_{2,eq}$ emission which can steer involved actors (house owners, building contractors, investors, users, operators etc.) by means of TERs, in other words, the answer to the question "What should be regulated?". This will create the preconditions necessary for formulating effective and efficient regulation (and their implementation) in the second project phase (which is not a part of this work), or in other words the answer to the question "How should regulations be implemented?" In the second phase discussions with the Cantons regarding the future MuKEn:20XX can be held, underpinned by the basic ideas generated in the first phase, and relevant topics such as legislative aspects, formulating specific content, thresholds and enforcement could be considered.

Furthermore, this work is intended to improve the understanding of energy regulations and their potential to encourage innovation. It is also intended to indicate how far energy regulations can, for example, support new ranges of services, and how they can contribute to finding solutions which make energy goals more efficiently, rapidly and economically achieved.

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[1] *Equivalent CO_2 emissions ($CO_{2,eq}$) is a measurement unit which standardises the climatic effects of various greenhouse gases.*

[2] *Regulations and provisions are regarded in this report as terms with the same meaning. A regulation includes laws and provisions. In the literature, technical energy regulations (TERs) in the building sector are frequently known as Building Energy Codes (BEC). In this report the terms TER and BEC are used synonymously.*

2 Introduction

Energy demand from buildings accounts for about 31% of global final energy demand and 23% of global energy-related carbon emissions [1]. In industrialised nations these values reach even higher levels. In Switzerland the contribution of buildings via room heating, warm water and building technology is about 37% of the final energy demand [2] and about 27% of $CO_{2,eq}$ emissions, calculated in accordance with the guidelines of the UN Climate Framework Convention [3], and about 37% of the $CO_{2,eq}$ emissions calculated according to IEA [4], respectively.

Energy consumption in buildings in Switzerland is, therefore, still one of the main causes of $CO_{2,eq}$ emissions in the country. In order to achieve climate goals, buildings must be made more energy efficient, and fossil-based energy systems must be replaced by efficient renewable solutions. The principal means of complying with this strategy in an effective manner requires the development of economic renovation techniques which must then be applied to the existing building stock. The renovation of the entire Swiss building stock to a state-of-the-art energy efficiency level would make a major contribution to achieving the energy and climate goals defined in the Federal Energy Strategy 2050 (ES2050).

The reductions achieved in past years, and newly developed technical solutions, underline the significant potential for reducing $CO_{2,eq}$ emissions in the building sector. Beyond this, buildings offer many opportunities for saving and producing energy economically [5]. According to the Global Energy Assessment Report (2012), energy requirements for heating and cooling up to the year 2050 could be reduced by about 46% of the 2005 values by using energy efficient technologies which are available today [6]. Many of these energy saving opportunities are, however, not exploited, although they are economically advantageous when compared to the carbon-intensive status quo in macroeconomic terms [7].

Political measures can contribute to reducing energy consumption and $CO_{2,eq}$ emissions in the building sector. Political instruments which have proven in the past to be very effective in reducing both energy consumption and $CO_{2,eq}$ emissions from the building stock are TERs. Such TERs lay down the minimum requirements for energy consumption and the generation of renewable energies in buildings [8], [9]. TERs were used as long ago as 1946 in Sweden, and have been introduced in many other countries since the oil crisis in the mid-70s. Current TERs deliver comprehensive regulation of residential and commercial premises, covering both new and existing building stock [8]. Prior studies have shown that TERs have made significant contributions to reducing energy consumption of buildings in Europe [10] and in China [11] by up to 22%, and in certain regions of India [12] by as much as 42%. In Switzerland the energy consumption for room heating over the past 20 years has dropped by around 10% despite significant growth in the energy reference area over this period [4]. In the context of the weighty contribution of building stock to the global $CO_{2,eq}$ emissions, the effectiveness of TERs has led to many countries integrating them in their climate change mitigation measures within the framework of the Paris Agreement on Climate Change [8].

Typical requirements laid down in TERs are structural measures such as thermal insulation of the building envelope, replacing old windows and the installation of renewable systems such as biomass boilers, photovoltaics and solar collectors, or heat pumps which use environmental thermal energy. Newer developments in TERs, currently only given limited consideration, are solutions at the district or area level such as district heating/cooling networks, micro-grids, district energy systems/plants, virtual power plants, local energy co-operatives for own consumption, etc. An important TER instrument in Switzerland, which makes the transformation of building stock possible, are the Cantonal Model Regulation in the Energy sector (MuKEn) which can be integrated into a TER at cantonal level. The long and successful history of the MuKEn and its predecessors shows that these instruments have been continuously subject to further development and adaptation, and also that they enjoy a high level of acceptance. The latest MuKEn:2014 [13] is currently in the implementation phase and will soon make way for the development of its successor. Comparison at international level shows that MuKEn:2014 is an up-to-date and at least partially innovative TER. However, the current concept and today's requirements have reached the point where its effectiveness, particularly in the case of new buildings, has plateaued, and is no longer adequate for dealing with the complexity presented by new solutions and planning processes [10], [14]–[16].

In view of the latest developments in novel technologies and solutions, and ever more stringent $CO_{2,eq}$ targets, it is clear that TERs must continue to develop. Consequently this research project concentrates on how the future TERs can be shaped, while focusing on the transformation of existing buildings. Current TERs will in future impact on technical, economic and social boundaries. To entirely retain today's measures, according to the principle of "carry on in the same old way", would be to miss a golden chance. New methods, concepts and elements in the TER framework should be investigated and when appropriate considered for integration in future TERs. The EnTeR research project, the subject of this report, therefore seeks new approaches with the goal of creating new foundations to shape and implement future TERs as simply as possible, in conjunction with the greatest possible degree of freedom to allow the greatest possible effect on future solutions.

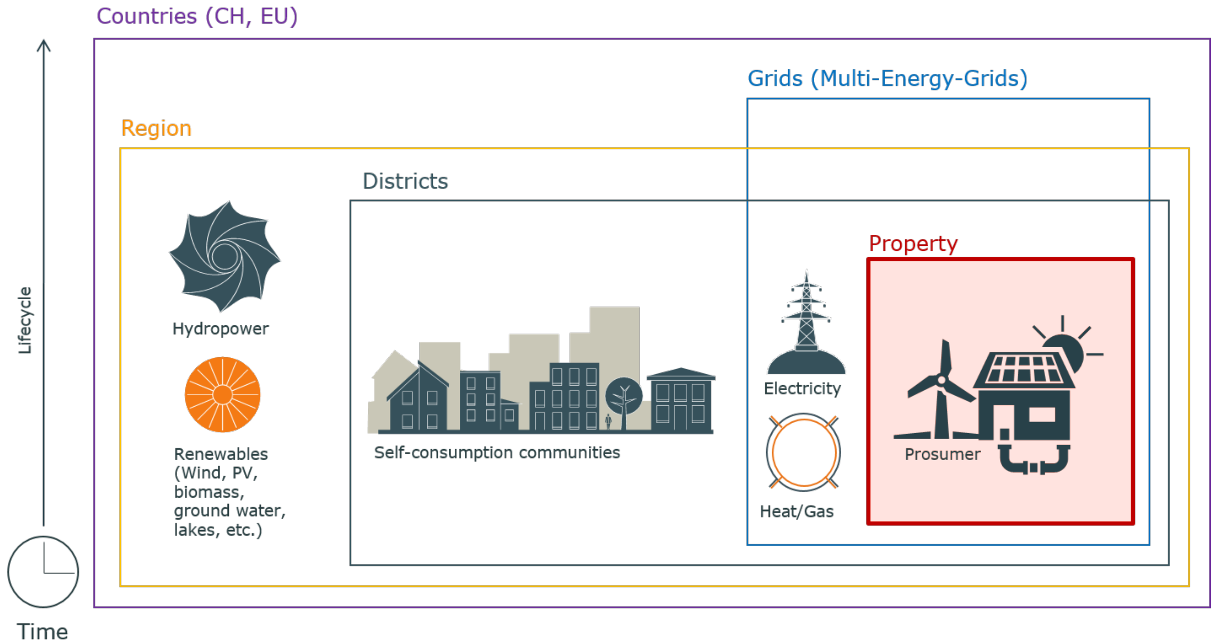

Figure 1: Solution space with extended system boundaries with focus retained on the building and its parcel of (owned) land.

3 Procedure

Whilst the measures in the existing TER relate principally to structural engineering issues and are limited to the space within property ownership boundaries, in this project the solution space for the future TER has been extended (see Figure 1). This opens up a wide spectrum of research questions, since many aspects of energy consumption and, increasingly, also the production on and in buildings have an influence on the energy system way beyond the property ownership boundary, and vice versa. The project consists of four progressively structured work packages (WP1-4):

WP1: Innovative approaches to TERs and their implementation at the national and international level will be identified, structured and evaluated.

WP2: Typical measures for existing and new buildings will be analysed with respect to their impacts (energy consumption and $CO_{2,eq}$ reduction) at the national scale. These measures will be assessed in terms of the ES2050 goals.

WP3: Swiss building stock will be modelled in order to determine which specific measures at the building and district scale are most effective in cost-benefit terms ($CO_{2,eq}$ reduction). This will allow the simulation of a range of measures and lead to the identification of optimal solutions.

WP4: Based on the results obtained from WP1 to 3, the most effective measures will be identified and, with the assistance of additional input from specialists in the field, possible future TER concepts will be derived. Following this a TER concept will be proposed incorporating measures which promise to offer the greatest impact in terms of regulation. Finally, a forecast will indicate the opportunities and challenges which exist in the implementation and enforcement stages.

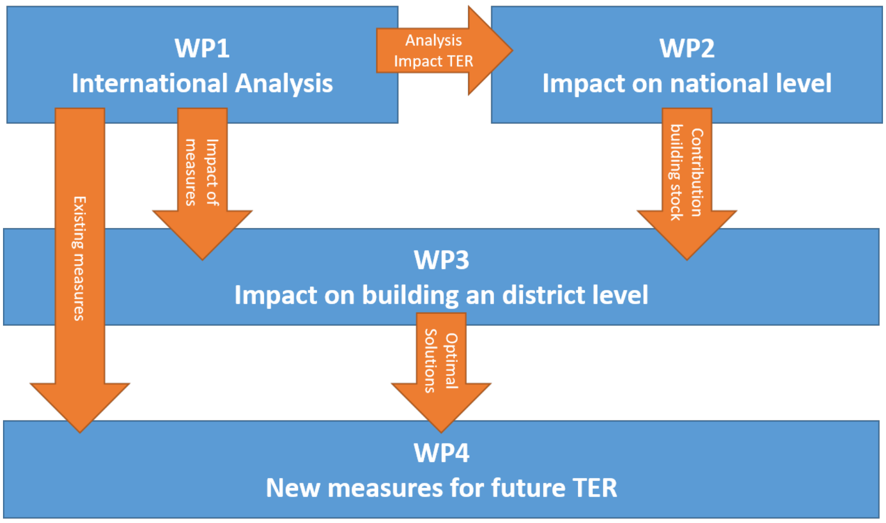

Figure 2: The structure of work packages WP1 to 4

4 Methods und Results

4.1 WP1: International Analyses

Basic principles and prior research: Despite their long history and success, policymakers increasingly recognise that TERs in their current design have reached a point of diminishing returns in terms of further decarbonisation of the building sector[3] [10], [14]–[16]. Literature covers the following five reasons:

(i) Increasing energy efficiency: TERs traditionally focused on prescriptive requirements (e.g. U-Value) for individual building parts rather than an overall building energy performance metrics and the associated $CO_{2,eq}$ emissions. To reduce energy use, the strengthening of such individual prescriptive requirements has by nature diminishing returns. For example, the initial application of thermal insulation to a bare wall reduces thermal losses by about 75%. Repeating this process with the same thickness of insulation results in a further reduction of only 11% [14].

(ii) Considering embodied energy: Current TERs concentrate on energy consumption during the use phase of buildings and thus neglect embodied energy (i.e. energy used to produce construction materials). While this might be appropriate for conventional buildings with up to 90% of their lifecycle energy use during their use phase, nowadays, net-zero energy buildings have up to one-third of their energy use, and up to half of their lifecycle carbon emissions embodied in their materials [15].

(iii) Increasing the share of renewable energy: Although taking first steps towards prescribing the use of renewable energy technologies in buildings, most TERs still allow fossil heating systems. These systems are thus the prevalent technology in the building stock (e.g. SFOE 2012), despite economically superior alternatives. Extending TERs to regulate better the integration of renewable energy in buildings is increasingly attended to. For example by the compulsory switch to renewable systems when replacement of the current heating system becomes necessary [14].

