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Review

A Review of the Measures and Instruments to Promote Efficiency and Renewable Energy in Domestic Water Heating

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Abstract: This paper identifies and characterizes the technical measures and policy instruments that can be used to promote energy efficiency and the use of renewable sources for domestic hot water (DHW). DHW presents a considerable potential for abatement of greenhouse gas emissions around the world. Measures were characterized in terms of level of transformation, impact and scope, among others. Policy instruments were characterized in terms of target groups, competences required for implementation, major challenges and nature of the instruments. A matrix showing the applicability of policy instruments per technical measure was derived, enabling policy makersto better choose articulated measures and policy instruments for their policy packs.

Keywords: domestic hot water; water heating; energy efficiency; climate change mitigation; climate policy; policy making; policy instruments

1. Introduction

The residential sector constitutes one of the greatest sources of untapped potential for energy efficiency improvements and reduction of GHG emissions. The CO_2 emissions reduction potential for the building stock in 2020 is estimated at 21–54% in developed economies, 26–46% in economies in transition and 18–41% in developing countries [1,2].

Water heating is one of the most basic energy services. It is the second largest energy use segment in the residential sector, accounting for 4% to 10% of the total energy used in developed economies [3]. Heating water for domestic activities comprises approximately 25% of households' energy use in Australia [4], 20% in Canada [5], 14% in the European Union [6], and 13.2% in US [7]. The importance of guaranteeing access to hot water and the weight of this service in the overall energy use in the residential sector make the achievement of more efficient and sustainable production and use of domestic hot water a global policy objective.

The socio-economic benefits of energy efficiency improvements associated with DHW are widely recognized, including the reduction of energy costs and the increase of wellbeing. Over the last decades, several governments have aimed for a better management of hot water use and promoted the use of renewable sources and/or more energy efficient systems.

Currently, the main challenge is to fulfill the sector needs with the most sustainable alternatives. Despite the large untapped potential for reduction of GHG emissions associated with DHW and the demonstrated political will to achieve it, there is still a lack of scaling-up of both technological and

non-technological opportunities for improvement [1]. Among the existing works, a thorough review on possible technical measures that may lead to the reduction of GHG emissions associated with DHW (through increase energy efficiency and/or the use of renewable energy sources) and the policy instruments that are more adequate for the respective implementation is still lacking and this gap may be hampering policy makers from taking informed decisions. Indeed, the identification of the technical measures to be promoted and the choice of policy instruments with which the later are promoted are key for a successful policy-making process (Figure 1).

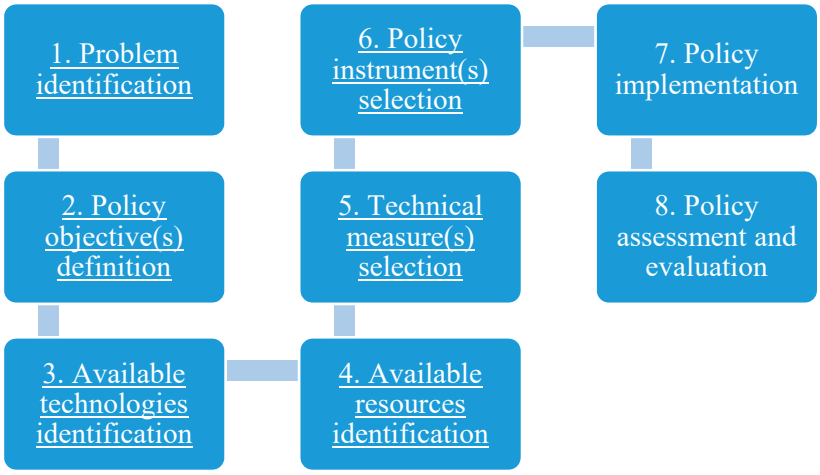

Figure 1. Water Heating System (WHS) Policy Process.

This paper aims to support WHS policy decision makers, with a focus on steps 5 and 6 as the steps where technical measures and policy instruments are to be selected, considering the WHS policy process described in Figure 1. The identification of their characteristics will allow the decision maker to better suit their selection criteria (preferences, resources and objectives) with the available options.

Regarding the organization of the paper, Section 2 provides an overview of the current and projected use of DHW around the world, including the associated energy use and GHG emissions. Section 3 describes the methodology followed to identify and characterize both the technical measures and the policy instruments. Section 4 presents the results of the review and proposes a classification scheme for the technical measures and for the policy instruments. Section 5 provides a discussion around the findings of the review, including on the relationship between technical measures and the policy instruments that are used for their implementation. Finally, Section 6 presents the conclusions.

2. Domestic Hot Water Situation Across the World

Water heating energy use varies across countries and regions, but, in general, it is associated with a high share of energy use. More than 50% of the residential energy use corresponds to thermal use, with a considerable contribution from water heating [2]. For the year 2000, the energy use associated with water heating in the residential sector corresponded to 480 Mtoe and reached 580 Mtoe in 2017 [8]. The increase in energy use can be associated with the increased use of hot water, which is not sufficiently counteracted by energy efficiency improvements. Moreover, future projections point to a significant increase of the associated energy use in the following years, especially in developing countries. Indeed, the growth in hot water use may imply a significant increase in the associated energy use or, on the other hand, reducing the hot water use would result in direct energy savings with their associated CO_2 reductions. For example, reducing the use of hot water in approximately 20% in the United States could lead to a reduction of 41 million MWh of electricity consumption and 240 billion cubic feet in the use of natural gas, corresponding to a reduction of about 38.3 million tons of CO_2 emissions [9].

