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Evaluating policy instruments to foster energy efficiency for the sustainable transformation of buildings

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Energy efficiency policies have the unique capacity to contribute to a more sustainable energy future at an economic net benefit even when co-benefits are not included in the evaluations. The purpose of this paper is to present quantitative and comparative information on the societal cost-effectiveness and the lifetime energy savings of all light eight building energy efficiency policy instruments.While certain instruments, such as product standards and labels are shown to be able to achieve the largest energy savings, from a cost-effectiveness perspective, it is not possible to clearly prioritize the policy instruments reviewed. Any of them can be cost-effective if selected, designed, implemented and enforced in a tailored way to local resources, capacities and cultures.

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Introduction

Buildings represent localized high energy consumption systems and were responsible for as much as 35–45% of the global annual primary energy consumption in 2010 [1–3]. This proportion is even higher in some developing regions, for instance 57% of national final energy demand in Africa [4]. The demand in developing countries is projected to continue to increase as the population grows and becomes more urban and more prosperous [5].

Market forces can heave demand side energy efficiency to some extent; however, the low inertia of autonomous change, the impact of barriers and the peril of lock-in require public policy to mainstream energy efficiency [6••,7].

The energy and policy systems, as well as the building sectors vary widely across countries, and policies appropriate for creating more sustainable energy consumption regimes will work lucratively in one system, but may be unsuccessful in another. Nevertheless, there are lessons to be learnt from each other. Sharing experiences and evaluating existing practices also has the benefit of reducing costs of new policy design [4,8], which is particularly helpful in countries that do not have the financial and technical means to invest in technical economic analysis and impact assessments [9–11]. The comparison of the cost-effectiveness of a broad range of building energy efficiency policies was conducted sporadically in the past [12••,13,14•,6••],[1] although such information could be important reference for decision makers to allow them to prioritize these.

The aim of our research was to pool the results of a large number of policy evaluations in a format that allows actual *quantitative comparison of the economic cost-effectiveness on the societal level and the environmental effectiveness in the form of lifetime energy saving impacts of building energy efficiency policies*. We focused on evaluations published since a similar analysis of Urge-Vorsatz *et al.* [12••,15••] in 2007, who provide — to the knowledge of the authors — the most comprehensive comparative study of a wide range of real cases of 20 sustainable building energy efficiency policy tools.

In our study, the direct additional costs for the society (all stakeholders) to design and implement the policies and the level and monetary value of the final energy savings were considered, thus ignoring the value of co-benefits. Such an approach was appropriate taking into account that in economies that are short on resources, policy makers have to be convinced through the net economic benefits of policies. Our assessment focuses on eight energy efficiency policy instruments for buildings, namely building codes, building certificates and labels, product energy performance standards (MEPS), product labels, awareness raising and information programs,

[1] There are other local efforts currently ongoing to assess energy efficiency policies, such as the projects bigEE (Bridging the Information Gap on Energy Efficiency in Buildings, http://www.bigee.net/) and AID-EE (Active Implementation of the proposed Directive on Energy Efficiency, http://www.aid-ee.org), however a worldwide comparative and up-to-date overview is currently missing.

voluntary agreements, energy efficient procurement rules and practices, and public leadership programs.

Data collection and methodology

Measuring policy impact is subject to a number of intrinsic limitations, such as the rebound effect and the free rider effect, double counting, hidden costs and hidden impacts [16], and methodological biases. Evaluation regimes have their specific traditions; the reports vary in data presentation,[2] depth of detail, and the calculation methods used [17–20].

Though these limitations are grave, the available experience could and should still be better utilized [21]. In our meta-analysis these limitations were partially overcome by rigorous selection of data sources and whenever possible going beyond the written report to clarify ambiguities. However, the figures presented should be considered as robust and indicative, serving therefore to the purposes of this analysis.

We identified 47 quantitative assessments from 23 countries that could be included in our assessment. Requirements for inclusion were the availability of data both on costs (total costs or costs per stakeholder) and information on energy savings and/or calculated societal cost-effectiveness. While serious efforts were dedicated to screening the literature for peer-reviewed sources, it is due to the nature of quantitative policy assessments that they typically originate from government papers and research documents. Therefore, after careful scrutiny, these have also been included in our analysis.

