Concept for next generation of technical energy regulations in buildings

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Abstract. The research project EnTeR analysed 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\textsubscript{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 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\textsubscript{2}-emissions below 10 kgCO\textsubscript{2}/m\textsuperscript{2} - typically at CO\textsubscript{2} avoidance costs of 200-400 CHF/tCO\textsubscript{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\textsubscript{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.
1. Introduction and Research Questions

Energy regulations historically represented an essential driver for increasing energy efficiency and reducing CO₂eq emissions\(^1\) in various economic sectors, including the building construction field. However, in their current design they are starting to show diminishing returns \([1,2]\), making further development of these regulations essential so that future systems, concepts and components can successfully be implemented. Such further development paves the way for the application and use of innovative technologies and concepts from the research sector. 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. This include building level solutions such as updating the building envelope or the installation of renewable based systems. Recently, district level solutions such as district heating networks, microgrids, energy hubs, etc. are becoming more important \([3,4,5]\).

The Energy turnaround – Technical – Regulations (EnTeR) research project \([6]\) 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\(^3\). 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, synergies mentioned which could influence the effect of a TER.

The overarching research question is: Which combination of TERs support and encourage the achievement of the UN sustainability goals #11 Sustainable Cities and Communities, #12 Responsible Consumption and Production and #13 Climate Action 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.

2. Method

The EnTeR project uses Switzerland as a case study and is consists of four progressively structured research work packages (WP1-4), which have been consolidated into one synthesis (see Fig. 1):

WP1: To analyze how TERs can reduce environmental impact of the building sector, the international analysis builds on the following four components. (i) Literature review has been used to identify pathways to advance the ongoing decarbonization of the building sector - which we will refer to in the following as leverage points. (ii) To identify countries that have already implemented innovative TER designs we started with review studies on TER design \([7,8,9]\). Ultimately, we selected Denmark (DK), France (FR), England (ENG), Switzerland (CH), and Sweden (SE) from the review based long list, as these countries share a comparable built environment and already implemented an approach addressing at least one of the leverage points. (iii) To understand the entire TER of which the innovative design is a part of, we analyzed the building regulations of the selected countries (707 pages) in depth and validated our understanding with secondary literature. (iv) We conducted 18 semi-structured expert interviews covering four topics to evaluate implementation challenges of such innovative approaches. To cover different perspectives, we interviewed researchers, practitioners, and policymakers.

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\(^1\) Equivalent CO₂ emissions (CO₂eq) 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.

\(^3\) Compulsory energy regulations in the building sector will be used as the object of research.
WP2: Typical measures for existing and new buildings were analyzed with respect to their impacts (energy consumption and CO₂,eq reduction) at the national level. These measures were assessed in terms of the Swiss Energy Strategy 2050 goals (ES2050), which agree with the UN goals #11, #12 and #13. For this purpose, a forecast tool was developed for the prediction of the future CO₂,eq emissions, energy consumption and electricity consumption of the Swiss building stock up to 2050. For residential buildings, the georeferenced building and housing statistics were used, while for non-residential buildings, a new calculation method was developed, using the statistics on the structure of enterprises as a source to identify business places and the vector based dataset which describes buildings as 3D models to match each business place with the gross area and height of its building. The model further allows the testing of individual, future scenarios with additional renovations like façade, roof, ground floor insulation and window replacements as well as the change of the heating system for space heating and domestic hot water [10].

WP3: In WP3 measures were analyzed in greater depth, with detailed modelling of buildings to enable the simulation of a range of retrofit and energy supply scenarios, and allow technically and economically based optimizations to be performed to identify the most appropriate retrofit solutions. In order to determine which solutions have the greatest impact, a combined simulation and multi-criteria optimization-based approach was developed. The focus of these optimizations is to determine specific measures at the building and district level that are most effective in cost-benefit terms (CO₂,eq reduction). The approach includes the following steps: i) clustering of archetypical buildings and districts which represent the current state of the building stock and districts in Switzerland, ii) the current performance is evaluated using an Urban energy simulation tool [11], iii) the optimal retrofit and system combinations are derived based on multi-objective optimization minimizing both costs and CO₂,eq emissions iv) the CO₂,eq avoidance costs are calculated for those solutions that reach the emission targets.

