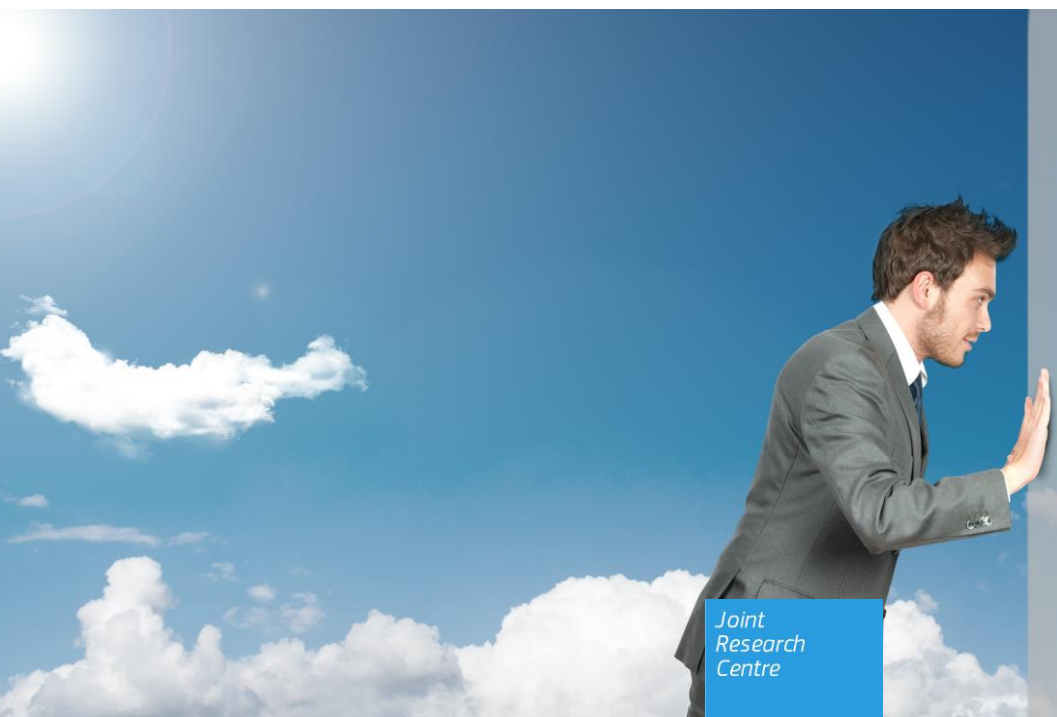European Commission

JRC SCIENCE AND POLICY REPORT

Market-based instruments to reduce air emissions from household heating appliances

Analysis of scrappage policy scenarios

Iñaki Arto, Kurt Kratena, Antonio F. Amores, Umed Temurshoev, Gerhard Streicher

2015

Joint Research Centre

Abstract

This document explores the potential for the use of a market-based instrument to contribute to reducing the emissions of particulate matter of less than 10 micrometres from household heating appliances in the framework of the review of the Thematic Strategy on Air Pollution. The study is focused on the assessment of the economic and environmental impacts of possible scrappage policies for promoting the accelerated replacement of existing heating appliances with cleaner ones. Under these policy programmes, households replacing an old appliance with a cleaner one would receive a subsidy from the government. This subsidy would compensate households for the residual value of the scrapped appliance and the opportunity costs of the early investment in a new one.
Two different scenarios are analysed: The scrappage and replacement of all the different types of conventional appliances that do not incorporate any emission control technology ('non-controlled'), and the scrappage and replacement of only 'non-controlled' firewood- and hard-coal-fired manual single house boilers. It is assumed that the scrappage programme is in force between 2018 and 2020. For each scenario, the study focuses on the effects of different levels of replacement of the 'non-controlled' appliances and the size of subsidies relative to the investment costs.

Market-based instruments to reduce air emissions from household heating appliances:
Analysis of scrappage policy scenarios

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September 2015

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[*] The views expressed in this paper are those of the authors and should not be attributed to the European Commission or its services.