(iv) Closing the performance gap: Until now TERs mainly regulated building design but not the current energy use [11], despite a significant difference between calculated and measured energy use – termed as "performance gap" [16]. With the magnitude of this gap on average at 34% for non-residential buildings[4], doubt about regulating calculated energy use has been increasing [1.1]. Reasons for the performance gap are manifold, besides others, limited understanding of impact of early design decisions, uncertainty in building energy modelling, inter-model variability, changes after design, and deviant occupant behaviour [1.2].

(v) Accelerating retrofits: Today's TERs are increasingly stringent for new buildings but also for buildings that undergo a retrofit. While thus retrofitted buildings are typically energy-efficient, retrofitting rates between 1

[3] TERs were originally introduced with the aim of reducing the energy requirements of the building sector. However since energy and climate policies have increasingly concentrated on the reduction of $CO_{2,eq}$ emissions, this study is focused on the decarbonisation of the building sector. This process is supported by two pillars, namely the reduction of building energy consumption and the readiness to use energy from renewable sources for the remaining energy requirements.

[4] This review study evaluates studies that measure the performance gap mostly based on design stage calculation, including equipment energy use and standard operation.

and 2% per year in many industrialised countries slow down the decarbonisation of the entire building stock [1.3]. In Switzerland the rate is as low as 1%[5] per year [1.4].

Next generation TERs should therefore particularly focus on accelerating energy-efficient and renewable retrofits. Although some studies investigate individual of these reasons – which we call 'leverage-points' in the following – a comprehensive analysis of how next TERs could address these leverage-points is still missing. Individual countries have already shown with innovative TERs how these leverage-points can be approached. We would therefore like to understand how these innovative TERs address the five leverage-points for an accelerated decarbonisation of the building stock (see section 4.1.1) and how Switzerland can learn from innovative TERs (see section 4.1.2).

4.1.1 Innovative TERs in the building sector

We identified five forerunner countries (i.e., Denmark, France, England, Switzerland, and Sweden) which have already implemented innovative approaches addressing one or more of the presented leverage-points. To understand how TERs of these countries address the key leverage-points for decarbonising the building sector, we:

1. Provide an overview of the state-of-the-art
2. Outline the innovative approaches

Overview of the state-of-the-art: Table 1 presents an overview on the state-of-the-art of the TERs in each of the five identified countries, and sketches the status of the five most important leverage-points.

		Denmark	France	England	Switzerland	Sweden
Energy Efficiency	Performance	Yes	Yes	Yes	Yes	Yes
	Prescriptive	Yes	Yes	Yes	Yes	Yes
	Capacity	-	-	-	Yes	Yes
Embodied Energy & Carbon	Performance	-	Yes (pilot)	-	-	-
Renewable Energy	Performance	Yes	Yes	Yes	Yes	-
	Prescriptive (direct)	Yes	Yes	-	Yes	-
	Prescriptive (indirect)	Yes	-	Yes	-	-
	Prescriptive (ban)	Yes	-	-	Yes	-
Performance Gap	Compliance Check	Yes	Yes	Yes	Yes	Yes
Accelerate Retrofit	Requirements when retrofitting	Yes	Yes	Yes	Yes	Yes
	Requirements to retrofit	-	Yes	-	-	-

Table 1: Overview of the state-of-the-art of the TERs in selected countries

(i) Increasing energy efficiency: To increase energy efficiency, the frontrunner countries adopted a central performance requirement, mostly considering primary and/or final energy demand. Additionally, all cases adopted either a prescriptive requirement for the envelope efficiency or another performance metric for total heating or cooling demand. Combining requirements for primary energy demand and total heating/cooling demand allows the countries, first, to minimise building's energy demand and, second, to minimise the use of

[5] *In the document "Energy Perspectives for Switzerland (2012)", the authors, prognos, state that the rate of energy-related building renovation in Switzerland is 1% without, however, defining exactly what the term "energy-related building renovation" means. A modernisation rate of 1% would seem to be rather improbable even if this included replacing heating systems or windows. The difficulty in defining and measuring the renovation rate exactly lies in the fact that this parameter is dependent on building component usage. The replacement of individual building components is often not recorded in planning permission statistics, exacerbating the problem.*

resources or carbon emissions to cover the remaining energy demand. Some countries further add prescriptive requirements for individual building technologies and capacity requirements for the heating or cooling power.

(ii) Considering embodied energy: In 2018, except France, none of the countries considered embodied energy. There, embodied energy and carbon are tested in a pilot phase and will be part of the 2020 regulation. The existing primary energy metric will include embodied energy. Further, embodied carbon will be considered in a new performance metric based on carbon emissions during the use phase, and in one that specifically focuses on the carbon emission during the construction of the building.

(iii) Increasing the share of renewable energy: To increase the share of renewable energy in buildings, the frontrunner countries adopted a performance metric (mainly primary energy demand) that supports the use of on-site and off-site renewables. Further, all countries except Sweden adopted additional prescriptive requirements for the use of renewable energy, for example by direct requirements for the use of renewable energy, bans of fossil fuels, or mandatory assessments of the economic feasibility of renewables.

(iv) Reducing the performance gap: To close the performance gap, the frontrunner countries check compliance with the technical energy regulations before the start of the construction (plan review) as part of the building permit process and directly after the construction (building decommissioning). Further all countries except Switzerland also conduct an airtightness test.

(v) Accelerating retrofit: To accelerate retrofits, the frontrunner countries include less stringent requirements for retrofits compared to new constructions. Further, all countries except Sweden allow buildings that are retrofitted to opt for compliance based on prescriptive requirements.

Innovative approaches: In the following section we describe innovative approaches which relate specifically to one of the leverage points mentioned above.

Denmark - Increasing energy efficiency through pre-announcing energy standards: Denmark reduced building energy use drastically by introducing voluntary low-energy classes and pre-announcing far ahead (i.e., 5-10 years) when they will TERs become mandatory, thus providing long-term targets for the building industry. The building industry perceived the announcement of future regulations as a strong signal that drives innovation and cost reductions, and therefore advocated for these. Knowing that a voluntary energy standard will TERs become mandatory, companies had time to develop and exploit investments in new technologies, materials and construction methods. Ambitious building owners, too, advocated for the announcement of future regulations as they provide a target to aim at. Denmark, however, stopped increasing the energy efficiency stringency for new buildings in 2020 due to costs but might announce future regulations for sustainability targets for buildings.

France – Considering embodied energy in central performance metric & Accelerating retrofits through situational retrofitting obligations: France will include embodied energy and carbon in the next update of the thermal regulations for buildings. However, the introduction of embodied energy and carbon is challenging, requiring extensive prior testing and continuous learning. Nevertheless, the lifecycle perspective on carbon emissions is expected to transform the French construction industry. Besides embodied energy, another target of French policymakers is to accelerate retrofitting of the existing building stock, for example by requiring all private residential buildings that consume more than 330 kWh/m2 per year to be retrofitted by 2025[6] [1.5]. However, while ambitious targets and laws exist, decrees to turn the targets into specific policy measures are still lacking due to: (i) retrofitting obligation triggers additional costs, (ii) the obligation is based on the French

[6] In France this covers more than 30% of all private dwellings. The average energy usage of buildings in France is 240 kWh/m².

Energy Performance Certificate, which is perceived as unreliable by the population, and (iii) it is perceived to result in more light retrofits.

England – Increasing the share of renewables through adopting a carbon emissions metric: England adopted carbon emissions as the key performance metric to strategically align requirements for buildings with national targets and international commitments. As a result, carbon-friendly technologies have been heavily adopted on the back of a carbon metric. In addition, the decarbonization of the electricity mix will pronounce the effect of the carbon emission metric on the technology landscape. However, the carbon emission metric is perceived increasingly critical, thus resulting in a potential shift to a primary energy metric due to: (i) reducing carbon emissions does not necessarily result in energy-efficient buildings, (ii) primary energy factors are more stable than carbon emission factors, (iii) the EU promotes the use of primary energy.

Switzerland – Increasing the share of renewables through prescriptive requirements: Switzerland pushes more renewables into buildings through, first, requiring new buildings to produce a certain amount of electricity on-site and, second, requiring residential buildings that have an oil or gas boiler to install a heating system based on at least 10% renewable energy in case of a boiler replacement. Swiss experts perceive both requirements as effective in pushing more renewables into buildings but also highlight their drawbacks: mandatory on-site electricity production is criticised for being technology specific and challenging to achieve for compact buildings; heating based on renewables in case of a boiler replacement is criticised for increasing investments costs for homeowners.

Sweden – Closing the performance gap through compliance based on measured buildings' performance: Sweden aims to close the performance gap by checking compliance based on the measured building's performance two years after its occupation. Such a measured compliance check is viewed differently by building developers, owners, and municipalities, particularly, the actor size plays a significant role in those preferences. Larger actors seem to prefer the measured over the calculated compliance check, while for smaller actors this is typically vice versa. Yet, despite these differences for large and small actors, the regulator pushes for the compliance path based on measured values. Three major challenges of the measured compliance path have TERs become evident. First, the available and required measurements are often different[7]. Second, sanctioning the building owner in case of non-compliance two years after the building's occupation is a delicate task. Third, smaller municipalities lack the personnel capacity to check compliance of buildings two years after their occupation. Sweden plans to address the latter two challenges by, first, shifting the authority for the final compliance control from local municipalities to the regulator and, second, combining the compliance check with the issuing of the energy performance certificate, which has already previously done by the regulator's energy experts.

By synthesizing the implementation challenges across our five case studies, we derive six policy design principles for TERs. These are generally applicable and ensure TERs function effectively – thus often separating the successful TER implementations from the failures. We argue that the benefits and drawbacks of innovative TER designs TERs become particularly salient when policymakers face new challenges during their implementation. This allows us to derive policy implications for how to design TERs that contribute to building decarbonisation. We recommend that policymakers apply these principles when implementing innovative TER designs to ensure broad acceptance across all actors in the construction sector – particularly important in view of TERs mandatory nature. Table 2 provides an overview of our six TER design principles and outlines examples illustrating how to follow them.

TER design principle	**TER design examples**

[7] *For example, usually the total electrical consumption is measured, whilst the consumption due to appliances is not regulated.*

Keep additional burdens for building owners light	- Include technical feasibility and cost-effectiveness tests - Combine TERs with additional policies such as zero-interest financing to lighten the burden of upfront investment
Create long-term regulatory certainty	- Align TERs with national energy and climate targets - Pre-announce upcoming TERs - Integrate continuous improvement processes
Beware technology-specific requirements	- Ensure that multiple technology options are available
Anticipate the impact of new regulations on smaller actors	- Support small firms by reducing unnecessary soft costs - Help small authorities by removing the burden of capacity-intensive compliance control
Promote knowledge of innovative design	- Pre-announce upcoming TERs - Conduct test programs - Build upon voluntary labels - Learn from frontrunner legislation
Integrate TERs in the local context	- Leverage the existing infrastructure - Consider the level and pace of ongoing grid decarbonisation - Leverage domestic resources - Consider the quality of the domestic construction industry - Check political feasibility

Table 2: Overview of TER design principles and design examples (references see report WP1)

4.1.2 How might Switzerland learn from innovative approaches to TERs?

The MuKEn:2014 takes a key role in Switzerland's transition towards a carbon-free building sector. It is a state-of-the-art regulation and beyond that takes a pioneering role through mandatory on-site electricity generation and renewables for heating. However, the successor of the MuKEn:2014 – the so-called MuKEn:20XX – could learn from innovative approaches of TERs of other frontrunner countries. In the following, we transfer the insights we have gained from the analysis of international and innovative TER to Switzerland. However, we want to stress that this section is not a final recommendation for the design of the MuKEn:20XX; it is more an overview of how Switzerland could include the presented innovative approaches of international TER.

<u>To increase energy efficiency</u>, MuKEn:20XX could reduce the number of individual regulations and instead focus on two central performance metrics, namely the total energy demand and the primary energy demand including on-site electricity production. While the former metric minimises the building energy demand, the latter metric minimises the use of fossil fuels to cover their remaining energy demand. Alternatively, the latter metric could instead focus on carbon emissions, thus stronger aligning building regulations with national decarbonisation targets. However, a remaining concern of central performance metrics is the enforcement in praxis and the compliance control.