The data for the identified *best practice examples* are herein presented in a normalized format and from a societal perspective. Thereby known costs incurred by *all stakeholders* (in particular authorities, program implementers, and end-users[3]) were summed and the direct energy cost savings were subtracted (as adapted from [22•,23]), using the following equation:

$$CE_T = \frac{\sum_{j=1}^{J} I_{j,(t=t^*)} \cdot a_j - \sum_{t=1}^{T} ES_t}{\sum_{t=1}^{T} \Delta E_t}$$

where

- CE_T is the **societal cost-effectiveness**, that is, the net total cost of the energy saving policy, expressed in $\$_{2010}$/kWh. Any calculation made by the original authors was assumed as best.
- A *negative* CE_T *means a positive financial return*.
- $I_{j,(t=t^*)}$ is the **cost of the policy** for stakeholder j. The costs in the literature were assumed to refer to additional costs of the intervention (as opposed to less sustainable alternatives), and to constitute a onetime (or in some cases the sum of the repeated) investment[4] at the beginning of the program at point t^*, unless otherwise stated.
- a_j is the capital recovery factor, calculated as

$$a_j = \frac{(1+r)^T \times r_j}{(1+r)^T - 1}$$

where r_j is the discount rate[5] for stakeholder j and T is the lifetime of the intervention.

- ΔE_t is the **environmental effectiveness**, that is, the final energy saved (TWh) in year t.
- ES_t is the monetary value of the energy saved in year t, calculated as:

$$ES_t = \Delta E_t \times P_t$$

where P_t is the consumer price of the relevant form of energy (gas or electricity) in that year.

Monetary data were converted into U.S. dollars ($) and adjusted for inflation to $\$_{2010}$.

Results

All policies can be implemented cost-effectively

An overview of the best practice examples (Figure 1) indicates that, regardless of the ancillary benefits, all the policy instruments reviewed have the potential to cost-effectively increase energy efficiency in buildings. For all the eight policy instruments in our study, it was possible to find examples with net-negative societal cost-effectiveness,[6] that is, with financial savings. Furthermore certain general trends can be concluded; however, it is difficult to clearly prioritize any instrument based only on the cost and environmental effectiveness.

Environmental effectiveness is widely distributed, with certain instruments scoring higher than others. Lifetime energy savings give an idea of reasonable program potentials; however, they are largely affected by country and program design specific determinants. Program titles and data information are provided in Table 1.

Environmental and cost-effectiveness of individual policy instruments

Product energy performance standards (MEPS) and their combination with *product labels* (*S&L programs*) perform significantly better in terms of environmental

[2] Variations occur of all aspects of these numerically expressed results, including a focus on carbon savings versus primary or final energy savings, the use of units, the coverage of end-uses and periods, etc.

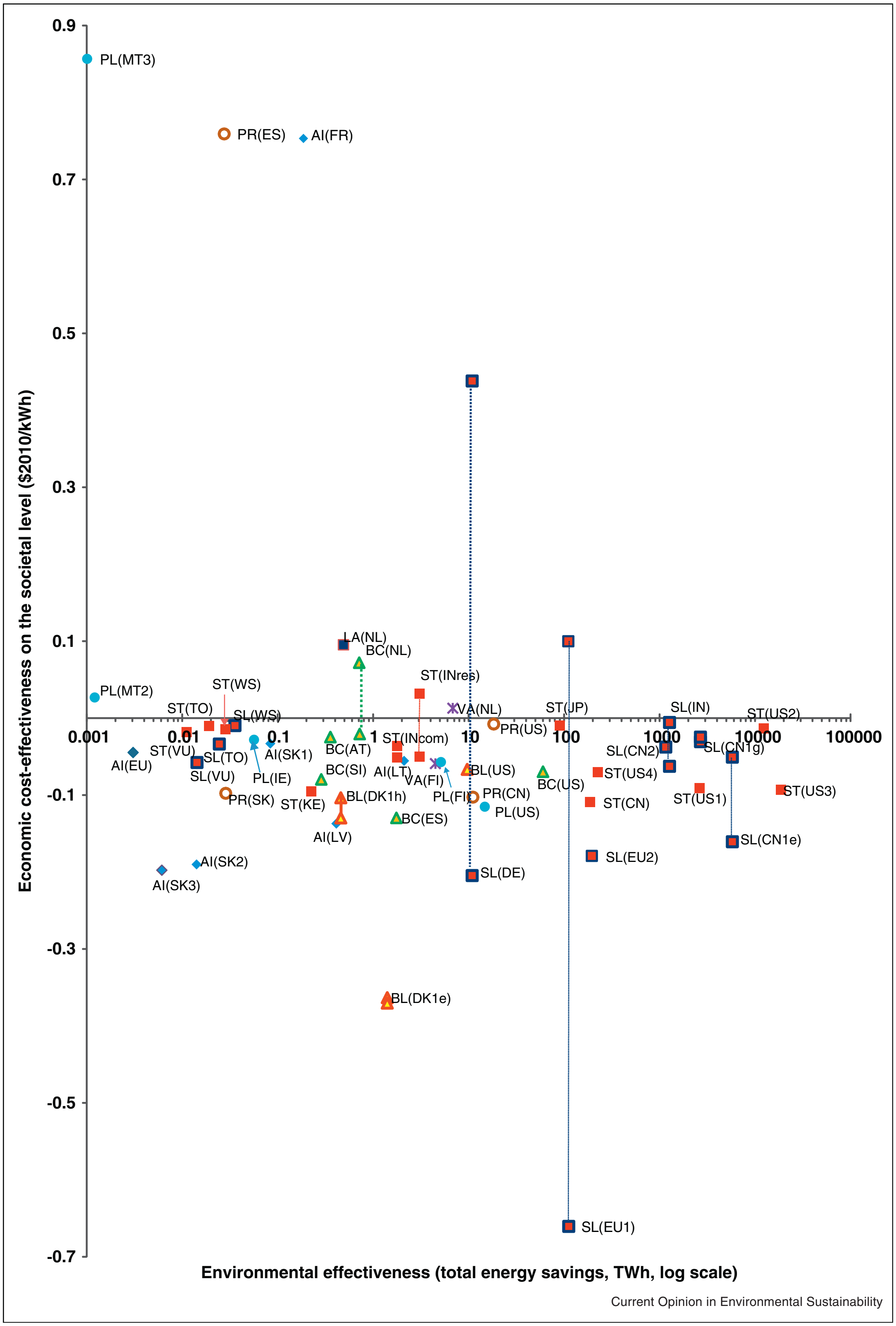
[3] Industry costs were typically excluded, unless shown that their expenses were not transferred to end-users.