Nowadays, the dominant technologies in the production of domestic hot water in buildings are either fossil fuels based or low-efficiency electrical technologies, with the exception of some developing economies where the traditional use of solid biomass is predominant [8].

Given the low-efficiency carbon-intensive technologies and the projected increase in the use of hot water, DWH comprises a large potential for energy efficiency improvements, and the reduction of GHG emissions [7]. The average level of emissions associated with the production of hot water varies significantly among the different DHW technologies, ranging from 0.02 $mtCO_{2\ eq.}$/Yr with a heat pump to 0.06 $mtCO_{2\ eq.}$/Yr with an electric water heater and to 0.87 $mtCO_{2\ eq.}$/Yr with a gas water heater [10].

Currently, the promotion of both energy efficiency and renewable energy use for water heating within the residential sector is already one of the priorities in energy policy at different governance levels. The set of solutions that can be promoted is large, given the wide variety of technologies available. The potential for reducing the CO_2 emissions associated with the production of hot water with the use of natural gas is estimated to be around 25.8 million tons of CO_2, while the adoption of electrical SWH technologies could lead to a reduction from 20.9 to 45.0 million tons [11].

3. Materials and Methods

In this paper, the identification and characterization of both technical measures and policy instruments used to promote energy efficiency and renewable energy use in DHW is based on an extensive literature review, identifying the WHS-related policies across the world.

To ensure the coherence of the review process, it was first necessary to define these concepts: "technical measures" and "policy instruments". Herein, technical measures refer to the actions that imply an actual change in the energy system and are implemented with the goal of achieving the established policy objectives. Policy instruments are tools of governance to influence targeted individuals or a group's behavior in order to achieve strategic public objectives [12]. Policy instruments can be considered as mechanisms that promote or support the implementation of the technical measures. Policies are normally executed through instruments or mechanisms that enable the implementation of the technical measures. Most of the instruments have been gathered from the policies where the technical measures were identified.

For the review, two databases on energy efficiency policies were taken as the starting point:

- The energy efficiency policies and programs database published by the International Energy Agency and retrieved from IEA (https://www.iea.org/policies) [13]. The list of policies was obtained by selecting the following filters: "heating and cooling" as sector and "Renewable Energy and Energy Efficiency" as topic.
- The solar thermal incentive database organized by and retrieved from Solarthermalworld (https://www.solarthermalworld.org/incentive) [14].

The selection of the two databases was based on the fact that these comprise a collection of several DHW policies, gathered from different national and international studies. They gather detailed information concerning several DHW policies, including location, timeframe, responsible authority, etc. More than 20 WHS policies across the world were retrieved from this review, including their correspondent technical measures and policy instruments.

To guarantee a more comprehensive review, an additional search was performed in the open browser google, under the expression "water heating efficiency technical measures". The first 50 sources displayed under this search were reviewed. This number was considered as a reasonable compromise between comprehensiveness and feasibility. The search lead to the identification of additional measures and consequently to the identification of additional policy instruments.

Finally, additional measures and instruments not found in the reviewed documents (e.g., prizes and awards, fines and tax increase, technology phase-out) were added to the list, supported by specific search based on personal experience and experts' opinions.

The review resulted in the identification of individual technical measures and policy instruments previously adopted in the promotion of energy efficiency and renewable energy use for domestic hot water. The identification of the combination of technical measures the policy instrument(s) used for their implementation was also performed. The results were organized in a table and are presented in Appendix A.

4. Results

4.1. Technical Measures

4.1.1. Identification of Technical Measures

The review of the energy efficiency policies led to the identification of a wide variety of technical measures, which were organized by type. Most of the reviewed policies promote a single technical measure, with only a few opting for the combination of several measures.

Measure 1: Adjusting the scale of the water heating system

1.1. Replacing collective system with individual WHS

Independent water heating systems (as opposed to collective) provide individuals with the possibility of controlling the devices' maintenance and operation, allowing them to make technical improvements when required. Moreover, individual metering allows for a detailed monitoring of the consumption pattern of each user, leading to a better identification of inefficiencies (technical or behavioral).

1.2. Installation of a collective WHS (building or district systems) in substitution of individual systems

Moving from individual to collective WHS is also feasible and may have advantages, depending on the context. The most adequate solution may vary depending on the characteristics of each building, but also criterion like the geographical location and the energy sources. A collective system could refer to a WHS which provides several dwellings in the same building or even several buildings. District heating is an example of a collective heating system (WHS included). The choice for a collective system may allow for the transition to more efficient and less carbon-intensive technologies that can only be effective in large-scale system. This could include the incorporation of renewable energy or excess heat.

Measure 2: Replacement of water heating technologies for more efficient or less-carbon intensive ones

Technology replacement is one of the most straightforward measures, as the replacement will normally imply the installation of a "better" technology (more efficient or cleaner technology). Differences in fuels, together with technical characteristics can be seen among the wide spectrum of options, varying from renewable energy systems, to electrical input devices and hybrid systems, existing in various configurations. The replacement trends vary from country to country, probably due to the context specificities as the benefits of the different technologies depend on the local conditions. The most common technology replacements identified through the revision of the different WHS energy efficiency policies are presented in Table 1. In general, electric and gas-based devices are replaced by cleaner source-powered technologies, as solar-powered devices.

Measure 3: Installation of solar thermal technologies (to complement WHS)

This measure corresponds to the installation of solar thermal panels to be combined with the already existing water heating device. This is an alternative to the replacement of the whole system, comprising the addition of the solar thermal system to the WHS already installed, reducing the use of energy by the later.

Table 1. Most common technology replacements.

