Review

Why We Continue to Need Energy Efficiency Programmes—A Critical Review Based on Experiences in Switzerland and Elsewhere

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Abstract: Energy efficiency programmes (EEPs) are schemes operated by utilities or other bodies in order to incentivize energy efficiency improvement, in particular by adoption of energy-efficient products and typically by means of an economic reward. Ample experience has been gained, especially in the U.S., where EEPs have been in use for decades, with the rationale of avoiding additional energy supply by improving energy efficiency. More recently, EEPs have been implemented in Europe and in Switzerland. This review paper presents insights from the U.S., the EU and especially from Switzerland, with a focus on levelised programme cost of saved energy (*LPC*) as a key performance indicator. These *LPC* values, which take the perspective of the programme operator, are typically low to very low compared to the cost of electricity supply, thereby representing an important argument in favour of their use. The country examples show that EEPs are being effectively and successfully put into practice, for example, in Switzerland both as (i) a national tender-based scheme (called ProKilowatt) and in the form of a (ii) utility-operated obligation-based scheme (in Geneva). EEPs not only call for diligent implementation but also for suitable legal settings, e.g., in the form of mandatory energy efficiency savings targets (as realised for energy efficiency obligations, EEOs) in combination with programme cost recovery. The main criticism of EEPs is the free-rider effect, which needs to be minimised. On the other hand, EEPs are accompanied by significant co-benefits (environmental, health-related and social) and spillover effects. In their currently prevalent form, EEPs allow one to effectively save energy at a (very) low cost ("low-hanging fruit"). They can hence play an important role in fostering the energy transition; however, they should be implemented as part of a policy portfolio, in combination with other policy instruments.

Keywords: energy efficiency; energy efficiency programmes (EEP), cost-effectiveness; free-rider effect; co-benefits

1. Introduction

Across the globe, both the supply of renewable energy and energy conservation are key components of national energy and climate policy strategies [1–4]. Energy conservation can be achieved by increased energy efficiency (i.e., by using less energy for the same

energy service) and by sufficiency (i.e., by reducing the demand for energy services [5]). Improved energy efficiency is a core strategy in the European Union (represented by the EU's principle of "energy efficiency first" [6,7]), in Switzerland (as part of the "Energy Strategy 2050" [8]), in the U.S. (where it is part of the so-called Integrated Resource Planning process of utilities; see, e.g., [9]) and elsewhere. In high-income countries with typically low economic growth, improved energy efficiency may allow one to avoid a rise in energy use; and according to numerous scenarios, it is expected to even enable a significant decrease in energy demand, which is often considered a prerequisite for achieving carbon neutrality under the Paris Agreement [10]. Apart from its contribution to the abatement of greenhouse gas emissions and the direct economic benefits associated with cost-effective measures, energy efficiency improvement results in numerous co-benefits, e.g., jobs, reduced energy bills, lower energy dependency and lower environmental impacts [11–13]. While the value of energy efficiency is widely acknowledged, it remains a challenge to exploit its potential. The main barriers to the adoption of economically attractive and socially desirable energy efficiency measures (EEM)—i.e., of concrete technical measures (e.g., LED lighting) or organisational measures (e.g., "good housekeeping")—are the presence of market failures, behavioural anomalies and other factors [14–21]. More efforts and more effective polices are required also because the rate of energy efficiency improvement is insufficient and seems to have been decreasing in recent years, with further with further setbacks due to the Covid-19 pandemic [1,2]). There are a number of policy options to promote energy efficiency, for example, compulsory energy audits, labelling, increased energy taxation, differentiated product taxation (bonus malus approaches) and enhanced implementation of minimum energy performance standards. The present review paper aims to answer the questions of whether energy efficiency programmes (EEP) are a suitable way to promote energy efficiency improvements and whether policy makers should more actively make use of EEPs.

1.1. What Are Energy Efficiency Programmes (EEP)?

EEPs represent a category of policy instruments that incentivize the uptake of energy-efficient solutions. Typically, energy programmes provide financial incentives (subsidies and/or rebates) and services (free-of-charge equipment; free installation of energy efficiency measures) in combination with information and awareness-raising campaigns (e.g., billing disclosure programmes) and/or capacity building (e.g., training for installers, energy managers and other contractors) in order to promote increased use of technological solutions and energy saving behaviour. EEPs aim to reduce the energy needed for the targeted energy services (e.g., lighting, heating or cooling) by increasing the market uptake of more energy efficient products (devices; appliances) and/or by the adoption of more energy-efficient practices (see, e.g., [22,23]). While also falling under the broad category of energy programmes, demand response programmes (DRP) can be seen as a complementary approach to energy efficiency programmes (EEP). EEPs focus on energy savings, whereas DRPs aim to shift the demand load to other time periods in order to better match energy supply and energy demand.

EEPs primarily address the uptake of readily available, commercialised options, and they do not primarily or explicitly aim for indirect effects, e.g., R&D. Today, EEPs are applied to all sectors, from the private to commercial and industrial, and in principle, to all types of energy carriers. Though EEPs are implemented across the globe, the importance given to such policy measures differs across countries.

1.2. Why Re-Analyse the Value of EEPs, and How Can It Be Done?

Energy utilities are operating EEPs in more than 50 jurisdictions around the world, in the context of public policy strategies, implemented by means of energy efficiency obligations or energy efficiency resource standards [24]. However, energy systems and energy policies differ across locations and they evolve, calling for continual assessment of a chosen policy mix. Robust data are scarce and become available only occasionally—

when they do, they offer new opportunities for critical assessment. While Switzerland has influenced energy policy in other countries—for example with its energy efficiency networks [25] or the European Energy Award [26] that was initially a Swiss scheme)—the Swiss experience with EEPs is hardly present in the scientific literature. The present paper closes this gap by means of a critical review for Switzerland, while putting the insights gained into the context of other countries and drawing policy conclusions.

2. Materials and Methods

The present review paper is based on reports and peer-reviewed scientific papers. We make use of both qualitative and quantitative information serving to answer the research questions specified above. Given the importance of cost-effectiveness as a criterion when evaluating EEPs, we extracted relevant data from the reviewed studies and made them comparable using the parameters/variables defined in Figure 1 and Table 1. The general equation of levelised cost is given in the top part of Table 1. The lower sections of Table 1 present the levelised programme cost of saved energy (*LPC*, as an indicator for the leverage effect of funds invested in EEPs) and levelised total cost of saved energy (*LTC*, as an indicator for the total cost of the EEP), which is typically dominated by the cost of the technical EEM—in Figure 1 denoted as total costs of energy efficiency Measures, TEEM). We thereby did not correct for the different approaches applied in the various sources when establishing energy savings (compare [27–29]) and costs (for example, we did not harmonize the assumptions made for discount rates and lifetimes; compare also EPA [30]).

Some of the sub-questions raised by this paper are whether sufficient experience has been acquired to date and what the outcomes have been (Section 3); what the strengths and weaknesses of this policy instrument are; how one should assess EEPs in a broader context (Section 4); and finally, which conclusions to draw for policy makers, policy analysts and researchers (Section 5).
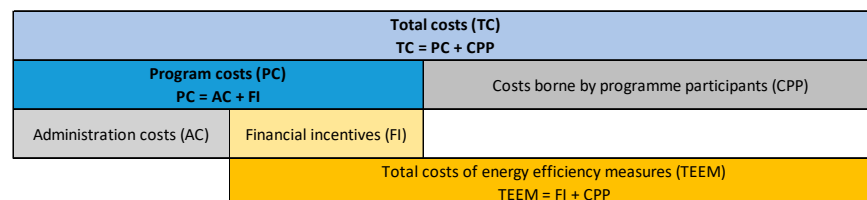
Figure 1. Types of costs considered when evaluating energy efficiency programmes (EEPs).

Table 1. Levelised cost indicators used for the evaluation of EEPs.