[4] Due to limited or no information about the data background, the costs sometimes refer to the measure period, which might cause significant underestimation, if shorter than the lifetime of the technology addressed or the change initiated. This is indicated in Table 1 as appropriate.

[5] The information was country and program specific, if possible extracted from the source, otherwise from literature.

[6] The cost-effectiveness for the end-users would be usually higher.

Figure 1



Cost-effectiveness and environmental effectiveness of the best practice examples reviewed. The codes are matched to the program information in Table 1.

Table 1

Cost-effectiveness of the case studies assessed. The unique codes used for each program correspond to the ones used in Figure 1.

Code used in Figure 1	Country	Program title (program period) (type of assessment)	Cost-effectiveness ($\$_{2010}$/kWh) (on societal level, otherwise stakeholder is indicated)	Comments on data, assumptions	Reference
Product energy performance standards (ST) are minimum requirements aiming at excluding the least energy efficient equipment and appliances from the market					
ST(US1)	U.S.	**34 new standards for electric appliances** (2013–2030) (ex-ante)	−0.091$/kWh	Data for 'appliances sold through 2030'. Electricity price: 0.10$/kWh	[24,25]
ST(US2)	U.S.	**Economic savings from future standards** (2010–2035) (ex-ante & ex-post)	−0.013$/kWh		[26]
ST(JP)	Japan	**Top Runner Households** (1998–2028) (ex-ante)	−0.0097$/kWh	Costs and benefits averaged over 30 years, $r = 3\%$. Exchange rate: 120.67Y/$ (2007)	[27]
ST(US3)	U.S.	**Existing US DOE standards and new standards to be introduced in 2010** (1987–2030) (ex-post and ex-ante)	−0.093$/kWh	Data for residential and commercial appliances	[28]
ST(CN)	China	**Phasing out inefficient lighting** 2010 (ex-ante)	−0.109$/kWh	The stakeholder bearing the costs is not clearly identified. All types of lighting included. Lifetime for new lamps is assumed to be 3 years, $r = 0$	[29]
ST(KE)	Kenya	**Phasing out inefficient lighting** 2010 (ex-ante)	−0.095$/kWh		
ST(US4)	U.S.	**Phasing out inefficient lighting** 2010 (ex-ante)	−0.070$/kWh (assumed society)		
ST(INres) **ST(INcom)**	India	**Cost of efficient residential and commercial equipment** (2012–2015) (ex-ante)	−0.05 to +0.032$/kWh (residential sector); −0.051 to −0.036$/kWh (commercial sector)	Assumed timely replacement. Electricity price 0.062$/kWh (2012)	[30]
–	U.S.	**Standards in Western US States** (2006)	−0.09$/kWh	Electricity price: 0.10$/kWh (2012)	[31]
Product labels (LA) are mandatory or voluntary schemes of providing simple information about the energy (and other) performance of equipment and appliances at the point of sale in a conventional manner					
LA(NL)	The Netherlands	**Labelling of appliances** (1995–2004) (ex-post)	+0.081$/kWh (government); −0.149$/kWh (consumer); +0.096$/kWh (society)	r for government 4%, for consumers 8%, real energy prices for consumers: 0.20€/kWh (source)., cost of energy production for government: 0.05€/kWh (source). Conversions: 1 kWh = 0.0036GJ	[32]
Standard and labelling programs (SL) are the combination of product standards and labels, often referred to as S&L programs					