EXECUTIVE SUMMARY

This document explores the potential for the use of a market-based instrument to contribute to reducing the emissions of particulate matter of less than 10 micrometres (PM10) from household heating appliances in the framework of the review of the Thematic Strategy on Air Pollution (TSAP). The study is focused on the assessment of the economic and environmental impacts of possible scrappage policies for promoting the accelerated replacement of existing heating appliances with cleaner ones. Under these policy programmes, households replacing an old appliance with a cleaner one would receive a subsidy from the government. This subsidy would compensate households for the residual value of the scrapped appliance and the opportunity costs of the early investment in a new one.

Two different scenarios are analysed: a 'Scrappage All' scenario where all the different types of conventional appliances that do not incorporate any emission control technology ('non-controlled' appliances) are replaced, and a 'Scrappage SHB' scenario where only 'non-controlled' firewood- and hard-coal-fired manual single house boilers (SHB) are replaced. It is assumed that the scrappage programme is in force for three years (between 2018 and 2020). For each of these scenarios, the study further focuses on the effects of different levels of replacement of the 'non-controlled' appliances and the size of subsidies relative to the investment costs.

Results for the EU-27 show that a scrappage programme designed to replace all types of 'non-controlled' appliances, and with subsidies limited to 20% of the investment costs, could contribute to the reduction of the emissions of PM10 from household heating appliances in 2020 by 18% (-79 kt), with a reduction of 7.4% (-22 kt) with respect to the average emissions of the period 2018-2030. This early replacement would increase the average annual investment costs of the period 2018-2030 by 11% (+ EUR 1.5 billion/year). Total subsidies to compensate households for the early replacement would amount to EUR 9.4 billion during the period 2018-2020. Health benefits of this policy scenario would total between EUR 0.9 billion and 2.7 billion per year. This scheme would increase the Gross Value Added (GVA) by EUR 2.3 billion/year.

The scrappage mechanism that only targets SHB, and with subsidies limited to 20% of the costs, could achieve 9% of the reduction resulting from the previous 'Scrappage All' scenario, while cutting the abatement costs and subsidies to 3.7% and 4.9% respectively. This mechanism would reduce PM10 emissions in 2020 by 3% (-13.3 kt) and the average emissions of the period 2018-2030 by 0.7% (-2.1 kt), and the costs would increase by 0.5% (EUR 55.6 million/year). Total subsidies during the period 2018-2020 would sum to EUR 411 million. Health benefits would range from EUR 147 million to EUR 424 million per year. Around 50% of the investment costs and subsidies, and 61% of the reduction in PM10 emissions, would be generated by the accelerated replacement of SHB in Poland. This scrappage mechanism would increase the GVA by EUR 106 million/year; 42% of the total increase in the GVA would be in Poland, 11% in Germany, 8.5% in Slovenia and 7% in the United Kingdom.

Content

1. INTRODUCTION

The Thematic Strategy on Air Pollution (TSAP) of 2005 (CEC, 2005) established objectives for the protection of health and the environment from the adverse impacts of air pollution. The Commission's 2013 work programme includes a comprehensive review of the Strategy with a view to making further progress towards the objective of the Environment Action Programme (established in the 6th and confirmed in the 7th EAP; CEC, 2013) of attaining '*levels of air quality that do not give rise to significant negative impacts on, and risks to human health and the environment*'. This review requires a comprehensive and integrated assessment of different policy options and instruments to contribute to the achievement of the TSAP objectives.

Over the last few decades, there has been growing concern about the impact on human health of the exposure to fine particles. One of the main sources of emissions of these pollutants is the combustion of solid fuels and biomass in household heating appliances. As a result, the review of the TSAP has devoted specific attention to the reduction of the emissions of fine particulate matter from household heating appliances.

In this context, this document explores the potential for the use of market-based instruments to contribute to the reduction of the emissions of particulate matter of less than 10 micrometres (PM10) from the combustion of solid fuels in household heating appliances which do not incorporate any emission control technology ('non-controlled' appliances). The study is focused on the assessment of the economic and environmental impacts of different scrappage systems for the purpose of promoting the early replacement of existing heating appliances with cleaner ones. Two different systems are analysed: a 'Scrappage All' scenario where all the different types of 'non-controlled' appliances are replaced, and 'Scrappage SHB' scenario where only firewood- and hard-coal-fired manual single house boilers (SHB) are targeted.