Indicators	Ref.
Levelized cost of Saved Energy $$Levelized\ cost = \frac{Invest \cdot AF + Operational\ costs_{annual} - Avoided\ energy\ related\ costs_{annual}}{Energy\ saved_{annual}}$$ *Invest*: Investment costs *AF*: Annuity Factor Operational costs: e.g., costs related to maintenance Avoided energy related costs: e.g., avoided fuel costs due to energy savings	[31]

LPC—**Levelized Program Cost of Saved Energy**
$$Levelized\ Program\ Cost = \frac{Program\ costs}{Energy\ saved_{simple}}$$ $Program\ costs = Costs\ of\ EEP = (Administration\ costs) + (Financial\ incentives)$ $Energy\ saved = (Energy\ consumed\ by\ \textbf{old}\ device) - (Energy\ consumed\ by\ \textbf{new}\ device)$

LTC — **Levelized Total Cost of Saved Energy**			
$Levelized\ Total\ Cost_{simple} = \frac{Total\ costs_{simple}}{Energy\ saved_{simple}}$	Comparison to old	$Total\ costs_{simple} = Total\ costs\ of\ \textbf{new}\ device$ $Energy\ saved = (Energy\ consumed\ by\ \textbf{old}\ device) - (Energy\ consumed\ by\ \textbf{new}\ device)$	[30]
$Levelized\ Total\ Cost_{reference} = \frac{Total\ costs_{reference}}{Energy\ saved_{reference}}$	Comparison to standard	$Total\ costs_{reference} = (Total\ costs\ of\ \textbf{new}\ device) - (Total\ costs\ of\ \textbf{standard}\ device)$ $Energy\ saved_{reference} = (Energy\ consumed\ by\ \textbf{standard}\ device) - (Energy\ consumed\ by\ \textbf{new}\ device)$	
$Levelized\ Total\ Cost_{advanced} = \frac{Total\ costs_{advanced}}{Energy\ saved_{advanced}}$	Comparison to standard plus age	$Total\ costs_{advanced} = (Total\ costs\ of\ \textbf{new}\ device) - (Total\ costs\ of\ \textbf{standard}\ device) + (\textbf{Remaining}\ present\ value\ of\ old\ device)$ a) During lifetime of old device: $Energy\ saved = (Energy\ consumed\ by\ \textbf{old}\ device) - (Energy\ consumed\ by\ \textbf{new}\ device)$ b) After remaining lifetime of old device: $Energy\ saved = (Energy\ consumed\ by\ \textbf{standard}\ device) - (Energy\ consumed\ by\ \textbf{new}\ device)$	[30]

3. Results—Learnings from Existing EEPs

In the past, numerous countries have–not rarely, but sporadically–set up energy efficiency programmes, often partly or even primarily driven by the objective of boosting demand for a certain category of goods (e.g., for boilers and cars in France; Tamma [32]). In their report on market-based instruments for energy efficiency, the IEA reviewed auction-based and obligation schemes for nearly forty countries or federal states, most of which were in the U.S. and Europe [24]. Insights on characteristics and best practices for designing and implementing obligation schemes in a total of more than 30 jurisdictions around the globe were compiled by both the Regulatory Assistance Project [33] and ENSPOL [34], and for Europe by Bertoldi et al. [35], Giraudet and Finon [36] or in the projects ENSMOV [37] and again ENSPOL [38].

The objective of this section is to update and to complement these studies by presenting in somewhat more depth the situation in a limited number of countries. In these, EEPs have been implemented for several years or even decades, for which a suitable legal basis is typically a prerequisite. As will be explained below, this is the case for a number of states in the U.S., and more recently, for some EU member states and for Switzerland. The critical review presented in this paper is based on the learnings from EEPs in these countries.

3.1. Switzerland (CH)

In Switzerland, no EEO scheme is in place at the national level, but there is a national tender-based electricity saving scheme called ProKilowatt. In addition, there are very few EEPs at the cantonal level, though there is one in Geneva. In the following, we first discuss ProKilowatt and then the EEP in the canton of Geneva.

3.1.1. ProKilowatt

The objective of the national tender-based energy saving scheme called ProKilowatt is to support electricity saving measures which could not be implemented without subsidies due to insufficient economic viability. ProKilowatt has been running since 2010, with its total subsidy volume now approaching 50 million CHF per year (SFAO, 2019). These funds originate from a small levy which must not exceed 0.1 CH cents (1 CHF = 1.01 USD = 0.899 EUR in 2019 [39]) per kWh of sold electricity according to the current Swiss Energy Law [40]. ProKilowatt funds two types of instruments, i.e., so-called programmes and projects: The objective of programmes is the large-scale implementation of similar individual electricity saving measures in companies, other organisations (e.g., hospitals, schools) and households, e.g., related to lighting, heating (circulation pumps, HVAC), appliances (e.g., induction ovens, laundry dryers) or compressed air. Projects, on the other hand, address single measures in companies or other organisations, with investment volumes of at least around 70,000 CHF per project. Examples are the replacement of motors in the manufacturing industry and measures related to refrigeration, compressed air, drying and lighting in any sector. The ProKilowatt administration organizes calls for tenders to which EEP operators (e.g., utilities, engineering firms or other types of ESCOs) respond with their proposals for programmes and projects. These are checked and ranked by the ProKilowatt administration in terms of their cost-effectiveness (measured by determining *LPC*, i.e., dividing the requested budget by the estimated electricity savings according to the tender). When preparing the tender, the EEP operator can freely choose the subsidised share of the investment cost. Since the EEP operators do not know how many programmes and projects will be submitted and how cost-effective the competing submissions are, the most rational strategy for them is to request the lowest possible subsidy share and to optimize their cost-effectiveness. According to ProKilowatt rules, the maximum subsidy level is 30% of the investment costs. In order to ensure the competitive character of ProKilowatt, the rules state that the total subsidy volume requested by all programmes and projects should represent at least 120% of the available funds; otherwise, the available budget will be reduced accordingly (i.e., otherwise eligible submissions are not funded). Programmes

have dominated the ProKilowatt portfolio in comparison to projects (by a ratio of 2.5:1 from 2010 to 2016—ratios close to 4:1 were present for 2015 and 2016).

ProKilowatt was recently (March 2017 to June 2018) evaluated by the Swiss Federal Audit Office (SFAO) —Eidgenössische Finanzkontrolle, Contrôle Fédérale des Finances, Controllo Federale delle Finanze, https://www.efk.admin.ch/de/ (accessed on 12 March 2021)—the supreme financial supervisory body of the Swiss Confederation [40]. SFAO's main point of criticism was that ProKilowatt does not correct for free-rider effects when reporting their cost-effectiveness. In policy analysis, the free-rider effect refers to the problem that some beneficiaries benefit from the policy measure, even though they would have acted in the same way or very similarly in the absence of the policy measure. In order to estimate the free-rider effects, SFAO conducted interviews. For projects, SFAO interviewed EEP operators and estimated the free-rider effect at 25–30% ([40], p. 20). For programmes, surveys organised by SFAO among participants indicated free-rider effects of around 50%; surveys among EEP operators indicated only approximately 25% (which SFAO rightly considers to be biased towards overly low values). In conclusion, SFAO considers the true energy savings (after consideration of free-rider effect) of the totality of all programmes and projects to be at least 25% lower than those reported by ProKilowatt. By separating EEP administration costs from financial incentives, SFAO consequently estimated the corrected cost effectiveness (Levelised Programme Cost, *LPC*) at 3.6 CH cents/kWh electricity saved instead of 2.7 CH cents/kWh saved, as reported by ProKilowatt (33% higher). Based on the analysis of case studies, SFAO argues that the electricity savings reported by ProKilowatt may be overestimated by also assuming overly long remaining lifetimes of incumbent technologies, disregarding the autonomous technological progress and by instead assuming an overly simplified reference scenario (current ProKilowatt rules aim to avoid overestimation by considering only 75% of the electricity savings established as the difference between the old and new technology). SFAO does not quantify the resulting error in ProKilowatt's electricity savings, but argues that empirically derived reference values should be developed in future for key technologies. These should be based on sample measurements, and they should account for autonomous technological progress in order to better assess whether the condition of additionality is met.

As part of the cost analysis, SFAO also estimated the levelised total cost of saved energy, thereby assuming an interest/discount rate of 5% p.a. They established values of 17 CH cents per saved kWh for the indicator LTC_{simple} (based on total costs) and 12 CH cents/kWh for the indicator $LTC_{reference}$ (based on total costs minus costs of standard device; see Table 1; both values exclude subsidies; the former is based on 348 projects and the latter is based on case studies). In view of SFAO's arguments regarding the overestimation of electricity savings by ProKilowatt (as mentioned above: overly long remaining lifetimes, neglect of autonomous technological progress and overly simplified reference scenarios), these LTC values may be considered as underestimated. On the other hand, they do not consider spillover effects (see also below).