<u>To increase the share of renewables</u>, the MuKEn:20XX could, first, accelerate the phase-out of oil and gas boilers in buildings and, second, extend the system boundaries of energy regulations from buildings to neighbourhoods. While the MuKEn:2014 requires residential buildings to install a heating system based on at least 10% renewable energy in case of a gas and oil boiler replacement, the MuKEn:20XX could directly ban oil and gas boilers (this is currently done in Denmark). Further, extending the system boundaries of performance metrics from a building level to a neighbourhood level can spur the integration of renewable energies TER because, first, for some buildings it is easier to include renewables than for others, and, second, neighbourhoods benefit from scaling effects regarding the economics of technologies and the balancing of load profiles.

<u>To consider embodied energy</u>, the MuKEn:20XX could take a lifecycle perspective and, first, include additional energy and carbon sources in the performance metric or, second, add a new performance metric for embodied energy only. As embedded energy and carbon is new to TERs in Switzerland, prior testing is recommended. The Swiss voluntary label Minergie-Eco defines requirements for embedded energy, and the

Swiss Society of Engineers and Architects document SIA 2032:2009 (Notice regarding Embodied Energy in Buildings) outlines a calculation method for embodied energy [8]. Building on data and experience of label and norm, Switzerland can identify cost-effective levels of embodied energy and, in turn, integrate these levels in the MuKEn:20XX. If the collected data is insufficient, a pilot phase similar to the French E+C-program could help. Further, pre-announcing requirements on embodied energy and carbon years in advance can provide a signal to the industry to reduce embodied energy in building materials, a strategy successfully used in Denmark for energy efficiency.

To close the performance gap, the MuKEn:20xx could, first, adjust the current compliance check or, second, switch to a compliance check based on measured data. Input parameters that are crucial for the calculation of buildings' performance are often over-simplified; inputs could correct for more fine-grained weather data and environmental conditions, while metering systems could deliver more data on real occupant behaviour. Further, the MuKEn:20xx could require compliance checks based on measured performance, rather than calculated performance, thus following Sweden. However, in Sweden, smaller municipalities lacked expertise and capacities to check buildings' energy performance two years after their occupation. Since many small municipalities are responsible for compliance control in Switzerland, testing this approach in a voluntary module or with Minergie standard 'MQS Betrieb' is recommended. In addition, the issuing of the cantonal building energy performance certificate (GEAK) [9] could be made conditional on completing implementation or successfully undergoing the compliance test.

To accelerate retrofits, the MuKEn:20xx could include requirements that enforce the retrofitting of low energy-efficiency buildings. Following the French example, the MuKEn:20XX could set minimum levels of energy performance for existing buildings decades in advance. To address the concern of increasing cost for building owners, the MuKEn:20XX could allow the building owner to bypass this retrofitting obligation when proving that retrofitting is not economically or technologically feasible – GEAK Plus could take the role of proving such feasibility. Further, the trade-off between the number and the depth of retrofitting has to be considered. Here GEAK Plus can also play a leading role by highlighting which investments are most profitable. In turn, building owners might not only invest in measures with the lowest investment costs but rather the measures that are recommended by the GEAK Plus.

[8] *Currently being revised – consultation round expected in 2019*

[9] *In Sweden, discussions are currently ongoing as to whether conformity tests on the basis of measured energy consumption could be combined with the issuing of Energy Performance Certificates, with the aim of relieving the workload on smaller communes. Energy Performance Certificates are obligatory for new buildings in Sweden.*

4.2 WP2: Impact at the national level

The expected effects of the TERs being implemented today have been investigated in work package WP2. The analysis is intended to deliver a quantitative estimation of the achievement of ES2050 objectives [2.1]. Two scenarios were investigated during the analysis: a) carry on as before, i.e. without implementing the current MuKEn:2014, and b) the fully implementation of MuKEn:2014 in all cantons. The development of energy demand and the energy carriers used, together with the $CO_{2,eq}$ emissions, were evaluated.

To quantify the energy and $CO_{2,eq}$ reduction potential, a top-down forecast model was developed [2.2]. The energy demand, the $CO_{2,eq}$ emissions and electric power demand of Swiss building stock to 2050 were calculated with the help of various different databases. For residential dwellings the Swiss Building and Apartment Register (GWS) 2015 [2.3] was used as a database, while for non-residential buildings a new calculation method was developed based on data sourced from the Swiss Business Register [2.4]. To identify business locations, topographical data obtained from swissBUILDINGS3D [2.5] were used. Hence, the non-residential buildings could be determined by their gross floor area and building height.

The measures applied were derived from MuKEN:2014 and their impact on the energy consumption and $CO_{2,eq}$ emission reduction was calculated. In doing so, on the one hand the reduction of the building energy demand as a result of retrofit of building elements such as the facade, windows and/or roof was taken into account, by considering a renovation rate of 1.5% per year. On the other hand, the reduction in $CO_{2,eq}$ emissions from heating systems was analysed for the case where 80% of the electrical heating systems were replaced by heat pumps and 60% of the oil fired and 20% of the gas fired heating systems were replaced with renewable energy-based heating systems. It could be shown that the reduction in energy demand alone contributed to a significant energy and $CO_{2,eq}$ reduction, but still not enough to reach the goals of ES2050. The replacement of fossil fuel based heating systems such as oil or gas boilers proved to be an efficient and effective measure in reaching the $CO_{2,eq}$ emissions target. All told, a combination of both measures proved to be the most suitable scenario in so reducing the energy consumption and $CO_{2,eq}$ emissions in Swiss building stock. The analysis shows also that the Swiss electrical grid would not be too heavily loaded if fossil-based heating systems were replaced by those dependent on electricity, such as for example heat pumps.

Energy vector	LCA-Method[10]	BAFU-Method [21]	Unit
Oil	301	265	$g_{CO2,eq}$/kWh
Gas	228	203	$g_{CO2,eq}$/kWh
Electricity	102	0	$g_{CO2,eq}$/kWh
Other (heat pumps, wood, district heating, solar etc.)	see reference	see reference	$g_{CO2,eq}$/kWh

Table 2: $CO_{2,eq}$ factors in the Life Cycle Analysis and Swiss Federal Office of Environment (BAFU) scenarios

Figure 3 shows (a) the $CO_{2,eq}$ emissions, taking into account the $CO_{2,eq}$ factors, based on the life-cycle analysis for various building types (see also Table 2 for the $CO_{2,eq}$ factors of the various energy carriers using the LCA method). Graphic (b) shows the $CO_{2,eq}$ emissions when the $CO_{2,eq}$ factors are based on the values defined in the Paris Agreement (see Table 2, BAFU method).

(a) (b)

[10] *According to the Coordination Conference of Construction and Building Services, Public Construction Contractors (KBOB) 2009/1:2016*

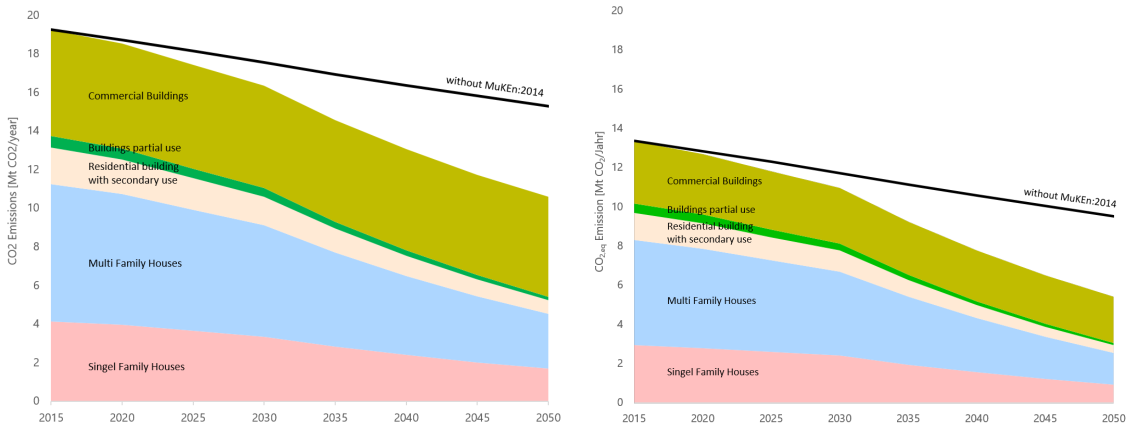

Figure 3: $CO_{2,eq}$ emissions of all existing buildings in Switzerland, excluding industrial and mobility-based emissions. Graphic (a) shows the emissions according to the Life-Cycle Analysis method for building operation only (e.g. not including building material embodied energy). Graphic (b) shows the emissions according to the Paris Agreement calculation method.

(a) (b)

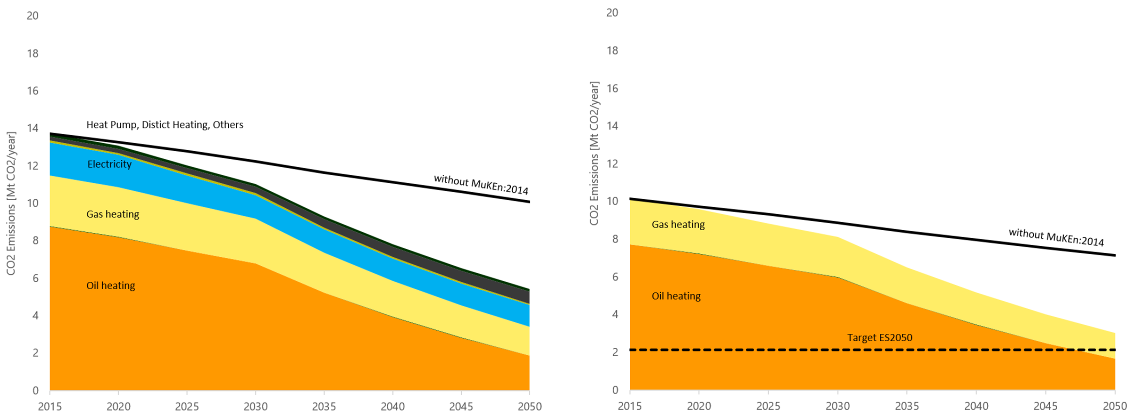

Figure 4: $CO_{2,eq}$ emission from Swiss residential buildings. If the current MuKEn:2014 is not implemented then $CO_{2,eq}$ emissions will only be slightly reduced (black line). Graphic (a) shows the emissions according to the Life-Cycle Analysis method for building operation only (e.g. not including building material embodied energy). Graphic (b) shows the emissions according to the Paris Agreement calculation method. If MuKEn:2014 is completely implemented in all cantons, the ES205 $CO_{2,eq}$ target (dotted black line) would be missed by about 30%.

The model calculation shows that the regulation proposed in MuKEn:2014 is insufficient to reach $CO_{2,eq}$ objectives. The ES2050 $CO_{2,eq}$ goal will be missed by a margin of 30% (see Figure 4b). To achieve the stated goals, additional more restrictive regulations, primarily relating to the replacement of fossil-fuelled heating systems, must be integrated into a new MuKEn:20XX. The current requirements relating to building envelopes for existing and new buildings are, however, satisfactory according to the MuKEn:2014. Figures 3 and 4 show the impact of the retrofit of building envelopes until 2030 and, after this, the additional effect of heating system replacements.

4.3 WP3: Impact at building and district level

The analyses in WP2 showed that current regulations are inadequate in terms of achieving the full potential for reduction in the building stock, in particular in relation to the replacement of fossil-fuelled heating systems. In WP3 measures will be analysed in greater depth, with detailed modelling of the building stock to enable the simulation of a range of retrofit and energy supply scenarios, and allow technically and economically based optimisations to be performed to identify the most appropriate retrofit solutions. In order to determine which solutions have the greatest impact, a combined simulation and optimisation-based methodology was developed executing a multi-criterion analysis. This takes into account costs and $CO_{2,eq}$ emissions. The focus of these optimisations is at both the building and district level.

4.3.1 Impact at building level

The first step is to identify the specifications and properties of the Swiss building stock. To do this an archetypical approach is used in which buildings are classified according to characteristics such as age, type, occupancy, number of apartments and number of floors, in addition to other available indicators. Statistical clustering methods such as the "nearest neighbour" and "k-medoid" algorithm are applied to define the optimal number and characteristics of the archetypical buildings which best represent the Swiss building stock as a whole. These "archetypal buildings" are then used to evaluate various energy efficiency and/or technology measures. Following this, information on regional and local potentials for renewable energy carriers is gathered, such as solar, geothermal and biomass potential. Also considered in the simulation are differences in energy demand based on climatic conditions. In addition to buildings (see Figure 5), archetypal communes were also identified which best represent the energy demand and availability of renewable resources in Switzerland with respect to its urban characteristics.