The modelling exercise is carried out in two steps. First, a model relating the use of energy, emissions, technologies and costs is developed in order to simulate the effects in terms of PM10 emissions and costs of the penetration of different technologies. This model was calibrated using relevant data from the GAINS model (see[1] Amann et al., 2011, for details on the GAINS model, and Klimont et al., 2002, for the modelling of PM10). Second, the cost structures resulting from this micro-model are introduced into the FIDELIO model in order to compute the macroeconomic impacts of each scenario in terms of changes in the Gross Value Added (GVA) (for details about FIDELIO, see Kratena et al., 2013).

2. SCENARIO DESCRIPTION

The following three scenarios are considered:

- The 'Baseline' corresponds to the GAINS TSAP-Dec2012, TSAP_Baseline_Nov12 scenario.

- On top of the 'Baseline' scenario, the 'Ecodesign' scenario assumes that, following the Commission regulations implementing the Ecodesign Directive (Directive 2009/125/EC) for local space heaters and solid fuel boilers (including fireplaces, automatic and manual single house boilers, and stoves), all new appliances sold

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[1] http://gains.iiasa.ac.at/models/

from 2018 onwards[2] will comply with the emission standards established by the new legislation. According to this scenario, the stock of 'non-controlled' fireplaces, manual single house boilers and stoves would be gradually replaced by cleaner ones according to their depreciation rates, in such a way that by around 2045 the whole stock of 'non-controlled' appliances would have been replaced.

- The 'Scrappage' scenario consists of the introduction of an early scrapping mechanism to promote accelerated penetration of cleaner technologies, taking as a starting point the composition of the stock of appliances of the 'Ecodesign' scenario. The objective of this policy is to reduce the emissions of PM10 from household heating appliances by accelerating the replacement of all or part of the existing 'non-controlled' appliances by new appliances between 2018 and 2020. Households replacing an old appliance with a cleaner one are assumed to receive a subsidy from the government. This subsidy will compensate households for the opportunity costs of early replacement. The mechanism is designed to be budget-neutral as the subsidy is compensated by an equivalent reduction in government expenditures. We assume that the scrappage mechanism is in place for three years starting from 2018 and is applicable only to fireplaces, manual single house boilers[3] and stoves (henceforth referred to as eligible appliances).[4] This scenario explores two different schemes of scrappage depending on the type of appliances targeted. In the first scheme, called 'Scrappage All', the replacement of all types of eligible 'non-controlled' appliances is subsidised. This scheme could achieve the maximum feasible reduction in emissions by replacing, in 2018-2020, all the eligible 'non-controlled' appliances reported by the 'Ecodesign' scenario for the year 2020. However, replacing the entire stock of 'non-controlled' appliances within the space of a few years could be very costly. Therefore, we also analyse the effects of replacing different shares of the stock of 'non-controlled' appliances. In the second scheme, called 'Scrappage SHB', only the replacement of eligible firewood- and coal-fired manual single house boilers (SHB) is subsidised; the rationale of this option is that 'non-controlled' firewood- and coal-fired SHB are among the most polluting and widespread installations, and their replacement could deliver high health benefits with limited expenditure. Again, different replacement shares are analysed.

Further details on the construction of these scenarios can be found in the Annex.

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[2] The scenario was built based on an initial proposal of the ecodesign regulation, which was later modified: The final text adopted by the European Commission establishes 1st January 2020 for solid fuel local space heating and 1-1-2022 for solid fuel boilers, instead of 2018 as for the rest of appliances. Besides, different Emission Limit Values where eventually adopted: In the impact assessment, the limits differentiated between wood boilers (20 microgr/m³) and coal (40 microgr/m³). Now they differentiate between manual (60 microgr/m³) and automatic (540 microgr/m³) boilers. The results for this scenario can therefore not be understood as representing an estimate of the costs or benefits of the actual ecodesign regulation.