SFAO estimated that ProKilowatt can contribute 15% (140 kWh per capita and per year after correction for free-rider effects) of the 2035 energy savings target according to the Swiss Energy Strategy (950 kWh/cap/year) and that the contribution of ProKilowatt is hence significant (while being far from sufficient in view of need for other policy measures to realize the remaining 85%). It can be concluded that SFAO overall considers ProKilowatt to be well designed and basically expedient.
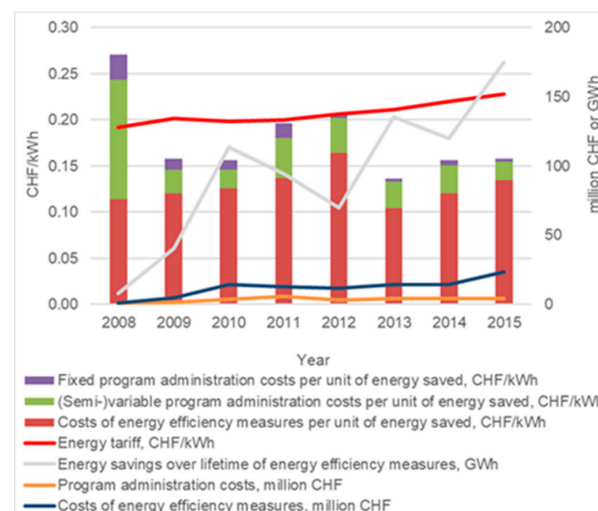
3.1.2. EEP in the Canton of Geneva

While, as mentioned above, there are very few EEPs at the cantonal level, the particular context in Geneva has resulted in a similar scheme of EEOs as in the EU: since the utility company serving the canton of Geneva belongs to the canton and the municipalities, the local cantonal government was in a position to request the utility company to save 150 GWh p.a. of electricity by the end of 2013 (150 GWh—in actual fact achieved over

the course of 2017— is equivalent to 5% of the original electricity demand) [41,42]. This type of agreement was relatively easy to settle because the Swiss energy sector is so far only partly liberalised (for large energy consumers) and because, unlike to other cantons, only one utility serves this canton. Contrary to EEOs in the EU, the operation of the EEPs (called éco21) in Geneva is not warranted for the longer-term because of insecure financing. Guaranteed financing would require a national approach with involvement of the regulatory authority for the electricity sector (i.e., ElCom in Switzerland), thereby providing a legal basis for financing EEPs by means of a levy paid by utility customers (the cost recovery mechanism is therefore sometimes described as ratepayer-funded). Operating EEPs costs money, even if the programmes are cost-effective (this means that they save more money than they cost). The reason why EEPs cost money is that investment costs for energy efficient technologies are higher than for conventional technologies—calling for subsidies—, and informing energy users about the opportunities and managing the subsidies both imply expenditures —so-called programme costs). Since the Swiss Energy Strategy 2050 foresees a gradual transition from a subsidy-based system to market-based instruments ([43], p. 5), there has so far not been enough support for a national approach in this direction.

In the past decade, electricity demand in the canton of Geneva levelled off and started to decrease. A part of this decrease was related to the EEP éco21. Using bottom-up approaches (deemed savings, treatment method, etc.) the electricity savings were estimated at 175 GWh in 2018 (as of 2008), which is equivalent to 6.2% of the canton's total electricity demand in 2018 according to Cabrera et al. [44]. This value of 175 GWh represents the effect of all energy efficiency measures implemented in 2018 and in earlier years as long as these are still effective in 2018. The total does not include future energy savings caused by the measures which have already been implemented.

To our knowledge, cost-effectiveness data on utility-operated EEPs in Switzerland are publicly available only for Geneva. The levelised programme cost of saved energy (*LPC*) amounts to around 4 CH cents/kWh (see below Table 2). For the levelised total cost of saved energy (*LTC*), data for individual sub-programmes run in Geneva were published by Yushchenko and Patel [45]. For the entire Genevan EEP portfolio, values representing the indicator LTC_{simple} (see Table 1) are displayed in Figure 2 (see bars), which shows fluctuating values in the range of 13.5 and approximately 20 CH cents/kWh of electricity (even 27 CH cents/kWh in the first year); in the last two years, LTC_{simple} amounted to nearly 16 CH cents/kWh (chosen value for Table 2; see below).

Figure 2. EEP in the Swiss canton of Geneva (éco21, electricity savings only): Energy savings and expenditure on energy efficiency measures and program administration in total and per unit of energy saved (results of updated analysis formerly published by Yushchenko et al., 2017 [45] and Freyre, 2019 [46]) (1 CHF = 1.01 USD = 0.899 EUR in 2019; OFX, 2020).

Table 2. A summary of the cost-effectiveness data from programmes in U.S.A., the EU and Switzerland (values for Switzerland concern electricity saving programmes only, while fuel savings are included in the values reported for the other countries).

Country	Sector	Scope	Year	Unit	Levelized Program Cost of Saved Energy (*LPC*)	Levelized Total Cost of Saved Energy (*LTC*)	Data Source
CH	Resid./Comm./Ind.	National (ProKilowatt)	2010–2016	CH cents/kWh	3.6	17 (LTC_{simple}), 12 ($LTC_{reference}$)	[40]
	Resid./Comm./Ind.	Local (Geneva)	2015	CH cents/kWh	4 *	16 (LTC_{simple}) **	updated calculations
USA	Residential	National	2015	US cents/kWh	3.3	n/a	[47]
	Residential	38 frontrunner states	2015	US cents/kWh	4.3	n/a	[47]
	Comm./Ind.	National	2015	US cents/kWh	2.2	n/a	[47]
EU-Italy	All (esp. Industry & Bldgs)	National	2017	EUR cents/kWh	1.1	n/a	[48]
EU-Denmark	Ind./Resid./Services	National	n/a	EUR cents/kWh	~1.0	2.9	based on [49]

Exchanges rate: 1 EUR = 1.12 USD in 2019 [39]; 1 DKK (Danish crown) = 0.134 EUR = 0.150 USD in 2019 [39]; 1 CHF = 1.01 USD = 0.899 EUR in 2019 [39]. * For electricity-saving programmes only (as is the case for ProKilowatt); the respective value including fuel savings amounts to 3 CH cents/kWh. ** For electricity-saving programmes only (as is the case for ProKilowatt); the respective value including fuel savings amounts to 12 CH cents/kWh.

3.2. U.S.A.

In the U.S., utilities and a small number of non-utility parties have been operating EEPs since the energy crisis in the 1970s, making it the country with arguably the longest experience with this policy measure ([34,50,51]. As in most other countries, the costs incurred by running EEPs are generally covered by a slight surcharge paid by utility customers [51,52]. Since the additional cost imposed on utility customers needs to be justified, EEPs have been evaluated on an annual basis ever since their existence in the U.S.

These evaluations include the assessment of the programme's cost-effectiveness by means of the concept of levelized programme cost of saved energy (*LPC*; see Table 1). As shown by Cho et al. [47], the average *LPC* of EEPs in the residential sector at the national level was 3.3 U.S. cents/kWh in 2015, while the respective value for 38 frontrunners with more ambitious EEPs amounted to 4.3 U.S. cents/kWh. For the commercial and industrial sectors, the U.S. average (savings-weighted) *LPC* equalled 2.2 U.S. cents/kWh in 2015 [47]. These values are low compared to the cost of electricity supply and the wholesale market price (see also Section 3.4). In contrast, the values of the indicator *LTC* (levelized total cost of saved energy) can clearly exceed those of the wholesale market price of energy and *LPC* (see below, Section 3.4).

In spite of the continuous existence of EEPs for nearly 50 years in the U.S., the cost-effectiveness analyses indicate that there is no shortage of economically attractive EE offerings. While the conditions in the U.S. differ from other countries, it is nevertheless plausible that innovation and changes on the demand side (e.g., new products, higher diffusion and increased comfort) have resulted in a continuous flow of EEMs which are at the threshold of cost-effectiveness and which therefore lend themselves to support by EEPs. Given the large unexploited technical potential, it seems reasonable to assume that this will continue to be the case at least for the medium term, and given the broad comparability of energy technology applied across the globe (e.g., for household appliances, industrial equipment and building technology), this finding is very likely to be transferrable to other countries too.

In approximately half of U.S. states, utilities are obligated to offer energy efficiency programmes [47], and most of them have introduced binding energy efficiency targets known in the United States as energy efficiency resource standards, or EERS [53]. In U.S. states with EEPs, per-capita expenditure on EEPs increased from around 5 USD/cap in 2006 to 20 USD/cap in 2015, with the highest spending levels being close to or beyond 80 USD/cap in 2015 (in Rhode Island, Massachusetts and Vermont) [47].

While the introduction and expansion of EEPs in the U.S. can be considered a success story, it is important to note that these EEPs were typically not implemented by the utilities as a voluntary act. Instead, it was a prerequisite that a suitable regulatory framework was in place which obligated the utilities directly or indirectly to implement EEMs [51].