Table 1 (*Continued*)

Code used in Figure 1	Country	Program title (program period) (type of assessment)	Cost-effectiveness ($\$_{2010}$/kWh) (on societal level, otherwise stakeholder is indicated)	Comments on data, assumptions	Reference
SL(EU1)	European Union	**Ecodesign Regulations** (including Air conditioners and comfort fans, Household dishwashers, Household washing machines, Refrigerators and freezers, Televisions, External Power Supplies, Simple Set-Top Boxes) (by 2020 and by 2030) (ex-ante)	+0.010 to −0.660$/kWh (2020) −0.100 to −0.480$/kWh (2030) (society, including also industry, retail sector, administration)	Lifetime of the products taken into account, costs for additional administration, related to industry and retail sector R&D, marketing, installation, end-of product costs. Business turnover changes are considered. Inflation and electricity price changes are not taken into account in some of the impact assessments	[33,34,35,36,37,38,39,40]
SL(EU2)	European Union	**Ecodesign Regulation** on standby (2020) (ex-ante)	−0.179$/kWh (society, including also industry, retail sector, administration)	Assumes insignificant product price increase as a result	[41]
SL(DE)	Germany	**Potential of the application of benchmark technology in electrical equipment** (2007–2020) (ex-ante)	−0.204 to +0.439$/kWh	Includes street lighting. Conversions used: 1 MWh = 0.6tCO_2. Electricity price used 0.254€/kWh (source)	[42]
SL(CN1e) SL(CN1g)	China	**Labelling and standards** (2010–2030) (ex-ante)	−0.161 to −0.05$/kWh (electricity); −0.030 to −0.024$/kWh (gas)	Includes industrial motors and transformers. Price of electricity 0.15–0.19$/kWh (2015), price of gas 13.16–15.53$/GJ (2015), r = 5.6%	[43]
SL(CN2)	China	**Impacts of current S&L programs (electric appliance)** (2000–2020) (ex-ante)	−0.037$/kWh (administrative costs + financial support)	Not fully transparent original data; seven products covered; costs had to be cumulated; monetary and energy savings were expressed for different timeframes, which had to be aligned	[44]
SL(IN)	India	**Potential in India of efficient appliances** (2010–2030) (ex-ante)	−0.005 to −0.062$/kWh	Conversion factor applied: 2.5	[45]
ST(WS) SL(WS)	Samoa	**Standard and labelling program** (2011–2020) (ex-ante)	−0.014$/kWh (standard) −0.009$/kWh (S&L) (including industry)	Industry costs are transferred to the consumer. r = 10%. The evaluation of the program in the three countries involved a comparison between stand-alone standards and a S&L programs	[46]

Table 1 (*Continued*)