		New Technology				
		Natural gas water heater	Natural gas central boiler	Solar water heater	Solar radiant heater	Renewable hot water (from DHC) *
Initial Technology	Fossil fuel water heater	X		X		X
	Electric tankless water heater	X				
	Electric storage water heater	X		X		
	Fossil fuel central heater		X		X	X
	Electric heat pump					X

* Renewable water heater includes district heating and cooling networks (DHC) and small-scale combined heat and power (CHP) units. It does not include solar water heaters (Source: own elaboration).

Measure 4: Insulation of boilers

Adding new or improving existing boilers' insulation can lead to energy savings. The insulation of already installed boilers can reduce the heat losses, and it may be a cheaper option than replacing the whole device.

Measure 5: Insulation of heating pipes

The piping system that is used in the distribution of the hot water by the different usage points can also be insulated, leading to a decrease in the heat losses of the whole WHS. The impact of this measure may depend on several factors, ranging from the outdoor temperature to the material of the pipes and the length of the distribution system.

Measure 6: Installation of (or replacement for) efficient water appliances

Water heating systems are combined with other appliances to provide end-use service, as could be the showerheads or the bathroom and kitchen taps. Thus, the installation of efficient (water saving or energy saving) devices may lead to a better use of the hot water. For instance, the installation of devices that reduce the water flow may lead to significant reductions of the total water use and, consequently, of the associated energy use.

Measure 7: Regular maintenance of Water Heating Systems

The performance of regular inspections may improve the daily operation of the hot water system and accelerate the identification and correction of malfunctions, and even the replacement of the devices (when necessary). The benefits of performing regular maintenance of the heating devices are numerous, including: to prevent system irregularities and cope with them opportunely, to guarantee that the energy performance does not get degraded faster than it should and to increase lifetime of the equipment.

Measure 8: Installation of smart systems

Nowadays, smart systems are available to improve the management of WHS at different scales (both individual and collective systems). These systems can include wireless monitoring and data collection systems. They could improve the monitoring of the heaters' operation status, allow for

automatic temperature control and to program schedules and other timing functionalities (tele control). In addition, monitoring functionalities can also comprise performance and malfunctions identification. Furthermore, some of the smart systems currently available allow for the automation of the WHS to turn on and off according to the individuals' preferences, as the hourly energy price or the availability of renewable energy sources (solar and wind).

Measure 9: Reduction in the use of hot water

Aiming to lower the water and energy consumption, actions like taking shorter showers or cleaning (dishes or clothes) with cold water can directly decrease DHW demand. The technical measures retrieved from the literature are shown in Table 2 and briefly described in the previous paragraphs.

Table 2. List of technical measures, type and source of identification.

Source	Policy Description			Technical Measure(s) Promoted	Type of Technical Measure(s)
	Name	Country/Region	Implementation Timeframe		
(Saskenergy, 2019) [15]	Energy Star Loan Program	Canada	2015	Device change (from fuel to gas)	Replacement of water heating technologies for more efficient ones Installation of solar thermal technologies
(FortisBC, 2019) [16]	British Columbia Energy Star Water Heater Program + Furnace and Boiler Replacement Program	Canada	2014		
(Energywise, 2019) [17]	Warm Up New Zealand: Heat Smart	New Zealand	2009	Device change (from oil boiler; Gas or propane furnace/boiler to more efficient ones)	
(Energywise, 2019) [17]	Insulation Programmes 2009–2018	New Zealand	2009		
(Domácnostiam, 2019) [18]	Slovakian Green Homes incentive programme	Slovakia	2019	Installation of renewable-based systems (SWH, photovoltaics, heat pumps, small wind-mills)	
(Enova, 2016) [19]	"Enovatilskuddet" (Enova grants)	Norway	2015	Installation of solar water heaters, pellet boilers and heat pumps	
(BAFA, 2019) [20]	Market Rebate Programme for Renewable Energy	Germany	2012	Installation of SWH systems, heat pumps, pellets tanks, woodchip equipment	
(Regulator for Energy and Water, 2019) [21]	Solar water heaters	Malta	2010	Installation of solar water heaters and heat pumps	
(Sklad, 2019) [22]	Eco Fund, Slovenian Environmental Public Fund	Slovenia	2009	Installation of Solar water heating systems and other renewable technologies	
(Bydlení, 2019) [23]	Nova Zelena Usporam	Czech Republic	2013	Installation Solar thermal systems, biomass boilers and heat pumps	
(Klima- und Energiefonds, 2019) [24]	Demoprojekte Solarhaus	Austria	2017		