WP4: The proposed TERs are 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. These specialists in the field of energy and building systems, were presented with sets of measures, i.e. multiple measures that have a synergetic
effect on the performance of a building, which they had to evaluate and rate. Based on a hedonistic evaluation of their rating [12], the measures deemed to be most effective are identified.

In a qualitative approach, the physical properties of buildings most relevant to the implementation of the effective measures were then determined and concepts for possible future TER were derived. As a result of this procedure, a TER concept can be proposed, incorporating measures which promise to offer the greatest impact in terms of energy efficiency and CO₂eq reduction. As a final quality check of the proposed TER concept, an outlook indicating the opportunities and challenges of the implementation and enforcement phases is given.

3. Results and Discussion

The literature review [13] revealed that TERs, despite previous successes in increasing the energy efficiency of the building stock, seem to be reaching their limits, particularly when concerning the decarbonisation of the building sector. Literature lists the following five challenges – or leverage points: (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. We then specifically looked at the selected five European countries which all addressed at least one of these leverage points in their TERs.

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 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 1 provides an overview of our six TER design principles and outlines examples illustrating how to follow them.

| TER design principle                              | TER design examples                                                                 |
|--------------------------------------------------|--------------------------------------------------------------------------------------|
| 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 1: Overview of TER design principles and design examples
Today's model regulation in the energy sector in Switzerland (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 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 (see Fig. 2 and 3) [14]. 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.

**Fig. 2**: 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 m$^2$ 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$.

**Fig. 3**: 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).
Through technical and economic optimization, it has been possible to identify solutions for the Swiss building stock which achieve specific CO$_{2\text{eq}}$ emissions below 10 kgCO$_{2\text{eq}}$/m$^2$ - typically at CO$_{2\text{eq}}$ avoidance costs of 200-400 CHF/tCO$_{2\text{eq}}$ compared to cost-optimal solutions (see Fig. 4). 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.

![Figure 4: 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$_{2\text{eq}}$ 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.](image)

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 neighborhoods. The investment costs of such district solutions are between 20 and 25% lower than standalone building solutions [14].

By scaling the technically and economically optimal solutions to the entire building stock, CO$_{2\text{eq}}$ 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, or addressing the UN goals #11, #12 and #13, respectively.

In order to provide the best possible regulatory environment for encouraging stakeholders to develop the building stock 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 aligned to the phase-specific relevant actors:

3.1. Regulation for the Design and Construction Phase

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 “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) Extension: 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.

3.2. Regulation for the Operation Phase

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.).

3.3. Regulations for the Decommissioning Phase

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).

4. Conclusion and Outlook

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.

The presented work is focused on technical energy regulations which have been very effective for increasing the energy efficiency in the past and will be effective for decreasing the CO$_{2,eq}$ emissions in the future. However, we acknowledge that such control and regulatory instruments work best if embedded and coordinated in a more comprehensive policy mix [15,16], as no single one can address all the market and behavioral failures [17]. The coordination with further policy instruments, being it economic and market-based (e.g. subsidies) or fiscal (i.e. taxes) instruments, or support, information and voluntary action, although not in the focus of this work, will be essential to achieve the greatest possible impact. Furthermore, the determination of the income and policy cost effects of the various mixes of regulatory instruments should also be examined and, if necessary, coordinated. This will establish holistic conditions for achieving the national objectives, like the ES2050 of Switzerland, or addressing the UN goals #11, #12 and #13, in an economically efficient and effective manner from a regulatory point of view. These further topics can be addressed in the subsequent research projects.

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