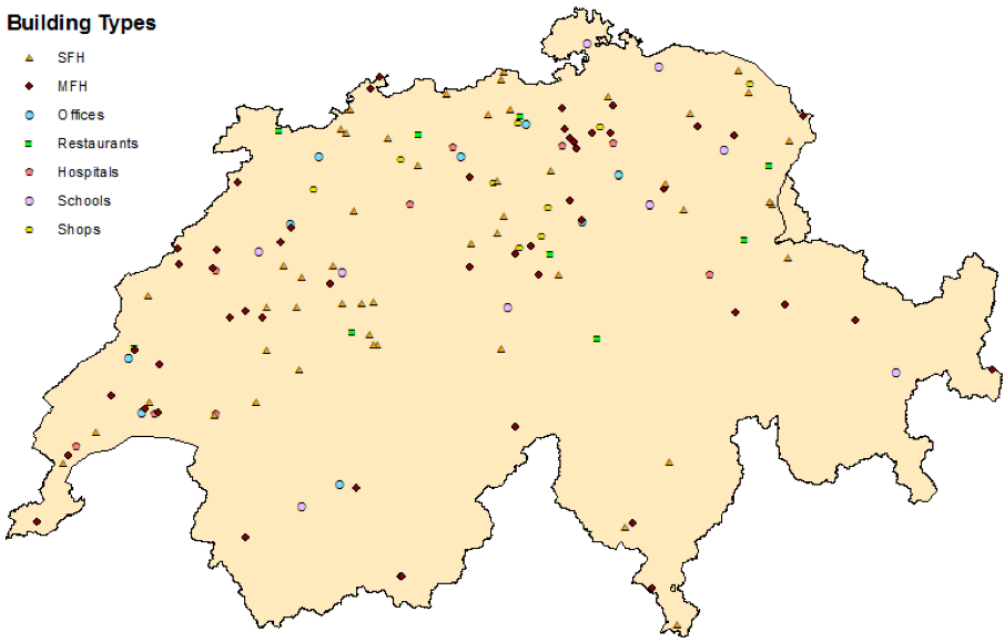

Figure 5: Choice of archetypes (in total 145 buildings) representing the build Swiss building stock (1.7 million buildings).

As a next step, a toolkit with a range of various measures was developed to raise the energy efficiency of buildings and/or reduce greenhouse gas emissions. Among the measures identified (in addition to the existing ones from the current MuKEn:2014) were others dealing with building and system efficiency enhancement, decentralised renewable energy technologies and district level solutions. To improve building efficiency, both partial and complete building envelope retrofit measures are considered, based on various combinations of window, wall, roof and cellar thermal insulation upgrades. To improve system efficiency, more efficient household electrical appliances, lighting and heating systems are considered, as well as the integration of renewable energy sources such as photovoltaic, solar-thermal and wood chip/pellet fuelled furnaces. Beyond this, heat pumps and storage technologies at the building level[11], and various types of heating networks sourced from renewable energy at the district level are also taken into account in the modelling process.

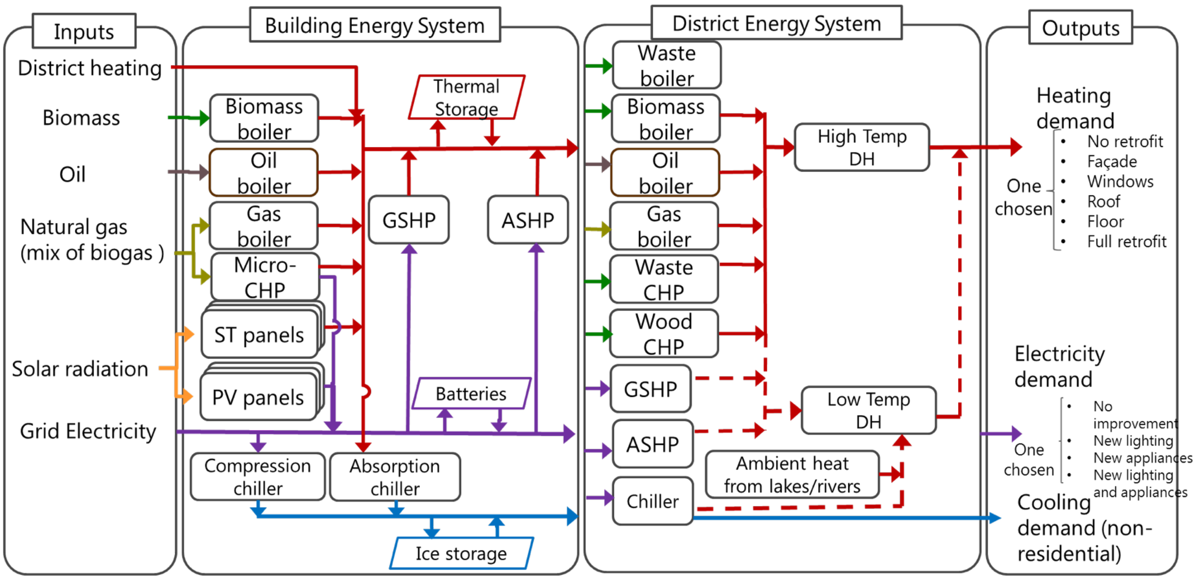

Figure 6: Energy hub model for the building and district level.

Based on the model described above, various measures identified with the help of the archetypical buildings and districts were assessed. The analysis is executed with a multi-criteria optimisation using the energy hub model [3.1, 3.2] (see Figure 6). This method is able to consider factors such as the retrofitting of building envelopes, the modernisation of building technologies, and the degree of implementing thermal networks, in addition to the integration of renewable technologies on site. The multi-criterion analysis simultaneously minimises both the greenhouse gas emissions (including emissions due to retrofitting and system improvements i.e. embodied greenhouse gases) and life-cycle costs. Possible strategies for reducing energy and $CO_{2,eq}$ intensity from 2015 to 2050 are also taken into account as evaluation criteria.

As for any energy system model, the boundary conditions for the system must be defined before the simulation is conducted. In this project both building and district levels are of interest, since at the district level more technologies may be available enabling a closer integration of certain energy carriers is available such as waste heat and biomass.

At the national level, the most economic solutions for various building categories can be identified. Figure 7 shows the aggregated Pareto fronts for single, multi-family and non-residential dwellings at building level. From this figure the optimal retrofit strategy (and associated costs) for each building category can be read off as a function of the required specific greenhouse gas emissions $CO_{2,eq}/m^2$. In addition the $CO_{2,eq}$ avoidance costs[12] for solutions with low $CO_{2,eq}$ emissions can be inferred. An example is given in Figure 7 for single family houses, showing the $CO_{2,eq}$ avoidance costs which would be incurred to reach the target value of 10 kg $CO_{2,eq}/m^2$.

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[11] *At the area level, no storage technologies are considered. An aggregation of storage at area level could offer economic advantages. The allocation of storage must be separately investigated.*

[12] *These are the costs which must be borne in order to reduce a given $CO_{2,eq}$ amount with respect to a reference technology (cost optimised solution in the Pareto front). In future it will be possible to extend the assessment to cover (dynamic) abatement costs.*

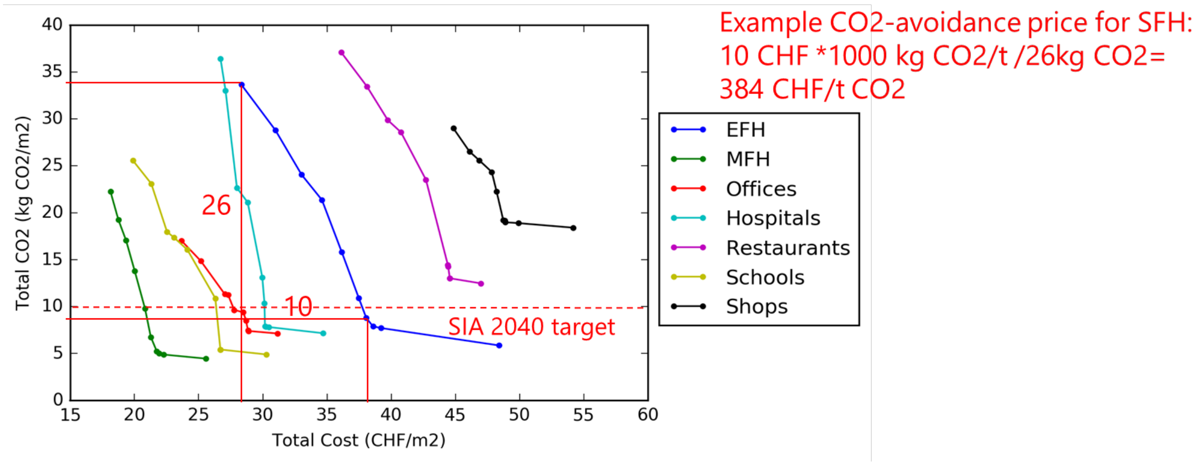


Figure 7: Pareto front diagram for single and multiple family dwellings, and non-residential buildings representing the Swiss building stock. The vertical axis is the total $CO_{2,eq}$ load (taken over the lifetime of the components installed, including operations) resulting from emission per square metre of energy reference area. The horizontal axis shows the life-cycle cost of the selected measures.

During the optimisation process the ideal retrofit measures and the system selection was decided according to the multi-criterion function. A retrofit option and a heating system are selected and, if applicable, a solar system is defined. Since a heating system is already installed in the building, the optimisation process can either keep the existing system (oil or gas fired boilers, biomass, electric or district heating) or select a new and more efficient system (air source heat pump, ground source heat pump, biomass, cogeneration heat and power system or gas boiler). Figure 8 shows the optimal combination of building envelope and systems for all archetypes of single and multiple family dwellings. The size of the individual markers represents the relevant building floor area in m^2. The graphic shows that in the case of single family houses roof renovations are the most frequently performed upgrade since this usually represents the most cost-effective action. The most promising heating systems are wood pellet systems or air source heat pumps. In certain cases the optimisation shows that electric heating systems may be retained after renovation, though this occurs in less than 5% of all optimised solutions for single family houses. Generally speaking, to reach the given targets both a retrofit of the building envelope and also a change of heating system is called for. The replacement of fossil-fuelled heating systems is mandatory for nearly all buildings in order to reach climate goals.

The analysis also shows that the age of the building is an important factor in deciding which solution should ideally be implemented. Figure 9 shows the optimal solutions for achieving climate target values ranked by building age. New buildings (constructed after 2000) take advantage of efficient technical systems and, in general, do not require retrofit of the building envelope in order to reach climate targets. Older buildings (constructed before 1990) are often economic to modernise and can be retrofitted with heat pump systems. Some of the most effective measures in reaching $CO_{2,eq}$ goals for the Swiss building stock include replacing heating systems with biomass boilers (fired with wood chips or pellets) or heat pumps (air source or ground source), roof insulation or window replacement in combination with facade insulation, and the installation of photovoltaic modules.

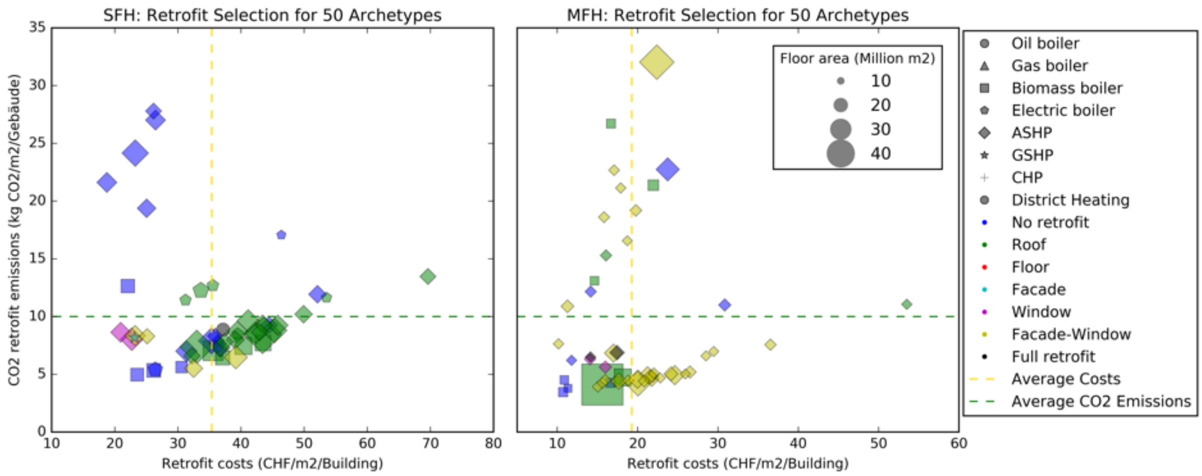


Figure 8: the optimal retrofit and system selection for 50 archetypal houses (left single family, right multiple family dwellings). The size of the marker indicates the built area in m² represented by it over the total building stock. These solutions represent the most economic versions of the Pareto solutions so that the total building stock achieves the target of 10 kg $CO_{2,eq}/m^2$.