Table 2. *Cont.*

Source	Policy Description			Technical Measure(s) Promoted	Type of Technical Measure(s)
	Name	Country/Region	Implementation Timeframe		
(Facility, 2014) [25]	Western Balkan Sustainable Energy Financing Facility II	The Western Balkan countries	2013	Solar thermal systems addition	Installation of solar thermal technologies (to complement WHS)
(Ministerio de Industria, 2014) [26]	Tax Rebate	Chile	2016		
(ANME, 2019) [27]	Prosol II	Tunisia	2005		
(Conservation, 2019) [28]	The National Financing Mechanism for Solar Water Heaters	Lebanon	2010		
(Ministerio de Industria, 2014) [26]	Solar Plan	Uruguay	2012		
(Economy Ministery, 2019) [29]	Programme for partial subsidising of purchased and installed solar water heaters for households	Macedonia	2017		
(Residential Energy Efficiency Credit Line, 2019) [30]	Residential Energy Efficiency Credit Line 3	Bulgaria	2016		
(California Solar Initiative, 2019) [31]	California Solar Initiative (CSI)-Thermal Program	California	2017		
(Agencia Andaluza de la Energía, 2019) [32]	Andalusia: Sustainable Construction Incentive Programme	Andalusia	2017	Installation of solar WHS (for new construction buildings)	
(Arctic Energy Alliance, 2019) [33]	Northwest Territories Energy Efficiency Incentive Program	Canada	2014	Electric hot water cylinder wraps installation	Insulation of boilers
(Aranda et al. 2017) [34]	Analysis of energy efficiency measures and retrofitting solutions for social housing buildings in Spain as a way to mitigate energy poverty	Spain	2017	Installation of efficient taps and showerheads	Installation of (or replacement by) efficient water appliances
(Savickas & Bielskus Directive, 2015) [35]	Technical measures to decrease heat energy consumption of final customer in multi-apartment buildings according to Energy Efficiency	Lithuania	2015	Independent heat substation for heat and hot water preparation; Hot water system balancing; Hot water metering for each final customer of the building; Smart intelligent wireless monitoring and data collection system	Individual/collective optimization of the water heating system. Installation of smart systems
(Poortinga and Steg, 2002) [36]	Viable behavioural and technological energy-saving measures	The Netherlands	2002	Rinsing dishes with cold water; shorter showers; Insulation of heating pipes	Reduction in the use of hot water. Insulation of heating pipes

4.1.2. Characterization of Technical Measures

In order to facilitate the assessment of the technical measures identified in the review process, these were characterized according to the following features: level of transformation; level of energy savings; scope (single vs. multi-apartment solution) and need for technical/specialized intervention (organized in Table 3).

Table 3. Characterization of the technical measures.

Technical Measure	Level of Transformation	Level of Energy Savings	Scope	Requirement of Trained Technician
1. Adjusting the scale of the water heating system.	Transformative	High Impact	Multi-apartment /Single apartment	Yes
2. Replacement of water heating technologies by more efficient or less-carbon intensive ones	Transformative	High Impact	Multi-apartment /Single apartment	No
3. Installation of solar thermal technologies (to complement WHS)	Transformative	High Impact	Multi-apartment /Single apartment	Yes
4. Insulation of boilers	Marginal	Low Impact	Multi-apartment /Single apartment	No
5. Heating pipes insulation	Marginal	Low Impact	Multi-apartment /Single apartment	No
6. Installation of (or replacement by) efficient water appliances	Marginal	Low Impact	Multi-apartment /Single apartment	Yes
7. Regular maintenance of water heating systems	Marginal	Low Impact	Multi-apartment /Single apartment	Yes
8. Installation of smart systems	Marginal	Low Impact	Multi-apartment /Single apartment	Yes
9. Reduction in the use of hot water	Marginal	Low Impact	Single apartment	No

- Level of transformation refers to the degree of change in the WHS due to the technical measure implementation. "Marginal" refers to small changes in the WHS, while "transformative" refers to significant interventions or changes. For example, the installation of more efficient appliances, as showerheads, can be considered a marginal transformation, while the installation of a solar thermal system to complement already existing WHS is a transformative measure. The analysis of this feature is important to understand if the measure can be implemented without a significant burden for the users, and without significant changes in the WHS system.
- Level of energy savings measures the energy efficiency improvements and it is classified as high or low, referring to the degree of energy-saving potential behind each measure, implying a change or considerable reduction in the fuel used, e.g., changing the shower head for more efficient ones saves up to 30% (low level of energy savings), while replacing technologies for efficient technologies can reach up to 90% (high level of energy savings) [37].
- Scope assesses if the measure can be applied to a single apartment and/or in a multi-apartment. This is important as it allows to identify the adequacy of the measures according to the dwelling typology.
- Need for technical/specialized intervention refers to how the measure implementation requires technical assistance or can be implemented directly by the final user. Its relevance relies on understanding if the measure requires specific workforce or skills for it to be implemented.

4.2. Policy Instruments

4.2.1. Identification of Policy Instruments

The policy instruments retrieved from the literature were organized by type. The different types of policy instruments identified are briefly described in the following paragraphs and also presented in Table 4.

Policy Instrument 1: Minimum Energy Performance Standard (MEPS)

As a well developed energy efficiency standard, MEPS establishes the minimum level of performance that a device must have to be sold in the market. With the aim of defining the required performance levels, standby losses are generally considered, for which testing procedures including standing loss tests are carried out [38]. MEPS normally lead consecutively to selling and installing products that are at least as efficient as defined in the standards. The use of energy standards is widely spread, whereas international agencies have participated through the creation of international references. The definition of standards can also happen by geographical areas, as has happened in North America (Canada, USA and Mexico) and in Australia and New Zealand [39]. The first standard creation for WHS in the EU was established in 1998 for gas boilers [40]. International standards have served as tools for national governments to base some regulations and achieve objectives [41]. Depending on the objectives, standards can be mandatory or voluntary.

Policy Instrument 2: Mandatory Standards

They are set as the obligatory requirements to be fulfilled by certain technologies. The obligation behind the mandatory standards provide support to policy makers to fasten the outcomes behind the supported policies.

2a: Voluntary Standards

Out coming as best practice from industry guidelines, voluntary standards can address a diversity of products. Standards may benefit final consumers by raising the quality or any other product characteristic. The application of voluntary standards is not exclusive to the industrial sector.

2b: Technology phase-out

Prohibit the installation of certain technologies represents another measure to cope with the energy-inefficient technologies, leading to ban the production and/or distribution of certain devices or systems with certain characteristics [42].