3.3. EU

This concept of obligating the utilities is a special form of EEP which, in Europe, is referred to as an energy efficiency obligation (EEO) scheme (this expression is more commonly used in the EU than in the U.S.). In the 1990s and early 2000s, four countries (Denmark, France, Great Britain and Italy) followed the U.S. by implementing EEO schemes. While the U.S. schemes had been (and still are) operated in highly regulated markets, their implementations in Great Britain and France and later on in Italy and Denmark demonstrated their applicability in liberalised markets [54,55].

The EEOs were then encouraged in the EU Energy Services Directive (2006/32/EC; [56]) and more strongly in the EU Energy Efficiency Directive (2012/27/EU), which includes as one of its key elements, Article 7 on the implementation of national energy efficiency obligation (EEO) schemes [57]. It establishes that Member States shall establish an EEOS and/or make use of alternative measures, to achieve a minimum amount of energy savings over a given obligation period. For the period 2014 until 2020, the minimum EE target was set in terms of new annual energy savings equivalent to 1.5% of the annual sales of energy

to the final customers. In practice, a range of options was made possible for Member States to reduce their targets down in most cases to about 0.75%/year. The 2018 amendment to the Energy Efficiency Directive [7] sets the minimum end-use energy savings to at least 0.8% of final energy consumption for the period 2021 to 2030, to be reached by EEO schemes, alternative policy measures or both. In principle, the savings objective for EEOs applies to all types of energy carriers transformed, distributed and transmitted; this concerns primarily electricity and gas, but likewise district heating and cooling, heating oil, fuels for transport and sometimes biomass (e.g., in Austria). When implementing an EEOS, Member States are entitled not to impose EEOs on small utilities in order to avoid an unreasonable administrative burden. In 2020, EEOs were implemented in 16 countries that altogether represent 58% of the total final energy demand of EU28 [58]. Four Member States relied fully on their EEOS to meet their target for the Article 7 EED. Twelve Member States combined an EEO scheme with alternative EEMs; and the remainder (12 Member States) exclusively chose alternative EEMs. For the forerunners Great Britain, France, Italy and Denmark, and for Austria—and for comparison, also for Vermont and California— Rosenow and Bayer [28] published in 2016 performance indicators of the respective EEO schemes, a summary of which is given in Appendix A. For the reporting periods covered (all falling into the timespan from 2006 to 2015), the weighted cost of the EEO schemes in the five EU countries amounted to 0.4 to 1.1 EUR cents (1 EUR = 1.112 CHF = 1.123 USD (0.899 EUR = 1 CHF = 1.01 USD in 2019 [39]) per kWh. That cost, which can be considered as a levelised programme cost (*LPC*) of saved energy for the entire EEO scheme, is rather low, also compared to the U.S. It should, however, be considered that, depending on the practical rules of the schemes (e.g., eligibility of action types, baselines used to calculate the energy savings), the saving rates can correspond to different ambition levels and may be characterised by different levels of additionality or free-riders. In practice, there are a number of other reasons why the performance indicators across countries are not directly comparable [59], with the available data not allowing one to assess the key indicators in a harmonised way.

While information on the effectiveness of EEOs in more recent years is still scarce and scattered, we compiled the latest available data for Denmark and Italy which are explained in some detail in Appendices B and C.

3.4. Summary

Table 2 shows the levelised cost of EEP in Switzerland from the perspective of the respective values for the U.S., Italy and Denmark. The values should not be directly compared due to the somewhat different ways of quantifying energy savings (e.g., due to different definitions of the reference trajectory), different ambition levels (e.g., across leaders and laggards among the EEPs in the U.S.), different policy scopes (e.g., the values for Switzerland refer to electricity savings, while the values for the other countries include fuel savings) and other reasons [59]. Nevertheless, it can be concluded that the values for *LPC* range between approximately 1 and 4 (U.S. or CH) cents per kWh electricity saved. *LPC* values are generally lower than the wholesale price of electricity (5 CH cents per kWh; this value was assumed by the Swiss Confederation, Revision of Energy Act (2020) [60] as well; 1 U.S. cent and 1 CH cent are roughly equal). This is one important reason why EEPs have become a strategic component of so-called integrated resource planning ("integrated resource planning" is a technical term which is commonly used in the U.S. to describe the process leading to a long-term utility plan for matching the energy demand projected for a given area by both supply-side resources and demand-side resources, with the latter consisting of energy efficiency and load management [9,61]). It also explains why energy efficiency is referred to as "low-cost, low risk resource" in the U.S. [62] and why the "energy-efficiency-first principle" is pursued in the EU [6,63]. However, it must be kept in mind that the indicator *LPC* only represents the leverage effect of an EEP, i.e., the ratio of the programme cost to the energy savings (see Figure 1 and Table 1).

Less data are available for *LTC*, but the accessible sources for Switzerland indicate a range of values between 12 and 17 CH cents per kWh electricity saved. Values for the indicator *LTC* are hence larger than for *LPC* by a factor 3 to 4, and they clearly exceed the wholesale price of electricity.

4. Discussion

Based on insights from the literature and from practical experience, we compiled the main strengths of EEPs and their main drawbacks, which are summarised in Table 3 and described in more detail in Appendix D.

Table 3. Overview of the strengths and drawbacks of EEPs.

Strengths	Drawbacks
Cost-effectiveness	**Free-rider effect**
- EEPs allow one to save energy at lower cost than producing it. - This statement refers to Levelised Programme Cost of Saved Energy (*LPC*), and not to Levelised Total Cost of saved energy (*LTC*).	- Is possibly the most widely quoted drawback of EEPs
Reducing upfront cost	**Continuous adaption to markets and legislation**
- Subsidies, rebates etc. help to overcome barrier of higher investment costs of EE technologies).	- Careful tracking of market and product trends and continuous EEP adaptation required to ensure effectiveness
Attracting attention and creating awareness	**Possible lack of visibility for market actors**
- EEPs attract attention of households and companies. - Higher awareness contributes to accelerated market uptake. - EEPs ensure a minimum market volume, thereby incentivizing market actors to develop new business models and offers.	- Many EEPs are long-lasting, but some have been terminated (e.g., Danish EEOS at end of 2020). More generally, targets and rules might change significantly over time, creating uncertainty for market actors. **Metering energy efficiency is challenging** - Quantifying the energy efficiency gains is more demanding than metering renewable energy.
Providing guidance to energy users	**Conflict of interest for utilities**
- Multitude and heterogeneity of EE technologies is confusing for consumers. - Information provided by impartial body facilitates decision making.	- For EEPs and EEOs operated by utilities in largely liberalised energy markets (can be addressed by decoupling policies)
Enhanced market diffusion and market transformation	**Risk of fraud**
- EEPs can catalyze market diffusion and market transformation. - Familiarisation with new EE technology within EEP may enhance implementation elsewhere (spillover effect).	- Presence of large budgets entails risk of fraud - The large number of actions supported can make it difficult to control their quality or compliance.
Low indirect environmental and health impacts	**Fuel poverty**
- In general, less environmental and health impacts than conventional technologies and renewables.	- EEP may exacerbate fuel poverty when their costs are recovered through the energy prices (as for most EEOs), unless special attention is paid to low-income households.

Table 3. *Cont.*

Strengths	Drawbacks
Local implementation	**Upfront cost to set up the scheme**
- Applicable at smaller scale, e.g., at the level of provinces or cantons	- -EEPs often require significant efforts to establish (e.g., for the monitoring & verification system), which are only worthwhile if the scheme is meant to be long-lasting.
High level of acceptance	
- Valid especially for EEPs implying subsidies, rebates etc.; less so for EEOs.	
Combinability with tradable White Certificates (WhC)	**Focus on short-term effectiveness**
- Combination of EEPs with WhC can be effective.	- Some EEPs (WhC in particular) might trigger the easiest actions, but possibly creating lock-in effects (e.g., partial insulation instead of deep retrofit).
Economies of scale	
- E.g. lower price by large-volume purchases of energy-efficient appliances	
Green growth and positive employment effects	
- Positive impacts on GDP and employment to be expected	
Link to sufficiency strategies	
- Inclusion of sufficiency in EEPs as future development option	

In the following, we discuss the factors which are most decisive for the overall assessment of EEPs.

The free-rider effect and the high administrative burden discussed above are accompanied by a number of disadvantages, but arguably the most important ones are their negative impacts on the policy measure's effectiveness and its cost-effectiveness. Therefore, if in spite of the presence of free-rider effects and the cost of programme administration, the effectiveness and the cost-effectiveness of an EEP are sufficiently high, there would be strong arguments in favour of its implementation. The question is, therefore, whether that is the case. One way of answering this question is to compare quantitative information on the cost-effectiveness, while another is to discuss the effectiveness in a conceptual manner. In the following, we subsequently apply both lines of argumentation (a and b).