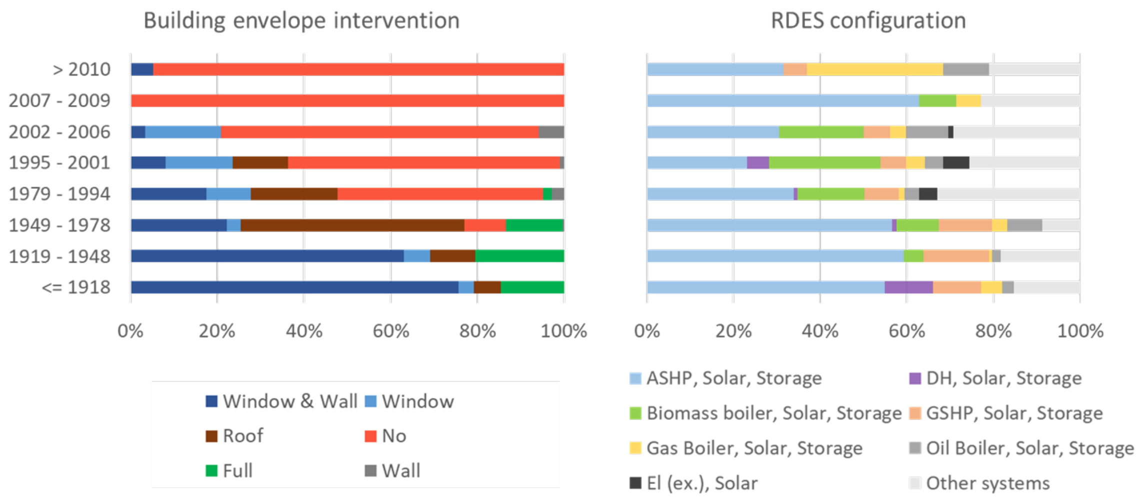


Figure 9: Typical solutions under 10 $kg\ CO_{2,eq} / m^2$ annually, ranked in by building age. Photovoltaics are the most popular choice in the solar system category.

Finally, in view of the long-term nature of the analyses, several sources of uncertainty were identified which conceal the risk of the selected measures being less than optimally combined. For this reason uncertainty and sensitivity analysis methods were applied to test the robustness of the selected measures. To identify a robust set of solutions, the required impact for a range of different boundary conditions was investigated. The analysis is based on Monte Carlo simulations and takes into account uncertainty due to economic, technical and energetic factors as well as the availability of renewable energy carriers.

The analyses described above were carried out in a deterministic fashion, that is, it was assumed that all the input parameters to the Energy Hub model were known with absolute certainty. In reality, however, most of the input parameters should be viewed as being uncertain, either because they represent inherently stochastic factors (e.g. solar irradiation patterns) or because it is very difficult to determine their true values exactly (e.g. future energy prices). In order to obtain robust building retrofit measures it is therefore important to investigate how the optimal building renovations and optimal energy systems vary as a function of the different values of uncertain model parameters.

To this end the most important model parameters are mapped onto a probability distribution. These include the building energy demand, solar irradiation patterns, investment costs, and the $CO_{2,eq}$ emissions generated by energy systems and renovation measures, energy prices and emission factors as well as the technical characteristics of energy technologies. The probability distributions reflect the fact that it is difficult to determine the exact values of most parameters. In particular the uncertainty associated with the cost reduction over time of novel technologies such as photovoltaics or batteries, coupled with the uncertain impact of climate change on building heating and cooling demands, is worthy of mention.

After the probability distributions have been defined, several random samples are obtained for each indeterminate parameter and the Energy Hub model is executed repeatedly in order to identify variations to the optimal solutions. As an example, the variations of optimal building envelope retrofit and improvements to the energy systems for single-family houses are shown in Figure 10.

The comparison between the deterministic and stochastic solutions shows that the results of the stochastic analyses show a greater variability with respect to optimal retrofit solutions, particularly for solutions which achieve the required $CO_{2,eq}$ goals (i.e. emissions of <10 $kg_{CO2,eq}/m^2$ as per SIA 2040). For example, in the deterministic case the great majority of the solutions with emissions of less than 5 $kg_{CO2,eq}/m^2$ envisage the installation of a biomass boiler. In the stochastic case, on the other hand, a more balanced mix is observed which calls for the use of heat pumps (air source or ground source heat) alongside biomass boilers. Similarly the deterministic solutions for the case <5 $kg_{CO2,eq}/m^2$ suggest “no renovation” in more than 40% of model outcomes, while the stochastic solutions not only suggest a lower proportion of “no renovations” result but also include cases calling for “comprehensive renovation”.

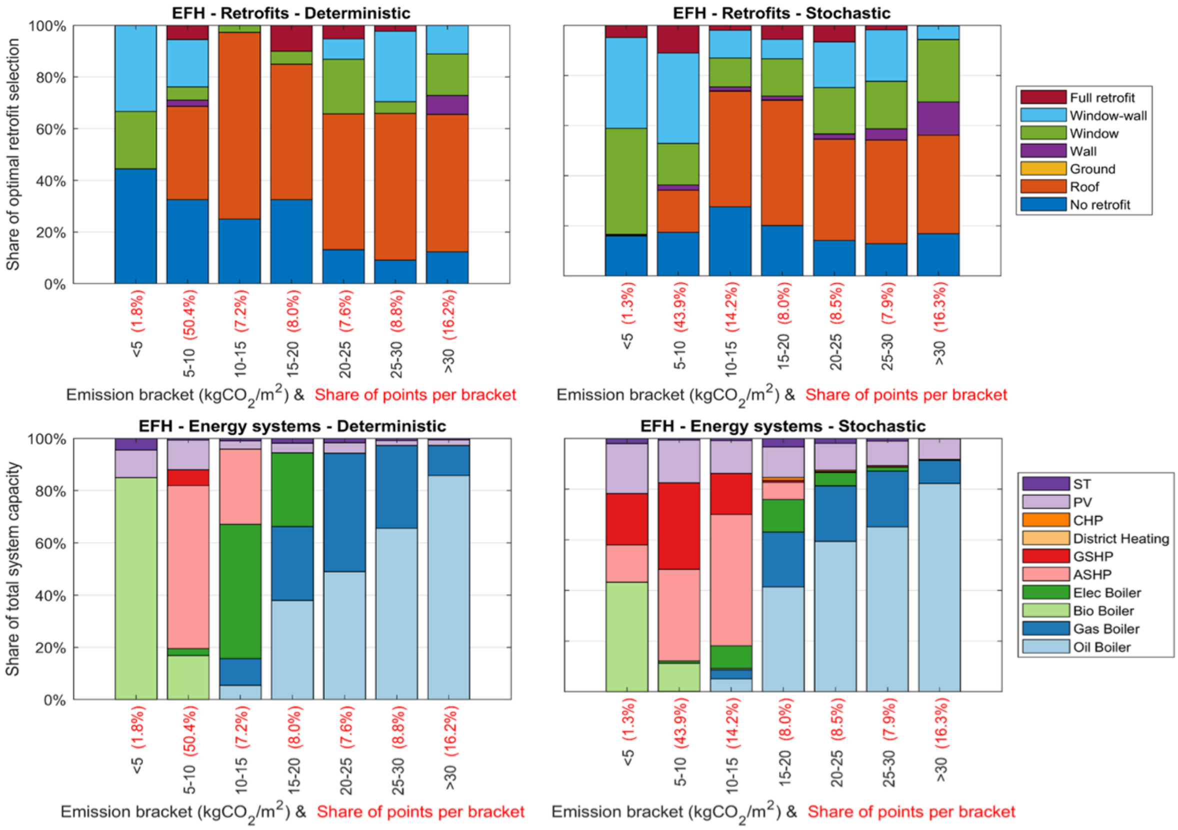


Figure 10: Optimal building envelope retrofit and energetic system change for single-family houses based on the results of deterministic and stochastic analyses. (Points reflect representative buildings for the Swiss building stock)

Table 3 compares the set of typical solutions generated by deterministic and stochastic analyses. To identify typical solutions, all combinations of building and energy system renewals are used which result in emissions below 10 $kg_{CO2,eq}/m^2$. Solutions which occur with a frequency of less than 4% are eliminated, being considered irrelevant. Both the deterministic and stochastic analyses produce a broad spectrum of optimal solutions in terms of renovation measures. The main difference, however, lies in the selected energy systems. In the stochastic case significantly fewer solutions proposing a biomass boiler are suggested than in the deterministic case. Instead, the stochastic results primarily encompass heat pump technologies, a fact which can above all be ascribed to forecasts for lower technology costs in the future, based on technological improvements, industry learning curves and so on.

Stochastic Solutions				
MFH				
Envelope retrofit type	Heating system	Solar system	Battery	Share
Window-Wall	ASHP	PV	×	12.8%
Window-Wall	GSHP	PV	✓	9.5%
Window-Wall	ASHP	PV	✓	6.8%
No retrofit	GSHP	PV	✓	6.3%
Full retrofit	ASHP	PV	×	5.4%
Window-Wall	GSHP	PV	×	5.3%
Full retrofit	GSHP	PV	✓	5.2%
Window	Biomass	PV	✓	4.0%
				55.3%
EFH				
Envelope retrofit type	Heating system	Solar system	Battery	Share
Window-Wall	GSHP	PV	✓	14.6%
Window-Wall	ASHP	PV	×	8.4%
Full retrofit	GSHP	PV	✓	6.9%
Window-Wall	ASHP	PV	✓	5.6%
Roof	ASHP	PV	×	5.5%
Roof	GSHP	PV	✓	5.2%
No retrofit	ASHP	PV	×	5.0%
Window	Biomass	PV	✓	4.0%
No retrofit	GSHP	PV	✓	4.0%
				59.2%

Deterministic Solutions				
MFH				
Envelope retrofit type	Heating system	Solar system	Battery	Share
Window-wall	ASHP	PV	×	41.3%
Roof	Biomass	PV	×	8.15%
No retrofit	ASHP	PV	×	6.27%
Window	ASHP	PV	×	5.01%
No retrofit	Biomass	PV	✓	4.07%
No retrofit	ASHP	PV	✓	4.07%
				69%
EFH				
Envelope retrofit type	Heating system	Solar system	Battery	Share
Roof	ASHP	PV	×	25.5%
No retrofit	ASHP	PV	×	19.3%
Window-wall	GSHP	PV	✓	7.72%
No retrofit	Biomass	PV	×	5.02%
Roof	Biomass	PV	×	4.25%
Window-wall	ASHP	PV	×	4.25%
				66%

Table 3: A comparison between the typical deterministic and stochastic robust solutions below 10 kg$_{CO2,eq}$/m^2. The Proportion column shows the frequency of the selected solution in the applicable building segment (here multi-family (MFH) and single-family (EFH) dwellings). Air Source Heat Pumps (ASHP), Ground Source Heat Pumps (GSHP).

The analysis performed shows that it is quite possible to achieve $CO_{2,eq}$ emissions below 10 kg$_{CO2,eq}$/m^2, typically with $CO_{2,eq}$ avoidance costs of 200–400 CHF/t$_{CO2,eq}$ in comparison with cost optimised solutions. The optimal solutions from the technical and economic perspective are characterised by three measurement strategies at the building level: (i) carry out partial improvements on the building envelope in terms of energy efficiency, (ii) replace oil and gas fuelled boilers in practically every case and (iii) the usage of PV technologies and, in individual cases, the installation of electric and/or heat-storage systems.