[3] The scrappage mechanism does not consider the replacement of automatic single house boilers, since the emissions of these appliances are low compared to other appliances.

[4] The full list of appliances can be found in Table A2 of the Annex.

3. RESULTS

3.1. Emissions from household heating appliances

Figure 1 shows the development of the emissions of PM10 from EU-27 household heating appliances for the 'Baseline', 'Ecodesign' and 'Scrappage' scenarios for the period 2018-2045. Emissions of particulate matter in the 'Baseline' scenario decrease by 178 kilotonnes (kt), from 543 kt in 2018 to 365 kt in 2045 (-33%); and focusing on the period 2018-2030, emissions are reduced by 131kt (-24%). The emission standards proposed for fireplaces, single house boilers and stoves in the preparatory studies for setting the Ecodesign requirements of the Ecodesign Directive for solid fuel small combustion installations (Bio Intelligence Service, 2010) are considerably lower than the current emission coefficients of new appliances currently on the market.[5] Consequently, the introduction of the new particulate matter emission standards for those heating appliances could contribute to a significant reduction in emissions.

Figure 1. Change in the emissions of PM10 (kt) from household heating appliances for different policy scenarios, EU-27, 2018-2045
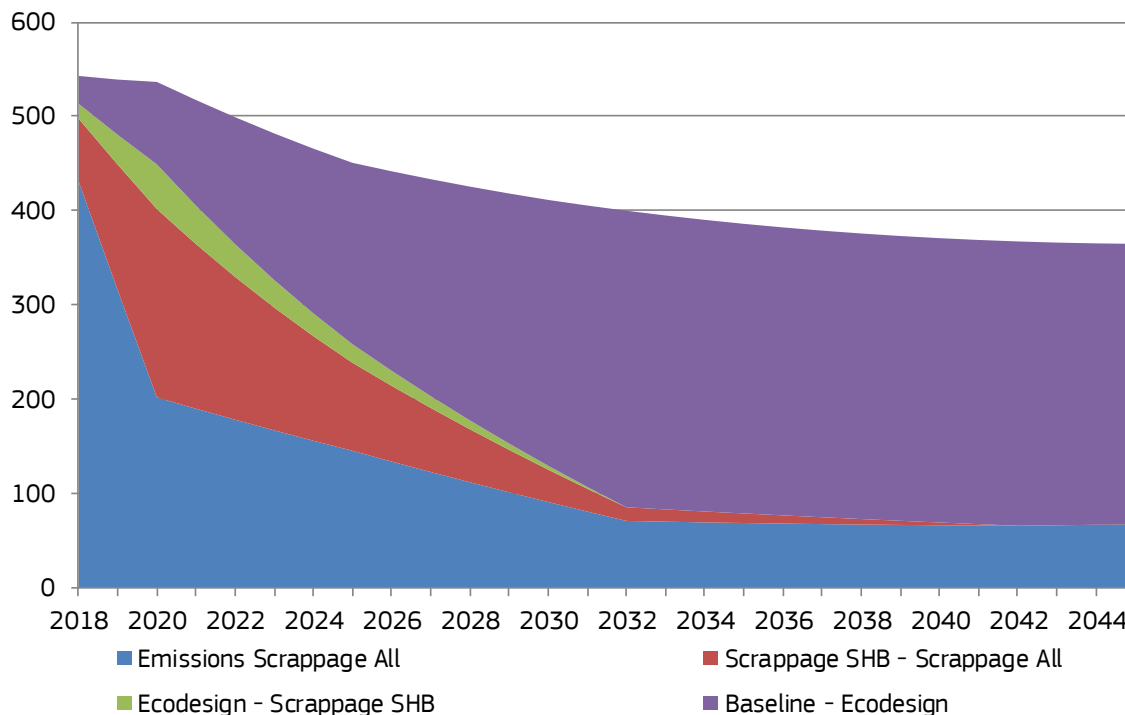
Source: GAINS and own elaboration.
Note: Each area presents the change in the emissions between two scenarios, except in the 'Scrappage All' scenario for which the area represents the emissions of the scenario. The reductions in the emissions of the scrappage scenarios correspond to the cases in which the whole stock of 'non-controlled' appliances and SHB is replaced.