(a) As presented above, the percentage of the free-rider effect found in the literature varies widely. Generally speaking, it seems unlikely that an EEP with a free-rider effect clearly beyond 50% is economically viable (see also below). EEP operators should ensure minimal free-rider effects, presumably below or well below 50%. Possible reasons for accepting a certain level of free-rider effects and the related additional costs may be the willingness to support (i) protagonists who help promoting the energy transition, (ii) companies as a somewhat hidden form of innovation support (unless conflicting with other regulations) or (iii) low-income households as a contribution to social policy. To be more specific, cost-effectiveness data need to be compared. As explained in Section 2, this can be done using the indicators levelised programme cost of saved energy (*LPC*) and levelised total cost of saved energy (*LTC*). We argue that the former—representing the utility's perspective—is an overly partial view. The latter, *LTC*, is closer to the cost of society (without, however, considering indirect effects) and is therefore our indicator of choice. As the basis for our discussion based on *LTC*, we revert to the Swiss EEP schemes. According

to Table 2 in Section 3, the *LTC* values amount to approximately 15 CH cents/kWh saved (in more detail, ranging from 12 to 17 CH cents/kWh depending on the source and the indicator choice). These values can be compared to the levelised cost of energy supply, and in particular, that of renewable energy supply (to ensure coherence with the Swiss Energy Strategy 2050). We hereby follow the approach chosen by SFAO which compiled in their study the levelised cost of energy supply shown in Table 4. This comparison indicates that *LTC* values of EEP are typically lower compared to the levelised cost of renewable energy supply in Switzerland with the exception of large hydropower, for which the low end of cost of 5–6 (2–10) CH cents/kWh represents generation in partially amortised plants. Future costs of new plants are reported to gradually rise to higher values. According to Bauer et al. [64], a total of 1.6 TWh/a can be generated at a cost below 15 CH cents/kWh (this value excludes consideration of the requirements related to the Water Protection Act). In addition, large to very large photovoltaic plants ($\geq$100 kW$_{peak}$ and $\geq$1000 kW$_{peak}$ (see Table 4) allow one to generate electricity at lower cost than EEPs. Here, the comparison is complicated by the fact that intermittent renewable energy supply technologies do not supply electricity all the time, whereas EE technologies reduce the electricity demand when they are operated, and many contribute to a reduction of peak load. A fair analysis would consider the temporal patterns and would need to consider back-up or energy storage technologies for intermittent renewable energy supply [65] and renewables, which are not always available (e.g., small hydropower), hence resulting in higher supply cost. This would make EEPs more competitive than the lowest values for PVs indicate. Overall, it can be concluded that the cost of EEPs is generally well within the cost ranges that can be expected for renewable energy in Switzerland. We herewith draw a different conclusion than SFAO, which considers the differences in cost effectiveness between EE and renewable energy to be substantial and therefore argues in favour of more flexibility in funding between these two domains [40]. However, if the reported levelised cost values for EEPs are underestimated as a consequence of underestimated free-rider effects, this would clearly reduce the attractiveness of EEPs.

Table 4. Levelised cost of renewable electricity supply in Switzerland [64].

Renewable Electricity Source		Levelized Cost CH cents/kWh	Comment
	Large hydropower	7–30	includes partially amortized plants for which a range of 5–6 (2–10) CH cents/kWh is reported
	Small hydropower	12–28	excluding electr. generation in existing drinking water pipes for which higher values are reported
	Wind power in CH	15–20	-
PV	6 kW$_{peak}$	26	-
	10 kW$_{peak}$	23	-
	30 kW$_{peak}$	18	-
	100 kW$_{peak}$	12	-
	1000 kW$_{peak}$	10	-
	Biomass (combustion of wood)	18–36	-
	Industrial and agricultural biogas	20–49	-

(b) We now proceed to the conceptual, qualitative discussion on the cost-effectiveness. Many authors consider EEPs to be less effective and less cost-effective than alternative policy measures such as taxes [66]. At the same time, there is widespread consensus about the inelasticity of energy demand. By analogy, stricter regulations for existing buildings (e.g., stricter building codes) may be more effective than EEPs. However, as for carbon taxes, the limited acceptability by private consumers and companies also poses limits on strongly tightened building codes. Against this background, Labandeira and Linares [67] concluded that carbon pricing at the level needed to compensate the externalities is not feasible, thereby calling for "second-best" instruments. In combination with the multiple

objectives pursued by energy policy (e.g., different sectors, different product lifetimes, different decision making criteria etc.), this explains why there is wide agreement that a combination of several policy measures is needed (see, e.g., [68]). In such a portfolio, EEPs could be included because they enjoy a high level of acceptance and they help to overcome specific barriers (e.g., awareness/information, technology choice and high upfront cost).

In the literature and as evidenced by the considerations above, major attention is being paid to the free-rider effect, whereas this is by far not the case for its counterpart, the spillover effect. In the context of the present article, the spillover effect represents the indirect promotion of EE technologies as a consequence of an EEP, e.g., by installation companies which start offering it (supply side) or by customers who request it (demand side; for example, in some locations, e.g., Zurich, public buildings such as schools, hospitals and municipal buildings have been preferentially constructed according to the low-energy building code "Minergie"). The spillover effect is an essential and highly desired mechanism in the market transformation towards clearly more energy efficient products and services. It should therefore actually be considered on equal footing with free-rider effects. A possible reason for the lower level of attention paid to the spillover effect is that it may be even more challenging to quantify. This may be partly related to the fact that spillovers imply longer market transformation processes, with numerous other influencing factors playing roles (e.g., R&D and innovation policy, pre-existing knowledge base, etc.), whereas free-riding reduces the cost-effectiveness immediately.

The line between free-riding and effective promotion is thin, indicating how challenging diligent programme operation is: An EEP should incentivize the market transformation at adequate cost (see below), but it should avoid subsidising a transformation process that would occur autonomously, since this would simply result in more free-riders and lower cost-effectiveness. On the other hand, it is often not clear at early stages of market diffusion and even in more advanced stages of the market transformation process whether any dominating autonomous trend is present. Moreover, the cost-effectiveness may strongly depend on the local circumstances. For example, while in general, LED lighting can be considered cost-effective today, this may not be the case in high halls requiring a movable scaffold for replacement; economic viability may also depend on whether only the light source (lamp) can be exchanged or whether the luminaire needs to be replaced too. It is at the programme operator's discretion to make this type of decision. It also needs to be considered that incumbent technologies which have been prohibited in the past years or which have been outpaced by new technologies in economic terms may remain in use for long periods of time if no dedicated policy is implemented.

Programme operators and/or policy makers will also have to decide about the ambition level which influences the cost-effectiveness:

(i)　If the focus is on lowest possible cost (as is the case for competitive tendering under the ProKilowatt programme), only so-called "low-hanging fruit" is picked (the most opportunistic approach); this programme design may come along with a relatively high level of free-riding.

(ii)　EEPs may have highest effect for technologies with medium cost-effectiveness where the more ample use of these technologies as a consequence of the EEPs can help to bring down the investment costs.

(iii)　EEPs for measures with very high investment costs and typically long payback times can rapidly become very expensive. It is possible that such measures will nevertheless need to be implemented in order to reach ambitious energy and climate goals (as defined in CH and the EU). In this case, implementation may have to be limited to certain buildings or sectors (e.g., private sector). The combination with other policy measures (e.g., a large green fund) may be another possibility in order to realize deeper energy efficiency improvements than have so far been achieved with known EEPs.

These considerations are actually not only relevant for EEPs, but rather for EE technologies in general; they nevertheless complicate the assessment of EEPs, since the

cost-effectiveness of EEPs will differ partly as a function of the ambition level; this can then lead to apparently conflicting findings which may ultimately act as a barrier to EEP implementation.

EEPs may also differ in terms of temporal scope and continuity. For example, projects and programmes implemented in the context of ProKilowatt are funded for a maximum operating period of three years and their spatial coverage is subject to the programme operator's choices. In contrast, the oldest parts of the EEP "éco21" have been operated in the canton of Geneva since 2009 and can be expected to have allowed Geneva to achieve higher levels of market transition (albeit possibly at higher cost).