4.3.2 Impact at district level

Swiss district archetypes are calculated using a two-stage method. Initially Swiss districts [3.3] are classified into three urban types, namely urban, suburban and rural. A clustering method for each district classification is then applied which categorises Swiss communes in an archetype. This method takes into account building typologies, building age and the potential for using renewable energies. Based on these clustering analyses, twelve archetype districts are identified and used for the optimisation of the energy system at district level. Figure 11 shows the installed capacity of individual systems for the 12 archetype districts. Reddish shades indicate building technologies and greenish shades the district systems. The individual columns show the variation in solutions as a function of the $CO_{2,eq}$ values achieved. The goal is to identify the optimal energy system solutions for the type of building or district. The results show that thermal networks ("district heating systems") are primarily selected for town and some suburban clusters (agglomerations), whereas in rural regions individual energy systems are preferred. Cost optimised solutions are currently often based on oil fired heating systems. As more stringent $CO_{2,eq}$ goals are introduced, these systems are gradually replaced by heat pumps (both air source or ground source types) or waste heat supplies (cogeneration heat and power). $CO_{2,eq}$ optimised cases call for a mix of different energy sources such as waste heat, heat pumps or biomass. The results further indicate that thermal networks are suggested in 50 to 80% of the cases in urban districts, falling to 50% in more densely populated or industrialised suburban areas. The integration of PV technologies is one of the solutions proposed in the optimisation which can be pushed to the limits of maximum available capacity for all district categories. Figure 12 shows a representation of the investment and operating costs for solutions which meet $CO_{2,eq}$ targets. The figure shows that the investment costs for districts with a large number of district solutions are between 20 and 25% lower than for districts with a large number of building system solutions.

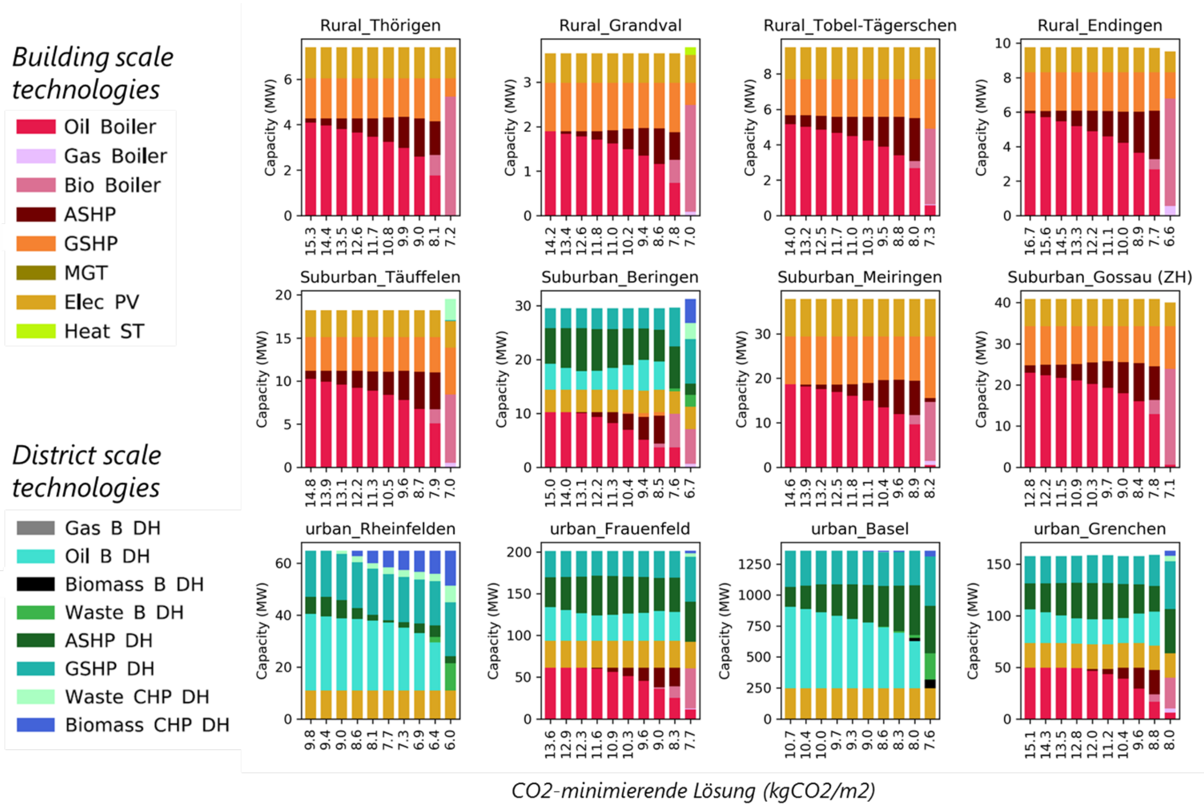


Figure 11: Optimal selection of energy system for archetypal districts (rural, suburban and urban archetypes)

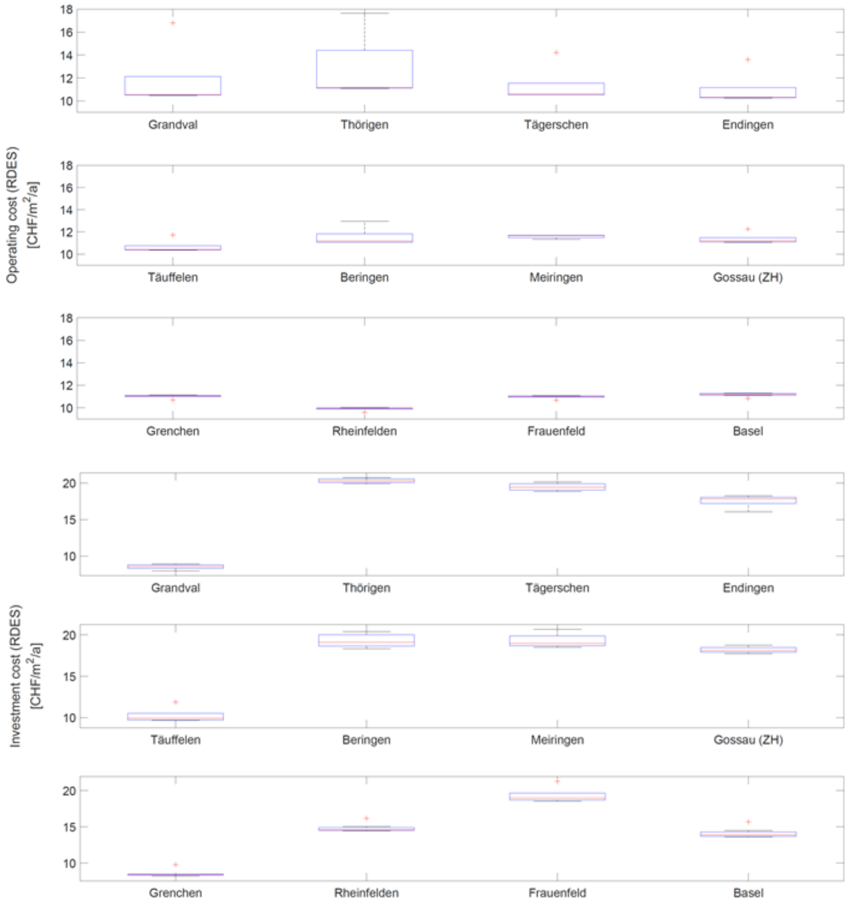


Figure 12: Range of investment costs (left) and operating costs (right) for district energy systems of the 12 archetypes which achieve the goal of $10\ kg\ CO_{2,eq}/m^2$.

Scaling the technically and economically optimal solutions up to cover the entire Swiss building stock would result in CO2,eq emissions being reduced by up to 80%. This result shows that it is technically and economically possible to achieve the ES2050 goals for the national building stock. The regulatory measures which are necessary to achieve this target are described in the next chapter.

4.4 WP4: Measures for a new TER

Based on the technical and economic potentials which have been demonstrated in the previous work packages, in this work package (WP4) possible TERs will be proposed which support achieving ES2050 goals for the Swiss building stock. The advantages and disadvantages with respect to the current requirements of MuKEn:2014 will be indicated at the end of this section. Implementation of the suggested TERs, i.e. the legislation and enforcement aspects, will not be further considered in this Phase 1, and will be discussed in Phase 2 of the EnTeR Project.

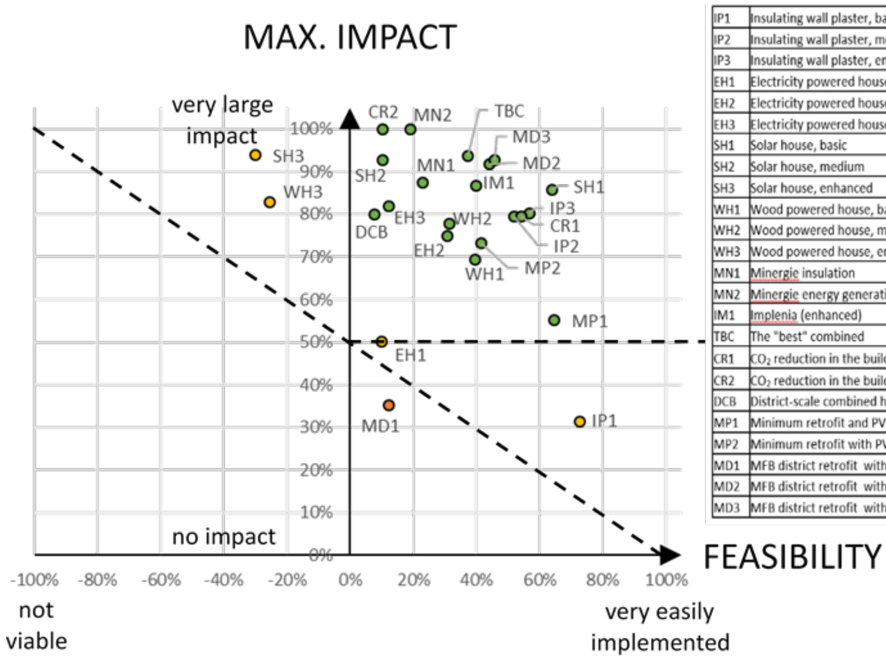
The derivation of the proposed TERs is based on the results obtained and conclusions reached in the previous work packages, WP1, WP2 and WP3. Also taken into account were the opinions of an expert group tackling the issue of the formulation of possible future TERs.

4.4.1 Identification of effective measures

The opinions of an expert group (specialists of Lucerne University of Applied Sciences and Arts, also representing the standardisation work of SIA) were obtained over four workshops. The introductory question posed was "What regulatory measures are possible and necessary in Switzerland to enable the ES2050 goals to be reached?" This issue was discussed intensively in the first workshop and the different opinions which emerged were grouped into various categories. The responses most frequently given (which also happened to correspond with the literature search results from WP1), were:

- Moving from fossil fuels to renewable energy sources
- Create incentives to renovate existing buildings
- Increase energy efficiency
- Align legal requirements with the building life-cycle (planning, construction and operation)
- Involve the user more closely as contributor (in role as operator)

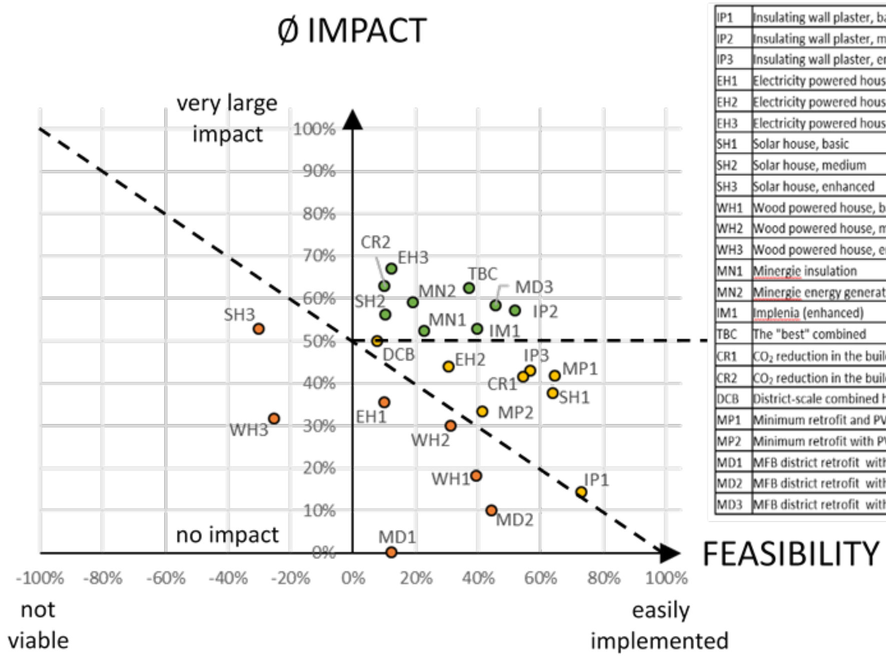
Before discussions with the expert group began, individual technical measures and bundles of measures included in existing laws, standards, regulations and studies were researched [4.2, 4.3, 4.4 among others]. This data was then presented to the expert group with the aim of completing and evaluating it. The assessment was carried out using the principle of hedonistic calculation [4.1]. The impact of the bundles of measures on renovation and new construction projects was evaluated for the ideal environment, i.e. where there is adequate space in and around the building, where sufficient resources are available and where there are no limitations applied to technical infrastructure (see Figure 13).