Code used in Figure 1	Country	Program title (program period) (type of assessment)	Cost-effectiveness ($\$_{2010}$/kWh) (on societal level, otherwise stakeholder is indicated)	Comments on data, assumptions	Reference
ST(TO) **SL(TO)**	Tonga	**Standard and labelling program** (2011–2020) (ex-ante)	−0.010$/kWh (standard) −0.033$/kWh (S&L) (including industry)		
ST(VU) **SL(VU)**	Vanuatu	**Standard and labelling program** (2011–2020) (ex-ante)	−0.018$/kWh (standard) −0.057$/kWh (S&L) (including industry)		
Building codes (BC) are regulations that set minimum (energy use) requirements for entire buildings or for specific building systems					
BC(NL)	The Netherlands	**Building codes** (1996–2004) (ex-post)	+0.001 to +0.014$/kWh (government); −0.094 to +0.0042$/kWh (consumer); −0.020 to +0.072$/kWh (society)	Energy prices at the level of the end-user (including taxes): 0.37€/m^3 (residential), 0.32 €/m^3 and 0.11€/kWh (tertiary). ca. 50% of the energy savings are in natural gas and 50% in electricity generated from gas. Conversion factor: 1.25	[47]
BC(SI)	Slovenia	**Regulations on the energy performance of buildings** (2010–2016) (ex-ante)	−0.079$/kWh (government)	The price of gas: 0.06€/kWh	[48]
BC(ES)	Spain	**Building code** 2008–2012 (ex-ante)	−0.129$/kWh (unclear, assumed society)	The stakeholder baring the costs is not clearly identified. Energy prices: 0.1€/kWh	[49,50]
BC(AT)	Austria	**Multiple measures, with standards at their core in upper Austria** (1993–2007) (ex-post)	−0.024$/kWh	A package of policies for the improvement of buildings energy performance	[51]
BC(US)	U.S.	**Building codes APA+ACELA** (2010–2030) (ex-ante)	−0.064$/kWh (2020) −0.069$/kWh (2030)		[52]
–	U.S.	**Building codes in Western US States** (2007)	+0.01 to +0.027$/kWh	Electricity price used: 0.020$/kWh	[31]
Building certificates and labels (BL) are performance rating systems which, intending to make this information available, include the provisions for the disclosure of the certificate					
BL(DK1h) BL(DK1e)	Denmark	**Energy Labelling of Small Buildings** (1999–2005) (ex-ante)	−0.129 to −0.103 (heat) −0.3698 to −0.3627 (electricity)	Natural gas prices of 0.146$/KWh and electricity prices of 0.381$/kWh. Target savings are combined with those of building codes in the original source.	[23]
BL(US)	U.S.	**Building energy performance labelling program (commercial and residential) APA+ACELA** (2010–2030) (ex-ante)	−0.049$/kWh (2020) −0.066$/kWh (2030)	Annual energy savings were cumulated (electricity + gas). Inflation has been applied	[52]
Green (or energy efficient) procurement rules and practices (PR) mean the organized purchase by public bodies following pre-set regulations including provisions for sustainability or energy efficiency					

Table 1 (*Continued*)

Code used in Figure 1	Country	Program title (program period) (type of assessment)	Cost-effectiveness ($\$_{2010}$/kWh) (on societal level, otherwise stakeholder is indicated)	Comments on data, assumptions	Reference
PR(SK)	Slovakia	**Application of the principle of energy efficiency in public procurement** (2011–2013) (ex ante)	−0.097$/kWh	No lifecycle cost savings considered, but only savings during the measure; measure includes vehicles. Assuming only electricity at 0.120€/kWh	[53]
PR(CN)	China	**Public procurement of seven products** 2003–2013 (ex-ante)	−0.102$/kWh	Additional costs are reported to be close to zero, because the price is of conventional and efficient units are about the same	[54]
PR(LT)	Lithuania	**Direct investment (mainly renovation)** (2010–2020) (ex-ante)	+1.58$/kWh	Assuming only natural gas at 0.038€/kWh. Unclear whether lifecycle cost savings were taken into account. This may have caused low cost-effectiveness	[55]
PR(US)	U.S.	**Federal Energy Management Program (FEMP)** (2005–2020) (ex-ante)	−0.007$/kWh	Assuming only electricity savings at 0.117$/ kWhAdditionally, 2 million GJ were saved in fuel, probably in transportation. Inflation was applied	[56]
PR(ES)	Spain	**Public procurement in Vitoria** (2010–2020) (ex-ante)	+0.76$/kWh	The direct and full investment costs were included, which results in low cost-effectiveness. Electricity: 0.177€/ kWh	[57]
In **public leadership programs** (PL) the public sector decides to lead by example, and undertakes actions to improve the sustainability performance of its buildings, change user behaviour, or use innovative solutions/technologies. These actions are communicated to relevant stakeholders in order to raise awareness, increase interest in sustainability, and/or demonstrate the feasibility and benefits of innovative technologies					
PL(US)	U.S.	**Federal Energy Management Program (FEMP) Contract Awards** (investments in 2008, 2009 and 2010)	−0.115$/kWh	Assuming only electricity at 0.117$/ kWh	[58,59]
PL(IE)	Ireland	**SEI Public Sector Building Demonstration Programme – support for new and retrofit public sector building initiatives** (2006–2010) (ex-post)	−0.028$/kWh	Adoption of larger targets than other sectors. Conversion factor: 2.5. Assuming all costs incurred by government are the ones specified for 2006, 2009 and 2010, and that all savings are in electricity (price 0.160€/kWh)	[60,61]

Table 1 (*Continued*)