The funding level (which is linked to the ambition level and the free-rider effect) is also a matter of available funds. Ratepayers ultimately finance the programme, and the size of the budget is a political decision which may be made at the national level (e.g., up to 0.1 CH cent/kWh in Switzerland for the ProKilowatt programme according to the Swiss Energy Law [69]) or at the local level (e.g., 0.6 CH cents/kWh up to 1.0 CH cent in the Swiss canton of Vaud and in a number of cities, e.g., Lausanne), albeit with differences in legal certainty.

As mentioned above, EEPs offer, apart from energy savings, a number of environmental, health-related and social co-benefits, also termed "multiple benefits." Examples are greenhouse gas (GHG) emission abatement, reduction of local air pollution, alleviation of energy poverty, innovation, competitiveness and productivity and energy security and macroeconomic benefits (employment and GDP; see above). Since these are challenging to quantify (some methods are being developed; see, e.g., [70]) they are most frequently discussed in qualitative terms or discussed individually (e.g., [28,29]). Instead, they could be expressed in terms of avoided external costs, which would require an agreement about the method to apply (compare [71–73]) and about the assumptions underlying the reference development without EEP.

It is also important to note that EEPs are not necessarily easily accepted within the implementing utility. For decades the mindset of utilities has been dominated by a culture of growth and expansion, which is common to our economy and society as a whole. From the perspective of the utility, an EEP can be seen as a business model of de-growth, which can induce cultural clashes and incoherent strategies within utilities (compare, e.g., [52]).

The acceptance of EEPs partly depends on the credibility of the programme operators, the complexity of the programmes and the effort to be made by participants. Some competition may be helpful while too many actors and programmes create confusion among potential participants and can be counter-productive, hence calling for some governance about the distribution of tasks and of the roles of the various stakeholders.

This also indicates that implementing an EEP raises questions of multi-level governance, e.g., about the roles of the grid operator, the energy suppliers and the authorities which depend, inter alia, on the level of (de)regulation, the utility structure and their scale and the reputation of the actors.

5. Conclusions

In the U.S., utilities have been implementing EEPs for more than four decades, whereas the experience with utility-operated EEPs in Europe is mostly limited to one or two decades. Nevertheless, valuable insights can be gained from countries which have implemented this policy instrument rather recently.

Like all other policy measures, EEPs have advantages and disadvantages. An important argument in favour of EEPs is that they are characterised by high cost effectiveness, with the cost of saving energy use being cheaper than its supply. However, this partly depends on the chosen metric and the country context. For Switzerland, the finding was confirmed for the metric levelised programme cost of saved energy (*LPC*), whereas the available values for the indicator levelised total cost of saved energy (*LTC*) indicate a comparable cost level for saving energy as for generating renewable energy. In case the reported levelised cost values for EEPs are underestimated as a consequence of underestimated

free-rider effects (see also below) the attractiveness of EEPs would be lower. EEPs can be effective and cost-effective even many decades after their introduction (e.g., in the U.S.) and even in the case of a high ambition level (e.g., in Denmark) but that calls for very good management and cost awareness. So far, EEPs have been implemented with the objective of leveraging low-cost energy efficiency potentials while more expensive measures (e.g., deep retrofitting of building envelope) have to date been addressed by other policies (building standards; subsidies—in Switzerland, the Building Programme—*Gebäudeprogramm, Programme Bâtiment*—is financed from the CO_2 levy and hence follows the same approach as an EEP.; in other countries this type of subsidies are financed from other sources —e.g., general tax revenue).

EEPs can help to overcome the investment barrier of high upfront cost. They also help to inform key stakeholders about key EE technologies, which can facilitate accelerated market uptake and spillover benefits. Some further strengths of EEPs include, inter alia, the co-benefits triggered by improved energy efficiency (see, e.g., [70]), the possibility of implementation at small scale and economies of scale when expanding the EEP. Possibly the most serious drawback is the free-rider effect (which typically increases the costs and deteriorates the cost effectiveness). Further challenges are the very high level of diligence needed in programme operation, the demanding nature of quantifying energy efficiency gains (e.g., compared to monitoring of renewable energy production) and the conflict of interest in the case of EEPs operated by utilities in largely liberalised energy markets without adequate legal framework.

Key conclusions are:

- Not unexpectedly, EEPs cannot serve as "silver bullets"; i.e., they should be seen as part of a portfolio of policy measures (see, e.g., [74,75]).
- At the same time, EEPs do allow one to address market failures, which are not or are hardly targeted by other policy instruments, particularly lack of information, lack of understanding and inelastic energy demand. EEPs help to accelerate the market uptake of energy efficient products and to renew the stock containing inefficient products and they incentivize the adoption of more energy-efficient practices without increasing taxes or the public dept.
- An EEP is a policy measure that enjoys a high level of acceptance. For these reasons it can, in principle, be recommended as element of an effective energy policy portfolio.
- When taking advantage of the fact that EEPs can be implemented at variable scales, it is recommended to gradually expand the activities, either as centralised policy (centred around a green national fund) or as decentralised activities with separate funding and management structures, while still collaborating (e.g., exchange of protocols, joint procurement) in order to speed up the learning, to make use of economies of scale and to reach more ambitious policy goals.
- In any case, an adequate legal setting is required for EEPs to successfully operate. EEP forms endowed with higher levels of empowerment are generally more effective. This implies mandatory energy efficiency savings targets (as realised for EEOs) in combination with programme cost recovery and possibly earnings opportunities tied to performance toward savings targets. As a further requirement, especially for large EEPs, the organisation acting as project operator must be trusted for its expertise and must be reputed for its integrity.

To conclude, EEPs programmes are very likely to be needed for the time being, at least as long as (i) EE and climate objectives have not been reached, (ii) barriers to EE continue to persist and (iii) the overall level of acceptance of EEPs is high. They should, however, be designed to be consistent with other policy instruments, and ideally, to operate in synergy with them. While traditionally EEPs have been implemented to "pick the low-hanging fruit," urgent energy and climate policy goals call for a deeper understanding whether and to what extent this policy instrument can be further developed in order to exploit more costly EE potentials and thereby bring about more significant change.

Future research could also elaborate criteria and indicators (e.g., building on projects such as Odyssee-MURE [76], ENSPOL [34,38] and EPATEE [77]), allowing one to establish whether or not the conditions for successful EEPs are met in a given country, province or canton. It should also be better understood how much emphasis to put on EEPs in a policy mix, which (sub)sectors and applications should develop EEPs and whether national (or even European) reference technology should be developed for expected energy savings (deemed savings) and the related costs, with the objective of both promoting EEPs and bringing down the cost of EE technologies. Further research could deal with strategies for minimising the free-rider effects and maximising the spillover dynamics, and with methods for monitoring, further optimising the operation of EEPs and the inclusion of sufficiency strategies in EEPs.

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Appendix A Performance Indicators of Energy Efficiency Obligation (EEO) Schemes

The data below originate from Rosenow and Bayer (2016) [28].

Table A1. Performance Indicators of Energy Efficiency Obligation (EEO) Schemes in five EU Countries (and Vermont and California for Comparison).

Country/Time Period		Energy Company Costs (Euros/capita/y) *	Weighted Average EEO Scheme Costs of Lifetime Energy Savings (euro cents/kWh)	Incremental Annual Savings Rate Compared to Final Energy Consumption	Comment
United Kingdom	2008–2012	16	1.1	0.5%	Residential sector Energy suppliers (electricity and gas)
France	2011–2014	6	0.4 [#]	0.4%	All sectors except for facilities subject to ETS Energy suppliers (elec., gas, LPG, district heating, transport fuels)
Denmark	2015	33	0.5	4.2%	All sectors except transport Energy Distributors

Table A1. *Cont.*

Country/Time Period		Energy Company Costs (Euros/capita/y) *	Weighted Average EEO Scheme Costs of Lifetime Energy Savings (euro cents/kWh)	Incremental Annual Savings Rate Compared to Final Energy Consumption	Comment
Italy	2006–2014	12	0.7	0.4%	All sectors Energy Distributors
Austria	2015	11	0.5	0.9%	All sectors but mandatory minimum share for residential sector (40%)
Vermont	2012–2014	62	3.2 **	1.7%	Residential, commercial, industrial, agricultural Energy distributors (elec. and gas)
California	2010–2012	19	2.1 *	1.0%	Residential, commercial, industrial, agricultural

[#] combinable with tax rebate scheme; * preliminary; ** for 2009–2011

Appendix B EEO Scheme in Italy

Italy introduced an EEO system which takes the form of a White Certificates (WhC) scheme requiring electricity and gas distributors with more than 50,000 customers to implement energy efficiency measures [77,78]. Introduced in 2004 and confirmed by the National Energy Strategy 2017 [79], it makes the energy savings available as tradable good, thereby increasing the instrument's flexibility. Nearly 60% of the savings are related to natural gas use ("tipo II"), and approximately 20% each concern electricity use ("tipo I") and other types of fuels ("tipo III") [80]. The savings are primarily realised in the industry sector (58%), followed by the built environment (38%; [80], Table 3.2). The energy efficiency target related to White Certificates amounted to 4.3 Mtoe of final energy per year in 2020 (from actions over 2014–2020) or 16.0 Mtoe cumulated over 2014–2020 (it is not straightforward to follow the evolution of savings in the various publications addressing it, with the main reasons being different time periods, different reference trajectories, deviations from the target in some years, usage of a correction factor—tau factor, introduced in 2011 and elimination some years later—and differences between certified savings and generated savings) (NEEAP 2014, quoted in [78]). This is equivalent to 60% p.a. of the national energy efficiency target under Article 7 of the EED [57,78]. The actual contribution of White Certificates to the overall energy efficiency target amounted to approximately 40% in the 2014–2020 period [81].