IP1	Insulating wall plaster, basic
IP2	Insulating wall plaster, medium
IP3	Insulating wall plaster, enhanced
EH1	Electricity powered house, basic
EH2	Electricity powered house, medium
EH3	Electricity powered house, enhanced
SH1	Solar house, basic
SH2	Solar house, medium
SH3	Solar house, enhanced
WH1	Wood powered house, basic
WH2	Wood powered house, medium
WH3	Wood powered house, enhanced
MN1	Minergie insulation
MN2	Minergie energy generation
IM1	Implenia (enhanced)
TBC	The "best" combined
CR1	CO_2 reduction in the building stock, basic
CR2	CO_2 reduction in the building stock, enhanced
DCB	District-scale combined heat and power generation with biogas
MP1	Minimum retrofit and PV
MP2	Minimum retrofit with PV and ventilation
MD1	MFB district retrofit with central heat generation, basic
MD2	MFB district retrofit with central heat generation, medium
MD3	MFB district retrofit with central heat generation, enhanced

Figure 13: Evaluation of bundles of technical measures for the "ideal" environment. Individual bundles of measures are depicted as points and labelled with their corresponding code. The bundles of measures are described in detail in WP4, section 11.3. The impact is depicted along the ordinate. 0% signifies that compared to the current situation no improvement in $CO_{2,eq}$ emissions and energy efficiency is to be expected. 100%, on the other hand, signifies that through the application of the bundles of measures a very significant $CO_{2,eq}$ reduction and a greatly increased building energy efficiency is expected. The feasibility is depicted along the abscissa. If the implementation of a bundles of measures is considered to be without complication, then the feasibility is evaluated to be 100%. If the positive and negative aspects of implementation are given equal weight, then the feasibility value is set to 0%. If significant social, technical or other obstacles are expected to hinder the implementation process, then the feasibility is given a value of -100%.

The bundles of measures were also evaluated for typical environments, where for example there was not enough space for a PV installation in all cases, or where it was not possible to sink geothermal probes (see Figure 14).



IP1	Insulating wall plaster, basic
IP2	Insulating wall plaster, medium
IP3	Insulating wall plaster, enhanced
EH1	Electricity powered house, basic
EH2	Electricity powered house, medium
EH3	Electricity powered house, enhanced
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MN1	Minergie insulation
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MD2	MFB district retrofit with central heat generation, medium
MD3	MFB district retrofit with central heat generation, enhanced

Figure 14: Assessment of packets of technical measures for the "typical" environment

Figures 13 and 14 depict a summary of the evaluation of all suggested bundles of measures. Green data points indicates bundles of measures which the expert group assessed as having an above-average effect (impact >50%) whilst simultaneously being easy to implement (feasibility>0%). Bundles of measures coloured yellow indicate cases with either a below-average impact (<50%) and good feasibility (>0%) or those which are difficult to implement (<0%) yet show good impact (>50%). These points all lie above the diagonals in Figures 13 and 14, which represent the limits of balance between impact and feasibility. All bundles of measures for which a rather poor feasibility and low-impact were predicted, and which therefore lie below the diagonals, are coloured red.

It is notable that many of the proposed bundles of measures are very suitable for at least one ideal environment. However when applied to the entire building stock, their impact and feasibility drops. Based on an analysis of the feedback from the expert group, it was possible to identify those measures which frequently occur and are assessed as being particularly impactful and possessing good feasibility:

- Replacement of oil or gas fired boilers with heat pumps or biomass boilers
- Economic partial renovation of building envelopes to guarantee freedom of damage or to enhance comfort and energy efficiency
- The use of photovoltaic installations.
- Connection to a thermal network (local/district heating and cooling)
- Energy-efficient appliances (electrical equipment, lighting, ventilation equipment etc.)

The discussion regarding the retrofit of building envelopes was controversial. By an “economic” upgrade of the building envelope, it is insulated in such a way that damages are prevented, based on SIA 180, which, in Table 7, defines the maximum thermal transmission coefficients (U_{max}) associated with damage prevention. The expert group expects this to lead to a greater acceptance of the current practice with significantly lower U values. The reason for this is, on the one hand, the greater freedom in terms of outdoor design and, on the other, the lower investment costs and loss of space when indoor insulation is applied. The potential energy efficiency of an individual building is not completely exhausted with these reduced thermal insulation requirements. It is expected however that as a result of these less ambitious requirements the rate of renovation will increase. Extrapolated over the entire building stock, the energy efficiency will increase despite the reduced requirements (see also results of WP2 and WP3).

Individual technical measures and bundles of measures demonstrate holistic solutions to increasing energy efficiency and/or reduction in $CO_{2,eq}$ emissions. Technology-specific measures such as, for example, an external wall insulation are individual solutions which leave the planner little leeway in implementation. On the other hand such measures have the advantage that the possible solutions are already known and can be simply implemented. However, in order to create room for innovation where new technological approaches with the same or improved impact can germinate and flourish new regulations must be formulated in a technologically open way. For this reason for each of the technical measures mentioned above an indicative value has been defined with which the implementation of the measure can be influenced. The indicative values have been classified into eight categories:

- Surfaces (envelope, floor, etc.)
- Volumes (building volume, zoning plan volumes, above/below ground, etc.)
- **Energy** (primary, end, useful energy, etc.)
- **Capacity** (reference power, installed load, etc.)
- Occupancy (numbers of residents, activity, etc.)
- Time (lifetime, operational time etc.)
- **Emissions** ($CO_{2,eq}$, “embodied”, greenhouse gas, etc.)
- **Mass** (structural design, thermally active, etc.)

The assignment of the indicative values to each of the technical measures (see also Matrix Report WP4, section 11.5) shows that energy, capacity, emissions and mass are most frequently used to support or inhibit technical measures.

The workshops showed that different indicative values are necessary in order to simultaneously enhance energy efficiency, increase the use of renewable energies and reduce $CO_{2,eq}$ emissions. The results can be summarised as follows:

- A single individual indicative value such as, for example, $CO_{2,eq}$ emissions from buildings, which could regulate all requirements associated with building energy, does not exist. The regulation of energy efficiency in buildings, which has a direct impact on the quantity of energy consumed and therefore the security and independence of the energy supply, must also find its place in a future TER. This statement stands in agreement with the results from WP1 (see section 4.1.2 above)
- The following three TER concepts are regarded as high impact in terms of regulating energy and $CO_{2,eq}$ emissions in a technologically open manner:
  - The regulation of self-consumption (thermal and electric),
  - The regulation of capacity (impact on infrastructure and provision of renewable energy)
  - The regulation of usage (impact on energy efficiency and operation)

4.4.2 Derivation of the TERs

The results generated by the previous work packages and the measures for improvement identified by them show that multiple approaches must be selected in defining a TER in order to cover the comprehensive political goals regarding energy and climate in Switzerland (increasing energy efficiency, raising the proportion of renewable energies used and reducing greenhouse gas emissions). Consequently it is suggested that these measures be subdivided according to the three main phases of the life-cycle of a building, namely construction, operation and decommissioning (environmentally appropriate demolition). A specific TER concept is proposed for each of these phases:

1. For the construction phase (planning and building the structure) a “**Capacity Limit**” TER is proposed. Data from WP3 shows that the cumulative frequency curves of capacity demand under conditions of standard usage are similar for respective building types. Consequently the maximum capacity demand also represents the energy efficiency of a building. Setting a capacity limit for heating, cooling and electrical consumption will ensure that constructional measures to the building envelope, structure and technologies are used to make energy-efficient operation of the building possible. Furthermore, capacity limiting will also have an impact on the energy supply plant outside of the building. Grid infrastructure capacity and the provision of reserve capacity for electricity, heat and gas supplies will be positively influenced by a TER of this nature.

2. The operation of a building largely determines its energy consumption and greenhouse gas emissions (see results of WP2). The proposed “**Energy Mix**” TER will limit the permitted $CO_{2,eq}$ emission occurring during building operation. Since restricting greenhouse gas emissions can be achieved both through the choice of an energy carrier with low emission intensity as well as by the reduction of energy usage, this TER will make possible a number of ways of complying with an energy mix limit.

3. The indirect proportion of energy consumption and greenhouse gas emissions associated with a building appears in the form of embodied energy or embodied emissions and arises from the building materials used in construction. WP3 shows that the non-operational fraction of emissions can reach up to 40% of the total over the life cycle of a building. The proposed “**Material Cycle**” TER is intended to reduce this “embodied” proportion by imposing a recycling fee on building materials. This will create an incentive to reuse, recycle or compost building materials. A comprehensive introduction to recycling processes in the building industry will offer opportunities for new innovative product and process development, closing material loops has a positive impact both on energy efficiency as well as building material resource usage efficiency, and represents a further step towards the decarbonising of the building industry.

The three TERs presented above can also be mathematically derived, see section 7 of sub-report WP4. The derivation shows why the maximum capacity demand, the limitations of $CO_{2,eq}$ emissions in operation and the recycling of building materials all play a significant role in the reduction of the $CO_{2,eq}$ footprint of a building:

$$M_{CO_2tot} = \sum_{i=1}^{n} m_i \cdot x_{CO_2,E,i} \cdot (1 - r_i) + \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=y}^{l} m_i \cdot P_{s,ik} \cdot \varepsilon_{CO_2,B,jk} \cdot t_{jk} \tag{1}$$

M_{CO_2tot}: $CO_{2,eq}-footprint\ of\ a\ building\ \left[kg_{CO_{2,eq}}\right]$
m: $Mass\ of\ construction\ matierials\ used\ \ [kg]$
$x_{CO_2,E}$: $Specific\ embodied\ emissions\ of\ the\ used\ constuction\ matierals\ \left[kg_{CO_{2,eq}}/kg\right]$
r: $Recycling\ rate\ [-]$
P_s: $Secific\ thermal, electrical\ or\ chemical\ power\ consumption$
$(relative\ to\ the\ mass\ of\ construction\ materials\ used)\ [kW/kg]$
$\varepsilon_{CO_2,B}$: $Emission\ factor\ of\ the\ energy\ mix\ \left[kg_{CO_{2,eq}}/kWh\right]$
t: $Operating\ time\ [h]$
i, n: $Number\ of\ construction\ materials\ used\ [-]$
j, m: $Number\ of\ energy\ carriers\ [-]$
k, l: $Number\ of\ time\ inervals\ (y = 1; 0{,}25; \ldots \rightarrow year, month, hour, 15min, etc.)\ [-]$

The goals of the new TERs are to reduce building $CO_{2,eq}$ footprints, to increase energy efficiency and to allow a large degree of freedom in choosing solutions, so as to leave plenty of scope for technical innovation. The structural and technical possibilities represented by the building mass (m) in Equation (1), leave a great deal of room for manoeuvre through the choice, the concept and the processing of materials for building owners, planners and contractors. The operation of a building, which is primarily determined by (t), is influenced by the activities of the users and it is difficult to apply limits here through technical regulations. Socio-economic regulations are a more effective method of influencing user behaviour, and consequently (m) and (t) should not be limited by TERs.

On the other hand, according to Equation (1) the value of the term ($x_{CO_2,E} \cdot (1 - r)$) can be reduced by choosing building materials with lower specific embodied emission coefficients, or by increasing the recycling rate of the materials used (“Material Cycle” TER). The parameter $\left(\varepsilon_{CO_2,B}\right)$, i.e. the energy mix emission factor, can be influenced by the choice of energy carrier (“Energy Mix” TER). The specific thermal, electric or chemical capacity consumption factor, (P_s), varies according to the choice of building energy concept (“Capacity Limit” TER).