Code used in Figure 1	Country	Program title (program period) (type of assessment)	Cost-effectiveness ($\$_{2010}$/kWh) (on societal level, otherwise stakeholder is indicated)	Comments on data, assumptions	Reference
PL(FI)	Finland	**Exemplary role of the administration: targets and energy efficiency saving plans by government orgs** (1992–2010) (combined ex-post and ex-ante)	−0.057$/kWh (government) −0.057$/kWh (councils) −0.054$/kWh (social)	A package of policies: preparation of an efficiency plan, dissemination of information to tenants, imposing energy efficiency obligations on property management agreements, voluntary agreements with local councils. Savings cumulated from the average of the savings 2010, 2016 and 2020. Assuming only gas at 0.0453€/kWh	[62]
PL(MT2)	Malta	**Malta's green leaders** (2010–2016) (ex-ante)	+0.027$/kWh	Savings cumulated from the average of the given 2 years. Assumed energy price: 0.170€/kWh. Unclear whether lifecycle cost savings were taken into account. This may have caused low cost-effectiveness	[63]
PL(MT1)	Malta	**Incentives for local councils to reduce** (2010) (ex-ante)	+1.33$/kWh	Assumed energy price: 0.170€/kWh. Unclear whether lifecycle cost savings were taken into account. This may have caused low cost-effectiveness	[63]
PL(MT3)	Malta	**Exemplary measures in social housing** (2010–2016) (ex-ante)	+0.857$/kWh	Savings cumulated from the average of the given 2 years. Assumed energy price: Energy of 0.170€/kWh. Unclear whether lifecycle cost savings were taken into account. This may have caused low cost-effectiveness	[63]
Voluntary agreements (AG) are tailored contracts between the authority and the building owners, tenants or organizations (e.g. developers, housing companies, local authorities), who commit to improving the energy performance on their building premises. These agreements define targets and/or a set of specific measures. The agreements also define the requirements for monitoring, incentives, and potential penalties in case of non-compliance					
AG(FI)	Finland	**Energy efficiency agreement for service sector and Local government** (2008–2020)	−0.059$/kWh	A package of policies: advice, monitoring, audits and subsidies. Annual savings were cumulated. Natural gas at 0.0453€/kWh	[62,64]

Table 1 (*Continued*)

Code used in Figure 1	Country	Program title (program period) (type of assessment)	Cost-effectiveness ($_{2010}$/kWh) (on societal level, otherwise stakeholder is indicated)	Comments on data, assumptions	Reference
AG(NL)	Netherlands	**The more with less programme (2008–2020)**	−0.0026$/kWh (government) +0.013$/kWh (society)	Price of natural gas 0.0727€/kWh	[65,64]
Awareness raising and information programs (AI) consists of transmitting messages about the advantages of energy efficiency in buildings to the general public or to specific target groups					
AI(FR)	France	**Local energy information centres** (2001–2003) (ex-post)	+0.049$/kWh (government) +0.648$/kWh (consumer) +0.754$/kWh (social)	Conversion used: 93gCO_2/kWh. Electricity price at 0.128€/kWh. Unclear whether lifecycle cost savings were taken into account	[23]
–	Brazil	**Electric energy conservation programs in Brazil (1998–1999)** (ex-post)	+0.05$/kWh (education) −0.053$/kWh (training)	Using electricity price of 0.08$/kWh. Government costs are assumed to be the societal costs, given the consumers do not incur expenses	[66]
AI(EU)	EU	**Estimate potential savings of behavioural campaigns** (2004–2007) (ex-ante)	−0.044$/kWh	Using electricity price of 0.208$/kWh. Government costs are assumed to be the societal costs, given the consumers do not incur expenses	[67]
AI(SK1)	Slovakia	**'Good Advice = Savings' awareness Campaign** (2008–2010) (ex-ante)	−0.0330$/kWh	Conversion used (2004): 396gCO_2/kWh. Assuming all savings in gas at 0.044€/kWh. Government costs are assumed to be the societal costs, given the consumers do not incur expenses	[53]
Ai(SK2)	Slovakia	**Information campaigns aimed at energy saving appliances** (2008–2010) (ex-ante)	−0.190$/kWh	Using electricity prices of 0.168€/kWh. Government costs are assumed to be the societal costs, given the consumers do not incur expenses	[53]
AI(SK3)	Slovakia	**Training retailers** (2008–2010) (ex-ante)	−0.197$/kWh	Using electricity prices of 0.168€/kWh. The measure was not implemented after all	[53]
AI(LV)	Latvia	**Information campaigns use of appliances** (2008–2016) (ex-ante)	−0.137$/kWh	Electricity: 0.119€/kWh	[68]
AI(LT)	Lithuania	**Potential behaviour change in Lithuania** (2010) (ex-ante)	−0.055$/kWh	Considering only gas: 0.043€/kWh	[55]

effectiveness than any other instrument, while they also rate high on cost-effectiveness, and can be implemented at a net social benefit in various environments based on the data available (see Figure 1 and Table 1).