Policy Instrument 3: Rating System/Building Index

Rating systems as evaluation tools, can serve to create a benchmark among buildings, providing an alternative for evaluating and comparing criteria (e.g., efficiency, use, costs). Different scales can be used through the ratings; the National Energy Performance rating system in the US uses a 1 to 100 scale, whereas the higher the score, the better energy performer the evaluated facility is [43]. One of the purposes of rating systems is to provide practical information to stakeholders and decision makers about the efficiency and inefficiency of buildings [44]. Building index is an organized form of building evaluation, whereas a score is given to every evaluated facility. They both can serve as a basis to building certification. More specifically, building certification is one way to certificate the energy performance. Buildings are required to guarantee the energy characteristics defined in the regulation. A framing option to certificate a building in some countries is the Nearly Zero Energy Buildings (NZEB). This approach helps to reduce the building footprints (carbon emissions), improving the energy efficiency. The scope of terms and categories under the concept of NZEBs embraces a wide variety. Under the scope of a NZEBs high energy performance buildings are included, but can also refer to the production of the energy consumed in the building by renewable sources produced on-site or nearby [45].

Policy Instrument 4: Labelling

Energy labelling, as the way to categorize products under certain characteristics, provide information regarding the product technical data (e.g., efficiency). By labelling, the energy efficiency requirements in the manufacture of the product is promoted, leading to impulse market take-up of certain products or technologies.

Policy Instrument 5: Certification

Certificating certain type(s) of equipment (boilers and WHS) may include the compliance of MEPS, minimum device age or any other characteristic validated under the regulation or market criteria. For WHS, some examples include minimum efficiency levels. It is closely related to Labelling.

Policy Instrument 6: Information, education and awareness campaigns

Education and awareness campaigns provide information to consumers, service providers and/or any other targeted stakeholders. Information aimed to be communicated to the targeted audience may comprise the potential for energy savings, available WHS devices and appliances. It is frequent, through this instrument, to inform the final consumer on the benefits and drawbacks associated with the different WHS technologies available in the market and advise them on how to improve their own performance. The provision of more specific information through training or workshops is another option, usually targeting a more specific audience as technicians and other service providers. In general, this type of instrument is relatively easy to implement and does not require significant investments [46].

Policy Instrument 7: Grants and Subsidies

Subsidies, as a financial support, aim to reduce the capital cost of a technology, enabling the market growth of the technology. These instruments have widely been used across the countries, and most of the times, the incentives become unnecessary, after the market has been developed [47].

Policy Instrument 8: Tax credits/tax incentives

This type of instruments corresponds to a positive financial incentive, meaning that incentivizes consumers (or other stakeholders) with actions that benefit the final user as tax rebates or tax exemptions. These aim to reduce the total investment of the WHS acquisition.

Policy Instrument 9: Fines and tax increases

As a negative form of incentive, fines and tax increase, are used to penalize the non-compliance or abuse of certain actions [48].

Policy Instrument 10: Low-interest loans/third-party financing

Another financial aid suitable for the acquisition of solar water heater (SWH) is to facilitate the access to credit. This option can be complemented with other policy instruments.

Policy Instrument 11: Prizes and Awards

This corresponds to the identification and recognition of best practices or any desired parameters through a prize or award. The prize could be economic or not [49].

All these types of instruments can be used alone or combined. The combinations of instruments is worth mentioning, whereas more than one instrument is applied, and it has been identified in different documents of this review.

Table 4. Policy Instruments list.

Reference	Policy	Country	Year	Detailed Policy Instrument	Policy Instruments Type
(Saskenergy, 2019)	Energy Star Loan Program (SaskEnergy/SaskPower)	Canada	2015	Fiscal incentives	Tax credits/tax incentives
(FortisBC, 2019)	British Columbia Energy Star Water Heater Program + Furnace and Boiler Replacement Program	Canada	2014		
(Arctic Energy Alliance, 2019)	Northwest Territories Energy Efficiency Incentive Program	Canada	2014		
(Ministerio de Industria, 2014)	Tax Rebate	Chile	2016	Tax relief	
(Energywise, 2019)	Warm Up New Zealand: Heat Smart	New Zealand	2009	Grants and subsidies	Grants and Subsidies
(Energywise, 2019)	Insulation Programmes 2009–2018	New Zealand	2009		
(California Solar Initiative, 2019)	California Solar Initiative (CSI)—Thermal Program	California	2017	Rebate	
(Regulator for Energy and Water, 2019)	Solar water heaters	Malta	2010		
(ANME, 2019)	Prosol II	Tunisia	2005	Grant or reimbursable credit	
(Agencia Andaluza de la Energía, 2019)	Andalusia: Sustainable Construction Incentive Programme	Andalusia	2017	Economic Subsidy	
(Enova, 2016)	"Enovatilskuddet" (Enova grants)	Norway	2015		
(BAFA, 2019)	Market Rebate Programme for Renewable Energy	Germany	2012		
(Bydlení, 2019)	Nova Zelena Usporam (New Green Savings/New Greenlight to Savings)	Czech Republic	2013		
(Economy Ministery, 2019)	Programme for partial subsidising of purchased and installed solar water heaters for households	Macedonia	2017	Subsidy for investment	
(Domácnostiam, 2019)	Slovakian incentive programme Green Homes	Slovakia	2019		
(Klima-und Energiefonds, 2019)	Demoprojekte Solarhaus (Demo Projects Solar House)	Austria	2017		
(Residential Energy Efficiency Credit Line, 2019)	Residential Energy Efficiency Credit Line 3 (REECL 3)	Bulgaria	2016	Loan and investment grants	
(LODA/LODA—Lviv Regional State Administration, 2019) [50]	Energy Saving programme for residents of the Lviv region for the year 2013–2016	Ukraine	2013	Low-interest loans	
(Csobod et al. 2009) [51]	Overview and Analysis of Public Awareness Raising Strategies and action on energy savings	Central and Eastern Europe (CEEC)	2009	Informative campaigns	Information, education and awareness campaigns
(IMT), 2009)	A roadmap for creating building energy rating systems in Central Asia	Central Asia	2009	Rating systems	Rating systems
(D'Agostino and Mazzarella, 2019)	What is a Nearly zero energy building? Overview, implementation and comparison of definitions	Europe	2018	Building Index	Building Index
(Dungen, 2011)	Energy Performance Standards How does New Zealand compare with other countries?	New Zealand	2011	Minimum Energy Performance Standard (MEPS)	Standards
(Johnson et al., 2013)	An International Survey of Electric Storage Tank Water Heater Efficiency and Standards	New Zealand	2013	Minimum Energy Performance Standard (MEPS)	
(Turiel, 2000)	Present status of residential appliance energy efficiency standards—an international review	International	2000	Other Standards	
(Pusok and Morris, 2018) [52].	Voluntary Energy Standards: ISO 50001 and the superior energy standards	International	2018	Other Standards	