Both $\left(\varepsilon_{CO_2,B}\right)$ and (P_s) can be effectively constrained through TERs, as is also shown by the existing TERs which were analysed in WP1 (see Pioneering Countries, WP1 report Table 2). In terms of minimising ($x_{CO_2,E} \cdot (1 - r)$), to date only a very few effective TERs have been defined. France alone is currently testing regulations to limit embodied greenhouse gas emissions (see WP1). Economic incentives, such as the introduction of a recycling fee on building materials, promise effective changes in building processes, subject to them being accompanied by suitable regulatory frameworks (see, for example, the take-back obligation for used electrical appliances).

4.4.3 Comparison with MuKEn:2014

MuKEn:2014 primarily sets requirements relating to the annual energy demand and thereby on energy efficiency. Relatively few, unambitious measures are aimed at encouraging the use of renewable energies, and none at all are concerned with regulating material cycles. The impact of such requirements is most effective in the case of new buildings, the renovation of an existing building (e.g. thermally insulating the envelope, replacing windows and so on), or when components must be replaced (e.g. heating systems). Evidence of meeting these requirements is demonstrated before construction starts, although the decision on exactly when to execute modernisation work is an open choice. Bulk consumers can be relieved of the obligation to meet these requirements if they enter into a target agreement with the cantonal authorities to gradually reduce energy consumption in a regulated manner. To be considered a bulk consumer, an entity must demonstrate an annual heating consumption of more than 5 GWh or an electric consumption of more than 0.5 GWh. Evidence of this consumption is gathered during the operational phase based on measurement values.

The legislation covering the proposed TERs will be addressed in the next phase (Phase 2) of the EnTeR Project, which means that not all details of implementation and enforcement are currently known. A comparison of the proposed TERs with the MuKEn:2014 is made at the conceptual level.

The “Capacity Limit” TER targets energy efficiency and therefore corresponds closely with the requirements of MuKEn:2014. However, now the emphasis is on capacity and not, as before, on the annual energy demand. The expectation today is that the same impact as with current practice will be achieved based on energy calculations using standard usage data. This can be demonstrated with standard solution combinations (as is the case now), or by means of system verification. Calculations will be based on the SIA 384.201 standard instead of SIA 380/1, or in the case of air-conditioned buildings on SIA 382/2. With the introduction of heating capacity regulations for domestic, office and school buildings, MuKEn:2014 already contains a capacity-related requirement. The advantages to be expected from a capacity consideration perspective rather than an energy viewpoint are as follows:

- As a consequence of climate change, heating energy demand will be reduced while cooling energy demand will increase. Extreme weather episodes will ensure, however, that the necessary supply level will remain high both in winter and summer. Capacity limitation will be more effective in future in encouraging the construction of energy efficient buildings.
- The capacity calculation is independent of the usage and is a function of the building construction.
- The calculated capacity value forms the basis for the dimensioning of the heating and cooling systems and this provides a simple way of monitoring compliance after the plant is installed.
- Other closely related sectors such as energy supply (electric, heat and gas) and mobility, can also be positively influenced by capacity limitation regulation i.e. the reduction of network and reserve capacity and the deployment of energy storage capacity.

Besides the advantages, the disadvantage must also be mentioned:

- The limitation of process capacity associated with heating and cooling systems must be given particular attention in the enforcement context.
- In the case of log-wood heating systems, capacity will not be determined by the heating requirement but as a function of the quantity of wood burned. This must also be considered during enforcement.

The “Energy Mix” TER is aimed at limiting $CO_{2,eq}$ emissions generated during operations. No comparable requirement exists in MuKEn:2014. This TER is similar in many ways, however, to the Basic Module part L “Bulk Consumers” of MuKEn:2014. The requirement refers to operations, and is based on measurement values. The MuKEn regulation is not limited to one building, indeed bulk consumers may combine to form a group.

The TER “Energy Mix” should be applicable to all type of buildings. The following advantages can be expected:

- Assessment of the effective $CO_{2,eq}$ emissions during operations and reduction of the performance gap, i.e. no conclusions drawn regarding operations from the standardised planning data.
- A high degree of freedom in finding solutions by selecting energy carriers, reducing energy consumption and/or increasing on-site production of renewable energy.

Disadvantages associated with the TER are:

- Time-consuming compliance process because of the necessity to evaluate operational data. (Possibly the implementation of new compliance methods such as automatic data analysis).
- Additional effort required to record, process and validate energy consumption data (Smart Meters)

As the energy efficiency of buildings steadily increases, the proportion of embodied emissions and embodied energy from building materials also continuously rises (see also the results of WP3). Therefore this should be regulated via the TER “Material Cycle”. To date the MuKEn:2014 places no requirements on embodied emissions or embodied energy. Appropriate requirements will be formulated in conjunction with certification to Minergie-ECO standards, the 2000W Society or SNBS (“Standard Nachhaltiges Bauen Schweiz”). The calculation is time consuming or based on standard values which may differ greatly from the constructed building figures. This difficulty can be circumvented, as suggested, by implementing a deposit system applied to building materials. In addition, this will provide an incentive to reuse, recycle or compost building materials when a building is demolished at the end of its lifetime. A crucial factor in the successful implementation of this method is the point in time at which the deposit system is introduced and the administration of the revenue. The difference between this method and the current, well-known processes for recycling electrical waste and PET is the timescale, the mass of material involved and the local markets. The elaboration and implementation of such a deposit system must be investigated in detail in future work.

By means of a reduction path covering capacity limits and energy mix boundary values, future TERs could, in addition, achieve a higher dynamic performance. Boundary values could be reduced by e.g. 2% annually, or a continuously increasing yearly reduction over 5 to 10 years could be laid down (with, say, a 0.5% reduction the first year, 1.5% in the second year, 3% of the third year and so on). This will forcibly encourage the renovation of existing buildings, since the longer a building remains un-renovated the more stringent the upgrade requirements become and therefore the more challenging and expensive the necessary remedial work. In addition, the use of a reduction path will afford a high degree of security to the building industry in terms of future boundary conditions which will encourage investment in innovation (see also WP1).

In the following section the proposed TERs “Capacity Limits”, “Energy Mix” and “Material Cycle” will be compared to today’s MuKEn:2014 with the help of a SWOT analysis (see Table 4).

Strengths	Weaknesses
Simplification through separate consideration of the planning/construction, operation and demolition phases. The required performance criteria are easy to monitor for compliance. By defining the requirements in terms of a reduction path there is a high degree of planning security and encouragement of innovation for future solutions.	The calculation of boundary values and costs (TER "Material cycle") is a challenging process (in particular predicting values in the far future). Monitoring and assessing energy consumption requires extended knowledge and sets new challenges in terms of compliance (data management).
Opportunities	**Threats**
Consideration of embodied energy Involvement of users and incentive for optimal operation Requirements of associated sectors could be considered (electric power, gas, heating). Motivation to install and commercialise energy storage technologies.	Changing over to the new TERs requires wide support from the entire building industry. Enforcement of TER "Energy Mix" requires new legislation (e.g. penalties via taxation). Personal privacy and data security issues associated with compliance data collection.

Table 4: SWOT analysis of the suggested TER concepts compared to the MuKEn:2014

5 Conclusions

The application of a life-cycle perspective permits the most effective measures and determining factors in the three main phases of a building's life (construction, operation and decommissioning) to be identified. By subdividing the problem in this way, TERs can be targeted directly at the actors who have direct impact on a particular phase.

In the construction phase (including renovation and new construction projects), the energy efficiency is influenced by constructional, material and technical factors. The energy efficiency of a building is, in turn, defined by a combination of its performance and its operational characteristics. The capacity demand can be directly influenced by those actors involved in the building design and construction including owners, investors, planners and contractors. At a later stage, these actors can only influence operations in a limited degree, since they are no longer responsible. The focus in the TER on capacity limitation is referenced to this situation. Furthermore, with this TER a simplification of the implementation and extension of the range of influence (system boundaries) of a TER can be achieved:

- Simplification: the calculation of the capacity is exclusively based on the type of construction, choice of materials and installed appliances. Operational assumptions such as solar energy input, internal loads, room temperatures etc. are negligible and play no role in such a calculation. Above all in the case of building renovation work, the primary focus is on installing a new heating system or improving the building envelope. These constructional measures can be effectively steered by the application of a capacity limitation strategy. Compliance can be tested in a similar manner to before, i.e. checking adherence to the limiting values during the planning phase and, more easily during construction by checking the capacity specifications of the installed appliances.

- Extension: the transformation of an energy system to using renewable energy sources is primarily a challenge for the electric power, gas and heating infrastructure and therefore also for the supply and distribution networks. Limiting the capacity available in a building has a direct impact on infrastructure requirements, since grid and reserve capacity can be limited, consequently increasing supply security. If in future the energy supply is purely based on renewable sources then the marginal costs tend towards zero (Rifkin, J., The zero marginal cost society, 2014). The predominant factor then becomes capacity, this also being true in the business models of energy utilities.

In the operational phase, users (tenants, house owners etc.) are able to exert the most influence on energy efficiency. The operational characteristics of the building affect the quantity of energy consumed. In order to consider the quality of energy carriers used, the resulting $CO_{2,eq}$ emissions should be evaluated. The user can ensure fulfilling $CO_{2,eq}$ limits by reducing his consumption, choosing energy products with no or low $CO_{2,eq}$ and/or increasing their own internal energy production e.g. PV, CHP supply, passive solar gains, waste heat utilization, etc.

The decommissioning phase at the end of a building's lifetime gives an indication of how strong the environmental influence has been as a result of the choice of materials during the construction phase. Building rubble can be recycled, reused in other ways, composted or disposed of as landfill. The latter case makes no further use of invested resources and should be avoided. The three other methods mentioned demonstrate the opportunities for resource usage in a circular economy. The challenge is to recycle such materials in an energy and $CO_{2,eq}$ low/free manner. Making the assumption that the construction industry must also decarbonise, incentives must be created which emphasise the reuse or recycling of materials in a closed loop. Such incentives can only be created in a rather complicated manner, by means of a TER (see international analyses in WP1). For this reason a monetary approach is suggested, namely the imposition of a recycling deposit on building materials. This incentivises the building owner to recycle materials while industry receives a boost to intensify recycling activities.

The two suggested measures, "Capacity Limiting" and "Energy Mix", are performance-based and open to new technologies. Moreover both measures permit market-based and political issues to be taken into consideration. The actors concerned can financially optimise methods of meeting limits as a function of energy prices, availability, incentive levies and so on (see also Pareto Fronts, WP3).

In contrast to a measure imposing a recycling deposit on building materials, the "Capacity Limiting" and "Energy Mix" measures can be integrated into a future TER, allowing the Swiss TER to continue along the same successful course as before with, however, necessary adjustments to meet the future challenges of energy system turnaround.

6 Outlook

The presented work (Phase 1) focuses on technical energy regulation. Legislative instruments to follow, such as spatial planning, subvention legislation and tax law are not considered in this initial part. It makes sense to coordinate these follow-on instruments with future TERs in order to achieve maximal impact. In addition, the tax effects of various regulatory instruments should be investigated and if necessary also be harmonised. This ensures the creation of wide spectrum of comprehensive, integrated conditions, allowing to achieve the goals of ES2050 in an economically favourable way from a regulatory perspective.

The additional instruments mentioned above allow the technical and economic potentials of district and area solutions to be comprehensively exploited. The suggested performance-based measures for buildings, namely "Capacity Limiting" and "Energy Mix", can also be applied analogously at the district and area scale. Spatial planning, including energy planning, could create supplementary incentives aimed at increasing the emphasis on district and area solutions.

Furthermore this work has restricted itself solely to deriving effective measures for a future TER. The opportunities and possibilities for implementing and executing the suggested measures were mentioned only in terms of comparison with the current MuKEn:2014. The further development of implementation methods, taking into account new possibilities to monitor compliance with limiting values, helps create an effective, impact-oriented TER. For example, measured values with application oriented temporal resolution obtained by the widespread use of smart meters could be used for applying sanctions when limiting values are exceeded. They could also be used to generate rewards when consumption values fall below the given limits.

A further aspect to be considered for an effective TER could be binding reduction paths for limiting values. The legislature thereby commits itself over the long-term and constrains its negotiating scope, while enabling building owners to prepare themselves for the up-coming limiting values and allowing them to choose the optimal time to conduct renovation work. At the same time the building industry gains security for its product and service development, since these would be compliant with future regulations, thereby encouraging innovation.

The future perspective described in the paragraphs above is not exhaustive and demonstrates the need for a follow-on study (Phase 2).

7 Acknowledgment

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