It seems that they are successful because they are not particularly vulnerable to the local conditions and some barriers [12••,15••,69], require small local (human and financial) capacities, and international experience and practices can be transmitted. While the achieved savings are largely influenced by the size of the markets (thus programs in the U.S., China and India have the highest environmental effectiveness [26,29,44,45,70•]), no other policy was found to achieve similar level of savings in the same countries. At the same time product standards and S&L programs work cost-effectively regardless of the market size, as the examples of Samoa, Tonga and Vanuatu suggest [71]. Although different in their market pull and push approach, the literature reviewed suggests that the Japanese Top Runner Program and the European type MEPS have similar societal cost-effectiveness, supporting the findings of [72].

S&L programs are the classic example of mutually reinforcing policy instruments [73], which might be the reason that we found only one best practice case assessing appliance labels separately [32]. The available data suggest that product labels are not cost-effective alone, on the other hand, MEPS seem to have a comparable level of environmental effectiveness and a slightly lower cost effectiveness than those of S&L policies.

Building codes[7] are among the most used policy instruments, implemented in over 30 countries and regions [74]. The data available for building codes indicate that they almost always have a negative cost-effectiveness, similar to product standards, while their environmental effectiveness is smaller. The resulting total energy savings is closely linked to the construction/renovation rate, and it is strongly influenced by the climate zone. Proper enforcement and combination with information (e.g. in the form of building labels) can dramatically increase effectiveness [51].

The public administration costs of building codes can be low depending on the design of the policy instrument (see for instance [75]), but implementation costs — primarily on the consumer side — pile up [76]. Some of the reviewed programs integrated subsidies to alleviate consumer costs, while in other cases it was clearly assumed that financial support is not necessary [77] or only necessary to promote above-standard buildings [47]; nonetheless it is notable that even with public support building codes could have a net social benefit.

Energy savings and costs depend on the level of stringency [76,78] and the stage in policy complexity. It is common that new buildings are addressed first, and existing buildings are integrated later [79], which might require additional financial incentives [80], thereby increasing program costs.

Being a relatively new instrument, case studies of *building certificates and labels* was scarce in the literature and this situation was aggravated because their effect is difficult to separate from those of building codes. Only two programs could be quantitatively evaluated in our study [23,52], and even these do not clearly separate the impacts from those of building codes. The environmental effectiveness of the building certificates programs was found similar to that of building codes, probably as a result of the problems with separation. The cost-effectiveness of a Danish program [23] was found particularly high; however — as stated before — individual values should not be used with care. Nevertheless, it is likely that building certificates alone and in combination with building codes also produce net social economic benefits and their main economic benefit may be to increase the value of properties [81•].

Voluntary agreements are widespread for industries, but their application for buildings is less popular and restricted to countries with a tradition for voluntary actions [64] (as in our sample, Finland and the Netherlands). Nevertheless this instrument may be particularly interesting as an alternative to regulation [64].

The societal cost-effectiveness could be calculated in case of the two above-mentioned programs [62,64,65] and was rather modest when compared to regulations. It is notable though that both programs included subsidies and other policies as part of the voluntary agreement, some of which might have caused an increase in costs. The environmental effectiveness is similar to regulations in markets of similar size, and much higher than that of building codes in the Netherlands.

The cost-effectiveness of *awareness raising and information* programs varies widely, from exemplary low costs (such as [53,68]) to programs with net societal costs [23]. At the same time, the environmental effectiveness is moderate, in the range of 0.005–5 TWh, and unrelated to the size of the country where the programs took place. In contrast, the size of the program and the type of target group appear to influence environmental effectiveness. As program size grows, the cost effectiveness of a campaign may decrease due to the loss of directness and applicability of advice [6••].

[7] Building codes most commonly address new buildings, but those for existing buildings are gaining popularity and are a way to upgrade existing, well-functioning schemes.

It is important that evaluations of these programs are probably the most prone to methodological challenges and to the lack of uniform and well-developed methods for the measurement of behavior change [15••,82]. Among the case studies in our sample, lifetimes are very short (2–3 years), or vaguely defined for the induced change (e.g. [23] for France), although, if a program results in technology adoption (for instance in the purchase of energy efficient appliances) the lifetime considered should be much longer.