Table 4. *Cont.*

Reference	Policy	Country	Year	Detailed Policy Instrument	Policy Instruments Type
(Reed, 2002)	National Energy Performance Rating System	USA	2002	Rating System	Rating System
(UNECE, 2018) [53]	Mapping of Existing Energy Efficiency Standards and Technologies in Buildings in the UNECE Region	UNECE Region	2018	Building energy codes; Energy Performance Certification; Labelling	Combined (more than one instrument)
(WEC, 2016)	Energy Efficiency Policies around the World: Review and Evaluation	International	2008	Labelling, Codes & Standards	
(Government of Australia, 2019)	Water Heating Energy Rating	International	2019	Labelling, Codes & Standards	
(Norden, 2015)	Nordsyn—energy labelling requirements for packages of water heaters and solar devices	International	2015	Labelling, Codes & Standards	
(National Housing Bank, 2015) [54]	Capital subsidy scheme for installation of solar thermal systems	India	2014	Soft Loans + Subsidy	
(Ministerio de Industria, 2014)	Solar Plan	Uruguay	2012		
(Conservation, 2019)	The National Financing Mechanism for Solar Water Heaters	Lebanon	2010		
(Facility, 2014)	Western Balkan Sustainable Energy Financing Facility II (WeBSEFF II)	The Western Balkan countries	2013	Loans and Grants	
(Sklad, 2019)	Eco Fund, Slovenian Environmental Public Fund	Slovenia	2009		

The instruments have been organized in Table 4 by the details of the policy or document where they were identified, their detailed instrument and type. Most of the instruments have been gathered from the same policies where the technical measures were identified.

4.2.2. Characterization of Policy Instruments

The identified instruments have been characterized regarding five major aspects and presented in Table 5:

(i) Required competences refers to the regulatory competences required to policy makers for the instrument implementation (buildings, technology development, market development and taxation definition).

(ii) Target group refers to the actors that are most commonly targeted by the different policy instruments (e.g., installers, construction sector and final consumer, technology developers or industry, etc.).

(iii) Most common levels of implementation correspond to the governance level(s) the different policy instruments are commonly implemented, including local, national and international approach.

(iv) Major or key challenges and barriers related to each policy instrument.

(v) The policy instruments retrieved have also been classified in three categories: (a) regulating; (b) informative; and (c) incentivizing. By "regulating" it is meant those instruments that are normally used to formally implement an action, normally through a binding status, compared with informative, whose aim is to provide information to different stakeholders. The instruments enlisted as incentivizing relate to the provision of stimulus (commonly economically) for the measure to be implemented.

Table 5. Policy instruments characterization/relation between technical measures and policy instruments.

Policy Instruments	Required Competences	Target Group	Most Common Levels of Implementation	Challenges/Barriers to Implementation	Categorization of Instrument
1. Minimum Energy Performance Standard (MEPS)	Communication with customers	Technology developers (industry), final consumers	Regional/National	Industry (manufacturers) capability (Johnson et al., 2013 [38]); clients or other stakeholders' disapproval	Regulating
2. Technology Phase-out	Market organization and regulation	Final Consumers	Local, National	Industry and other stakeholders' disapproval	Regulating
3. Rating System/Building Index	Expert qualification & planning	Construction sector	National	Info availability Public's general environmental ignorance and low awareness of social and economic benefits of energy efficiency ((IMT), 2009) Financial costs (D'Agostino and Mazzarella, 2019 [45])	Informative
4. Labelling	Information provision	Final Consumers	Regional/National	Lack of understanding by targeted audience	Informative
5. Certification	Planning	Technology developers (Industry), Final Consumers	National	High demand volume	Informative
6. Information, Education and awareness	Communication with customers	Installers, Construction Sector and Final Consumers	National, Regional, Local	Lack of interest from targeted audience	Informative
7. Grants and Subsidies	Communication with customers	Installers and Final Consumers	National, Regional, Local	Attraction of wrong audience Fiscal Costs (IMF, 2015) private-sector under-investment,	Incentivizing
8. Tax credits/tax incentives	Regulation; Proximity and communication with customers	Installers and Final Consumers	National/Regional	Attraction of wrong audience Market failure and negative effects private-sector under-investment,	Incentivizing
9. Fines and tax increase.	Regulation and planning	Installers and Final Consumers	National, Regional, Local	Not achievement of the policy targets	Incentivizing
10. Low-interest loans/third-party financing	Regulation; Proximity and communication with customers	Installers and Final Consumers	National/Regional	Attraction of wrong audience Supporting the wrong industry development (e.g., foreign vs local)	Incentivizing
11. Prize and Awards	Regulation, planning and economic resources	Installers and Final Consumers	National, Regional, Local	Expensiveness	Incentivizing

4.3. Relation Between Technical Measures and Policy Instruments

The relation between technical measures and policy instruments was assessed in this review by identifying the policy instruments that were adopted to foster the implementation of the different technical measures. This analysis is systematized in Table 6. The detailed technical measures have been enlisted with a corresponding policy instrument. This identification allows for the analysis of which instruments are more often used to promote the implementation of certain measures.