The value of the White Certificates varied from around 50 to 100 EUR (1 EUR = 1.12 USD in 2019 [39]) per tonne of oil equivalent (toe) in the period 2006 to 2015 to around 300 EUR/toe in recent years as a consequence of stricter targets (ENEA, 2019, p.49; EPATEE Italy; in 2017–2018 up to 480 EUR/toe due to fraud issues; Broc et al., 2020). For the period 2004 to 2017, the average value of a White Certificate amounted to 2.9 EUR cents per kWh of saved energy. According to Iorio and Federici ([48], Table 4) the total value for 13 years amounts to (12 + 7 GigaEUR)/57.3 Mtoe = 2.9 EUR cents/kWh, with 12 GigaEUR—or 1.8 EUR cents/kWh—representing the companies' annual expenses related to the energy efficiency measures, while public spending for the EEP (White Certificate scheme) accounted for the remainder. Of this total, 1.8 EUR cents/kWh were related to the expenses of the companies implementing the measure, while the remaining 1.1 EUR cents/kWh (for comparison: at most 1.7 EUR cents/kWh in the period 2005–2011 according to [78], p. 5) were related to public spending for the White Certificate scheme, hence representing the levelised programme cost of saved energy (*LPC*; [48]).

Appendix C EEO Scheme in Denmark

Together with the UK, Denmark was the first EU country to establish an EEO scheme some 20 years ago ([82], p. 4), and the country is considered a leader in its energy policy in terms of approaches and ambition level (e.g., 70% GHG emission reduction from 1990 until 2030 and net zero GHG emissions by 2050 at the latest [83]. For energy efficiency, its original energy target was around 3% p.a. [84], i.e., twice as high as required by Article 7 of the EU's Energy efficiency Directive [57]. Even if the target was corrected downwards in 2016 due to the increasing cost (partly as a consequence of more stringent criteria for additionality and due to a higher cost [85,86], p. 16), it still by far exceeds the requirements (between 2.6% and 3.0% of the Danish final energy consumption between 2013 and 2020; [86], p. 10; [87]).

Reported cost-effectiveness data are based on first-year final energy savings and they include weighting factors to represent the efficiency of energy conversion, to prioritize measures with long as opposed to short lifetime and to ensure additionality ([87]; the published values are hence not consistent with *LPC* as defined in Table 1). While levelised programme costs of saved energy (*LPC*) were not reported, we estimated them at a value in the order of 1 EUR cent/kWh. Division of total programme cost of around 121 million EUR (905 million crowns) in 2018 for 2100 GWh of final energy savings [49] results in costs of around 6 EUR cents per kWh of first-year savings. Assuming an average lifetime of around 10 years (this is a conservative estimate based on [88], p. 6) and a discount rate of 2% (resulting in an annuity factor of 11.1%) leads to levelised programme cost of saved energy (*LPC* according to Table 1) of 0.7 EUR cents/kWh. For comparison, Surmeli-Anac et al. ([85], p. 15) reported a cost-effectiveness of 0.5 EUR cents/kWh saved. According to the policy guide of bigEE [89], the levelised costs are in the range of 1 to 2 EUR cents per kWh saved. Our estimated value in the order of 1 EUR cent/kWh represents the total across all energy distributors (except for fuel oil distributors), i.e., utilities providing electricity, natural gas and district heating (43%, 45% and 12% of the final energy savings, respectively, with very similar individual cost-effectiveness; [49]). Savings are realised in buildings (30% of energy savings in households and 20% in the private and public service sectors) and industry (45%) ([85], p. 11). Programme costs increased by 22% from 2014 to 2016, but decreased again in 2017 and 2018, resulting in a more moderate increase by 12% from 2014 to 2018 ([49], Table 2). Additionality is ensured by excluding measures already foreseen by other policies ([85], 2018). In evaluations, additionality is assessed by surveying participants which are subject to large uncertainties due to biased answering [87] and may indicate that the actual cost-effectiveness is lower than reported (see also [88], p. 5). Next to the cost-effectiveness from the programme perspective, the socio-economic net value of the energy savings (accounting for avoided externalities) was also estimated, showing a high benefit (0.8 to 0.9 EUR cents per kWh saved [87]).

While the EEO scheme can be considered as highly successful and exemplary for other countries, the Danish government has decided to replace it by a grant fund in combination with an auctioning scheme as of 2021 (competitive subsidy scheme; [83], p. 100).

Appendix D Strengths and Drawbacks of Energy Efficiency Programmes (EEPs)

Appendix D.1 Strengths

Cost-effectiveness: A key argument that is repeatedly put forward in favour of EEPs is that they allow one to save energy at less cost than to produce it. For example, Molina (2014) [62] found that EEPs in the U.S. saved 1 kWh of energy at about half to one third of the cost of generating 1 kWh of energy from different energy supply sources [62]. In particular, EEP schemes that are characterised by a cost recovery mechanism and an EE target (in the U.S. referred to as energy efficiency resource standards, EERS) and financial performance incentives for EE are reported to achieve higher energy savings than EEPs where these features are not or only partly present ([52]. Where EEPs lower costs, they also lower risks, reduce emissions, promote local economic growth and employment and increase electric system reliability and resilience [52]. Further benefits put forward are the avoided energy-related and capacity-related costs, such as "avoided transmission

and distribution (T&D) costs, peak demand benefits, price mitigation effects in wholesale markets, and reduced pollution" [62]. These arguments are of particular importance in the European context in view of the foreseen electrification of heating (heat pumps) and transport (EVs).

It should, however, be noted that these arguments are primarily formulated from the utility perspective and thereby typically refer to levelised programme costs of saved energy (*LPC*; e.g., [24], p. 24). The data presented in Section 3 for the U.S., the EU and Switzerland largely corroborate the findings for *LPC*. In contrast, as mentioned above, the levelised total cost of saved energy (*LTC*; see Section 2) is by far higher than the wholesale market price of energy.

Reducing upfront costs: It is widely known that EE technologies (just like renewable energy technologies) are characterised by relatively high upfront costs (investment costs), which represents an implementation barrier even if the levelised cost (i.e., the total cost of ownership, including operation) is lower compared to the incumbent technology. EEPs tackle this barrier, e.g., by providing subsidies to those customers purchasing EE technology. In this way they also address to some extent the landlord–tenant dilemma.

Attracting attention and creating awareness: Supported by the media, subsidies and the related EEPs attract the attention of households and companies. Given the fact that EE technologies are typically not widely known, EEPs hence serve as important means of communication to end users, installers and decision makers. By disseminating essential information and raising awareness, they contribute to accelerated market uptake [90,91]. EEPs, and in particular EEOs, thereby follow the same mindset as developed by Michael Porter, who argued that, "Properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them" [92]. Porter argued that companies pay limited attention to cleaner, more efficient technology but that properly designed environmental regulation can incentivize them to develop new, competitive solutions that can result in early-mover advantages compared to other countries without comparable regulation.

Providing guidance to energy users: Today, there is no area of economic and human activity without energy use. The heterogeneity of technologies is consequently vast and is ever increasing, with the market power of producers and advertisements playing more and more important roles. Consumers and decision makers are (increasingly) puzzled over which option to choose (likewise for products that do not use energy [93,94]). In such a context, guidance (communication) by an impartial and well-informed stakeholder is essential. It can contribute to lower purchases of energy-wasting products (e.g., incandescent and halogen lamps prior to their ban).