Energy efficient procurement rules and practices and *public leadership programs* have a two-level energy saving impact. While directly achieving savings at public buildings, they catalyze further savings by setting an example to other consumers and by influencing the market through quantity purchase.

Examples of these two instruments imply that they are less cost-effective than the instruments discussed above, and in fact, just a few cases were identified with a net negative societal cost-effectiveness[8] (e.g. a green procurement program in China), which seems to be as cost-effectiveness as regulatory policies [54]. Other programs position on the lower end of both environmental and cost effectiveness based on the data available; however, reports seem to have methodological shortfalls, including the underestimation of energy savings (accounting for shorter periods than the lifetime of the impacts, e.g. [53]) or the overestimation of costs (when the total investment costs are reported instead of the additional costs [57,47]).

Conclusions

On the basis of the data presented herein, it is difficult to prioritize any of the reviewed eight policy instruments, because best practice examples were identified for all, suggesting that each instrument has the potential to be cost-effective and environmentally effective on the societal level if selected, designed, implemented and enforced appropriately to local conditions. Cost-effectiveness would be even higher from an end-user point of view and by adding ancillary benefits.

The data analysis suggests that regulations, especially product energy performance standards, can have the largest lifetime energy saving impacts. Combining MEPS and building codes with labels and certificates may increase cost-effectiveness and produce slightly larger energy savings, as implied by the reviewed literature. These policies almost always result in a net economic benefit on the societal level.

On the other end, data for public leadership programs and procurement regulations suggest that these are less cost-effective, with only few examples of negative cost-effectiveness and large environmental effectiveness, though data reliability problems should be kept in mind. Awareness raising and information programs vary widely, especially in terms of cost-effectiveness based on the literature reviewed. Examples of voluntary agreements for buildings were too few to make major conclusions, but their lifetime energy saving impacts tend to be close to those of regulations, though at a lower cost-effectiveness and with a higher sensitivity to implementation details.

Influence of context and careful implementation

Product energy performance standards, product labels, building codes and building certification programs have been shown to be robust instruments that can be cost and environmentally effective in a wide range of environments. The presently identified literature suggests that the structural features of the market (such as construction rate, availability of technology, climate) influence the cost-effectiveness of these instruments more than the exact program design and implementation details, though the level of stringency [76,78] and the stage in complexity is important [83]. On the other hand, voluntary agreements seem to be able to achieve smaller energy savings than most of the examples of standards, and require a culture of cooperation between the public authority and the contractors. Awareness raising programs, energy efficient procurement and public leadership programs are characterized by being size and design sensitive.

International transferability to reduce costs

Costs of designing and implementing MEPS, product labels, and building certificates and labels may be lowered due to their capacity to be easily adopted from other regimes. Simple tools to support the implementation of standards and labels (label designs, reference building types, monitoring rules) are widely and freely available [84], which makes these policy instruments potentially cheaper than others.

Using reinforcing policies to increase cost-effectiveness

Policies are rarely introduced alone and/or enter a virgin policy environment. The literature reviewed suggests that product energy performance standards and building codes are both cost-effective and environmentally-effective as stand-alone instruments, though packaging them with certification or labeling programs will increase their cost-effectiveness.

Awareness raising and information programs may act and be considered as catalyzers [85] to reinforce the impact of other policies, and their effects were not always clearly separated in the case studies reviewed (e.g. [51,62]).

[8] Note, not all case studies are represented in Figure 1 because of missing data on environmental effectiveness and because of comparatively low cost-effectiveness, which could not fit in the figure.

Furthermore, the success of awareness raising and information programs is significantly influenced by similar programs carried out previously.

Energy efficient procurement programs will be cheaper if other policy instruments are already in place. For example, labels can be used as benchmarks that can be referred to in procurement regulations, thus reducing costs. Financial tools and even more policies are often integral parts of voluntary agreements as seen in the examples assessed [62,64,65]. The effect of public leadership programs could be considered as overarching [62], and thus integrating the impact of several others, while savings from the 'leadership' itself are not quantified.

Further research needs

The presented conclusions should be taken as indicative of trends and more efforts should be allocated worldwide to collect published and also unpublished data, as well as to overcome data quality issues. The cost-effectiveness of policies and their selection thereof must be often reevaluated in order to follow market and social changes. To reflect the reality more properly, a methodology for the assessment of policy packages instead of individual policies should be sought. A regularly updated comparative assessment of costs and benefits of alternative policies and their packages would be a useful help for most countries, because the evolution of future governance regimes for a more sustainable building energy consumption depends on the successful selection of the most appropriate and most cost-effective policies.

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