Table 6. Combination of technical measures and policy instruments identified in the literature review.

		Policy Instruments										
		1. MEPS and other standards	2. Technology phase-out	3. Rating system	4. Labelling	5. Certification	6. Information, Education and awareness	7. Grants and subsidies	8. Tax credits/tax incentives	9. Fines and tax increase.	10. Low-interest loans/Third-party financing	11. Prizes and awards
Technical Measures	1. Individual/collect-ive optimization of the WHS	X			X							
	2. Replacement of WH technologies for more efficient or less-carbon intensive ones							X	X			
	3. Installation of solar thermal technologies (to complement WHS)	X		X			X	X			X	
	4. Insulation of boilers			X								
	5. Heating pipes insulation											
	6. Installation of (or replacement for) efficient water appliances			X	X	X						
	7. Regular maintenance of Water Heating Systems											
	8. Installation of Smart systems	X			X							
	9. Reduction in the use of hot water							X				

5. Discussion

The review resulted in the identification of a wide set of technical measures, that go from the installation of devices that improve the system's performance to the replacement of the whole existing system by a new one (more efficient, with a technology shift). The great majority of the technical measures found within the policies and programs reviewed refers to the replacement of the WHS technology or to the installation of devices or equipment that improves the system's performance.

When analyzing the identified measures, it was noted substantial differences and a wide spectrum of possibilities. When assessing the scope of the measures by their applicability in a single vs. multi-apartment, it was found that most measures are not constrained by the type of dwelling, being applicable to both, single and multi-apartment buildings. The installation of solar thermal and photovoltaic systems could be an exception, depending on the roof area available, together with the change from an individual to a collective WHS (Individual/collective optimization of the system). Moreover, when characterizing the measures according to the need for technical or specialized intervention, most of the identified measures require technical expertise to be implemented. There are still a few measures that can be directly implemented by the final user, as the reduction in the use of hot water.

By identifying the policy instruments used to support the implementation of the reviewed WHS policies, it was possible to observe that the instruments mostly used are either economic instruments, education and awareness campaigns or labelling and standards. For instance, regulatory instruments are not commonly adopted in the implementation of policies associated with DHW.

When characterizing the policy instruments under the selected variables, it was found that the competences required for the implementation of each instrument are considerably different. Even so, the competences required for the implementation of instruments under the incentivizing category are relatively similar. This coincidence can be explained by the similarity in their main activities, even if different instruments may require different specific actions for their implementation.

The two most common levels of implementation found are national and regional; not many instruments have been found to explicitly apply a local or international geographical scope.

Regarding the possible challenges or barriers faced by policy makers throughout the instruments' implementation, market-related problems are the most common, whereas the state of the market may be determinant for the instrument choice, e.g., the existing market (or institutional) barriers that are currently hampering the distribution and commercialization of certain technologies.

The large and diverse set of stakeholders that interact with the WHS-related markets may imply a difficulty in choosing the most effective policy instrument(s), as the impact on different stakeholders will vary substantially. Nevertheless, the selection of some instruments may lead to positive externalities, as the economic effect on certain technologies (price decrease), as a consequence of the market development and spread of those technologies (after the use of incentivizing instruments); or the innovation boost derived from the technological research encouragement behind the economic support of certain technologies.

Another important finding of this review refers to the features that need to be taken into account when choosing the technical measures to the promoted and the respective policy instruments. By classifying the instruments and relating them with the technical measures, it was possible to identify how the informative instruments are widely used, both directly and indirectly. Providing information, educating the consumer and other stakeholders and raising the awareness of different actors may be used to demonstrate the benefits and relevance of energy efficiency, help and assist a consumer with the installation of a more efficient device, and even incentivize regular inspections and maintenance work. Informative instruments could also lead to measures that require behavioral changes from final users, as using less hot water.

Moreover, it was also noted that economic instruments are often used to promote the implementation of measures that require engaging consumers, to commit to the policy objectives (partially or totally). Economic instruments are considered to be effective for consumer engagement, probably due to the positive response of consumers to financial rewards, and their willingness to change their energy use in exchange for a monetary compensation [55].

Even so, there are situations where the financial reward may not be enough. For instance, for gauging the attention and commitment of the targeted group, economic stimulus could be insufficient (as when a lack of interest from targeted audience can be experienced). These cases may be overcome by the combination of several policy instruments. For instance, when experiencing a low participation level to initiatives that are based on economic instruments, education and awareness initiatives may be used to foster participation and adhesion to the economic incentives. Therefore, the combination of the instruments should be seen as a possibility, which may have advantages depending on the policy objectives and characteristics of the target group as well as on the available resources.

6. Conclusions

This work led to the identification and classification of nine types of WHS technical measures. These were characterized in terms of scope, level of transformation, level of energy savings and the requirements for training for their implementation. By classifying the measures, it was also possible to understand and systematize the differences among them. After this, decision makers can evaluate their alternatives, taking into consideration the different features.