Enhanced market diffusion and market transformation: EEPs can catalyse market diffusion and contribute to market transformation. For example, installation companies which become familiar with novel technologies in the context of EEPs may well start offering or even giving preference to these options outside the scope of EEPs. This phenomenon, termed the spillover effect, is the counterpart of the free-rider effect, and it is similarly difficult to quantify in the context of EEP evaluations (interestingly, the phenomenon of spillover is not at all addressed in SFAU's evaluation discussed in Section 3.3).

Low indirect environmental and health impacts: The use of any technology causes impacts, but the sizes of the impacts differ and may be larger or smaller compared to incumbent technologies (traditional energy supply) and competing technologies (e.g., renewable energy technologies). For example, heat recovery implies the production and installation of a heat exchanger (both cause impacts), but typically these impacts are much lower than not having the EE technology (even when considering embodied or grey energy); this also applies to other EE technologies, e.g., thermal insulation of buildings or improved process control. EE technologies can be expected to cause, in general, less indirect environmental and health impacts than most conventional [23,95] and many renewable energy technologies (for example, compared to hydropower and biomass,

with the attendant needing to build roads and change the landscape, e.g., resulting in biodiversity impacts).

Local implementation: While certain policy measures such as CO_2 taxation and regulations of minimum energy performance for appliances or cars can only be introduced at the national or supranational level, EEPs have the advantage that they can also be applied at smaller scales, e.g., at the level of provinces or cantons [95]; for smaller geographical areas preferably rather in collaboration with larger EEP operators).

High level of acceptance: Since most EEPs imply subsidies, rebates or their like, and since policy measures of this type generally enjoy a high level of acceptance, this can also be expected for EEPs. Obviously, lower levels of acceptance can be expected for EEP and EEO versions which imply higher levels of commitment by the beneficiaries or which are accompanied by rigid controls and sanctions. The generally high acceptance of EEPs is a strength, even in comparison to some renewable energy policies which may lack acceptance for a diversity of reasons (e.g., nature conservation, or the NIMBY effect standing for "not-in-my-backyard").

Combinability with tradable White Certificates: The combination of EEPs and EEOs with tradable certificates, typically referred to as White Certificates—offering further flexibility—can be effective [96], and they have been successfully implemented in some countries. EEPs can also be combined with policy instruments from other domains. For example, EEPs in the U.S. have successfully teamed up with policy measures in the social housing domain, resulting in win–win solutions [47].

Economies of scale: Large EEPs can leverage economies of scale, e.g., when purchasing appliances in large numbers (e.g., energy efficient lighting or control equipment), which is an advantage that can be exploited once having proven the operability and the desired effects of smaller programmes (e.g., [45,97]).

Green growth and positive employment effects: While there are only very few macro-economic analyses of EEPs (e.g., [98–100]), positive impacts on GDP and employment can be expected. First, it is plausible that programmes that are economically viable from a private perspective, and make use of goods and services which are sourced domestically, result in benefits compared to, for example, systems that rely on fuel—which is imported by most countries. Second, there is substantial body of research on the macro-economic effects of sector-wide or even country-wide energy efficiency improvement (e.g., [101–104]; for further sources, see [98]). Most of these studies rely on input–output analysis, with the findings based on net effects (counterfactual approach) being more meaningful than those reporting gross effects [70,105]. These studies generally coincide in their conclusions about the positive effects for employment and in terms of GDP, with very few exceptions (e.g., models running with crowding out or model results for first years after the investment; [106,107]). Some studies refer to past or ongoing investments [100,101], while others study address the future implementations of energy efficiency policies (e.g., [108]). The latter approach applies to the models E3ME and GEM-E3, which were used by the European Commission to assess the macroeconomic impacts of energy efficiency policy [106,109]. E3ME is referred to as "a macro-econometric model, based on a post-Keynesian demand-driven non-optimisation non-equilibrium framework," whereas GEM-E3 is a general equilibrium model [110]. Most E3ME and GEM-E3 model runs show net benefits in terms of GDP and employment, but these are less positive for some model runs representing higher ambition levels of energy efficiency improvement, and they can then become negative in cases of self-financing (i.e. no borrowing, resulting in "full crowding out" [106]).

Link to sufficiency strategies: Since EEM alone may not allow one to reach the energy saving targets, there is increased attention for sufficiency strategies which concern the level and/or the reduction of energy services [111]. In principle, EEPs lend themselves to be expanded to sufficiency strategies.

Appendix D.2 Drawbacks

Free-rider effects: Possibly the most widely quoted drawback of EEPs is the free-rider effect. The extent of the free-rider effect depends on various parameters, e.g., the type of EE measure; the subsidy level; and a number of characteristics of the beneficiaries, including income, environmental attitude and risk and time preferences [112]. Not rarely, free-rider effects are in the order of 50%, with some authors finding clearly higher values (up to 90% according to [113]; further studies quoted in [112]), while others present clearly lower ones (12% according to [114]; around or below 20% in UK according to [115], but possibly higher values in Germany's KFW programme, likewise according to [115]). A higher level of free-riding is typically found in EEPs addressed toward households as opposed to the commercial and industrial sector.

Continuous adaption to markets and legislation: As discussed above, in the context of strengths, EEPs can help to transform the market towards a more energy-efficient portfolio. EEPs and similar energy policies are therefore sometimes referred to as "accelerators." If, on the other hand, EEPs drive a market transformation process which would autonomously anyway occur very soon afterwards, they are more unlikely to serve as effective and cost-effective policy measures. To avoid this type of phenomenon and in order to choose the right areas of energy demand (i.e., the areas where intervention really matters), programme operators need to continuously screen the market and be well aware of product trends (types of options and their cost-effectiveness), changes in legislation and their implications (e.g., the Swiss ProKilowatt programme stopped funding heat pumps for domestic hot water supply once these became mandatory to use according to revised building codes [116]). In other words, programme operators should function as efficiently as markets by anticipating developments, making strategic decisions about what to subsidize and pulling out again as quickly as possible once support is no longer needed. This implies great organisational effort, which incurs additional costs and can compromise the EEP's cost-effectiveness. At the same time, negligence on these matters also impairs the cost-effectiveness. In addition, it requires a high level of professionalism and an agile body. The latter is not a known feature of the reputations which public administrations have in most countries, and similarly, large utilities are often slow at decision making and they may lack flexibility. In order to remain effective, the rules under which EEPs operate need to be periodically modified, which is not only a challenge for the operator but also for the EEP applicants (in fact, the effort related to the preparation of an EEP tender as a consequence of the complex rules is a reason why the Swiss ProKilowatt programme has received less applications than desired, which in turn, limits the competitive character and calls for further corrective measures (in particular the so-called 120% rule in the ProKilowatt programme [116]). Experience is available on how to effectively and successfully manage EEPs (see, e.g., [82], p. 63; [85], p. 15).

Metering energy efficiency is challenging: A general challenge of EE policies, which is hence shared also by other measures apart from EEPs, is the fact that it is demanding to measure the energy efficiency gains: while the output of a renewable energy installation can be reliably established by means of a physical meter, quantification of the evolution of EE requires a model-based, counterfactual approach (correcting for boundary conditions such as changing energy prices) which is unavoidably subject to uncertainty. This becomes even more challenging when policy measures overlap (e.g., pre-existing measures as opposed to new measures), which is always the case in practice.

Conflicts of interest for utilities: For EEPs and EEOs operated by utilities in countries with largely liberalised energy markets, there is a conflict of interest: the utilities' economic well-being is proportional to their sales and therefore increased energy efficiency results in lower revenue. On the other hand, this can be addressed by decoupling policies which allow revenues to be "decoupled" from sales, making it possible for utilities to receive compensation for decreased sales (as a downside, this adds an administrative burden and the associated costs) [117,118]. Furthermore, EEPs and EEOs somewhat reduce the utilities' freedom of choice with regard to investments, which may ultimately reduce a utility's

associated earning opportunities, hence making it unattractive for utilities to invest in EE; this barrier can be addressed by performance incentives for achieving energy efficiency targets [117].

Risk of fraud: The presence of a large budget and the definitions of the rules according to which it is ultimately spent imply a risk of fraud, not only for White Certificates but more generally for EEPs.

Fuel poverty: Ratepayer-funded EEPs may be criticised for exacerbating fuel poverty, whereas government-led programmes funded by tax revenue can be designed to avoid undesired distributive effects. On the other hand, over the years, the EEPs cover most of the customers who then also benefit from the programmes. EEPs (including ratepayer-funded programmes) can further mitigate distributive effects by dedicating an above average budget share to low-income households (many EEPs do so). Finally, the increase in energy prices helps to limit the rebound effect and is an incentive for saving energy.

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