Moreover, eleven types of policy instruments were also identified and characterized according to the required competences for implementation, the most common levels in which they are implemented, and the challenges that may hamper their implementation. The characterization of policy instruments

according to their main features has been performed, enabling policy makers to compare them against the available resources and context characteristics, and to select the most suitable instruments.

Lastly, an identification and assessment of the most common combinations between technical measures and policy instruments was also included in this work. Results show that there has been a preference of using economic instruments to support DHW technologies. A notable relevance and applicability of the "education and awareness campaigns instruments was identified". Complementarity among instruments has been observed, leading to the policy instruments combination with other policy instruments, providing a wider set of alternatives.

- Considering the policy characterization performed in this work, some of the context specificities that should be assessed in order to choose the most adequate measure/instruments include:
- Policy objective (e.g., reduce GHG emissions, energy savings, reduced costs, etc.);
- Main type of dwellings covered by the policy;
- Availability of skilled/trained technical staff;
- Regulatory competences of the entity responsible for the policy implementation;
- Budget/resources availability;
- Policy target group (e.g., end-user, technology provider, technology developer, etc.).

Future work in this topic could include analyzing in detail the cost structure of the measures and instruments (average costs and who pays for it), and identifying/recommending regional differences regarding the choice of instruments to be adopted, based on the local specificities found. In this field there is ongoing work regarding the correlation of policy results with the contextual variables. Starting at the identification of suitable, criteria and indicators to characterize the results [56]. The development of this work should eventually lead to the possibility of adapting policies to the local geography.

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Abbreviations

DHW	Domestic Hot Water
GHG	Greenhouse Effect Gases
RES	Renewable Energy Sources
SWH	Solar Water Heater
WHS	Water Heating Systems

Appendix A

The identified technical measures have been enlisted with the policy instrument used to implement the policies.

Table A1. Technical measure with policy instrument.

Detailed Technical Measure	Technical Measure Type	Detailed Policy Instrument	Policy Instruments Type	Policy or Document
Device change (from fuel to gas)	Installation/Replacement of heating technologies with more efficient ones	Fiscal/financial incentives	Tax credits/tax incentives	Energy Star Loan Program (SaskEnergy/SaskPower)
				British Columbia Energy Star Water Heater Program + Furnace and Boiler Replacement Program
Device change (from oil boiler; Gas or propane furnace/boiler to more efficient ones)				Warm Up New Zealand: Heat Smart
		Rebate		Insulation Programmes 2009–2018
Installation of renewable-based systems (SWH, photovoltaics, heat pumps, small windmills)				Slovakian incentive programme Green Homes
Installation of solar water heaters, pellet boilers and heat pumps				"Enovatilskuddet" (Enova grants)
Installation of SWH systems, heat pumps, pellets tanks, woodchips equipment		Tax relief		Market Rebate Programme for Renewable Energy
Installation of solar water heaters and heat pumps		Tax credits		Solar water heaters
Installation of Solar water heating systems and other renewable technologies				Eco Fund, Slovenian Environmental Public Fund
Addition Solar thermal systems, biomass boilers and heat pumps		Grant or reimbursable credit		Nova Zelena Usporam (New Green Savings/New Greenlight to Savings)
Solar thermal systems addition	Addition/installation of solar thermal technologies (to complement WHS)	Economic Subsidy		Demoprojekte Solarhaus(Demo Projects Solar House)
				Industrial and Institutional solar thermal collector systems for water heating needs
				Western Balkan Sustainable Energy Financing Facility II (WeBSEFF II)
				Montesol
				Energy Saving programme for residents of the Lviv region for the year 2013-2016
				Prosol II
				Capital subsidy scheme for installation of solar thermal systems

Table A1. *Cont.*

Detailed Technical Measure	Technical Measure Type	Detailed Policy Instrument	Policy Instruments Type	Policy or Document
		Interest-free loans	Low-interest loans/third-party financing	The National Financing Mechanism for Solar Water Heaters
				Mechanism of Renewable Heating Systems and Energy Efficient Measures "Conto termico 2.0"
		Loan and investment grants		Solar Plan
		Low-interest loans		Programme for partial subsidising of purchased and installed solar water heaters for households
		Informative campaigns	Information, education and awareness campaigns	Residential Energy Efficiency Credit Line 3 (REECL 3)
		Rating systems	Rating systems	Energy Efficient Homes Package and Solar Hot Water Rebate
Installation of solar WHS (for new construction buildings)		Other Standards		Andalusia: Sustainable Construction Incentive Programme
Electric hot water cylinder wraps installation Insullation	Insulation of boilers	Rating System	Rating System	Northwest Territories Energy Efficiency Incentive Program
Installation of efficient taps and showerheads	Installation of (or replacement for) efficient water appliances	Building energy codes; Energy Performance Certification; Labelling	Combined (more than one instrument)	Analysis of Energy Efficiency Measures and Retrofitting Solutions for Social Housing Buildings in Spain as a Way to Mitigate Energy Poverty Aranda et al., 2017 [34]
Independent heat substation for heat and hot water preparation; Hot water system balancing; Hot water metering for each final customer of the building; Smart intelligent wireless monitoring and data collection system	Optimization of scale of the system; smart systems installation	Labelling, Codes & Standards		Technical measures to decrease heat energy consumption of final customer in multi-apartment buildings according to Energy Efficiency (Savickas and Bielskus Directive, 2015 [35])
Rinsing dishes with cold water; shorter showers; Insulation of heating pipes	Reduction in the use of hot water; Insulation of heating pipes	Soft Loans + Subsidy		Viable behavioural and technological energy-saving measures (Poortinga and Steg, 2002 [36]

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