After the entry into force of the implementing measures of the Ecodesign Directive for solid fuel and biomass local space heaters and boilers, the stock of appliances[6] would be gradually replaced by cleaner ones following their turnover rates, in such a way that in

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[5] See http://gains.iiasa.ac.at/models/
[6] It has been assumed that new standards affects to fireplaces, stoves and automatic and manual single house oilers.

2045 the whole stock of appliances would have been replaced. As a consequence[7], PM10 emissions would be reduced by 16% (-87 kt) compared to the levels of 2020, by 69% (-282 kt) relative to the levels of 2030, and by 82% (-297 kt) relative to the levels of 2045. The average emissions abated between 2018 and 2030 would total 169 kt (241 kt for the period 2018-2045).

Table 1. Change in the PM10 emissions of the 'Ecodesign' scenario in 2020 after the introduction of a scrappage mechanism, by Member State

	Scrappage All		Scrappage SHB	
	tonnes	%	tonnes	%
Austria	-670	-12.96%	-105	-2.03%
Belgium	-1 556	-45.53%	-161	-4.71%
Bulgaria	-5 817	-52.99%	-851	-7.75%
Cyprus	-23	-40.07%	-2	-3.89%
Czech Rep.	-7 898	-58.39%	-2 588	-19.13%
Denmark	-7 046	-56.30%	-1 588	-12.68%
Estonia	-2 019	-53.20%	-552	-14.55%
Finland	-1 790	-27.55%	-1 234	-18.99%
France	-30 707	-38.76%	-923	-1.16%
Germany	-3 788	-15.99%	-225	-0.95%
Greece	-6 825	-73.62%	-491	-5.30%
Hungary	-8 021	-79.09%	-1 903	-18.76%
Ireland	-1 615	-45.05%	-916	-25.55%
Italy	-19 823	-76.14%	-29	-0.11%
Latvia	-5 729	-54.30%	-229	-2.17%
Lithuania	-2 354	-52.63%	-718	-16.06%
Luxembourg	-68	-49.52%	-5	-3.55%
Malta	0	0.00%	0	0.00%
Netherlands	-88	-4.43%	0	0.00%
Poland	-97 558	-69.56%	-28 942	-20.64%
Portugal	-8 847	-69.98%	-1 318	-10.42%
Romania	-20 940	-53.17%	-1 120	-2.84%
Slovakia	-1 950	-80.34%	-70	-2.86%
Slovenia	-2 058	-78.81%	-1 923	-73.66%
Spain	-5 410	-32.09%	-156	-0.92%
Sweden	-17	-0.63%	0	0.00%
United Kingdom	-4 600	-64.22%	-1 353	-18.90%
EU-27	**-247 216**	**-55.04%**	**-47 401**	**-10.55%**
EU-27 average 2018-2030	**-125 847**	**-41.09%**	**-22 449**	**-7.33%**

Source: GAINS and own elaboration.
Note: The reductions in the emissions of the scrappage scenarios correspond to the cases in which all the stock of 'non-controlled' appliances and SHB is replaced.

After the introduction of the new standards, in the year 2020 almost 60% (260 kt) of the emissions from household heating appliances are estimated to be released by eligible 'non-controlled' appliances (see Table A3 of the Annex), of which 66% corresponds to stoves, 20% to fireplaces, and 14% to manual single house boilers. At the country level, 40% of the emissions from 'non-controlled' appliances are located in Poland, 12% in France, 8.4% in Romania and 7.9% in Italy. In the rest of the Member States, emissions from 'non-controlled' appliances are below 5%. For SHB, 80% of the emissions are concentrated in

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[7] See footnote 2.

Poland, followed by the Czech Republic (5.1%), Hungary (4%), Ireland (2.9%) and the United Kingdom (2.4%).

In this context, the introduction of a scrappage mechanism contributes to a net reduction of the PM10 emissions of the 'Ecodesign' scenario in 2020 ranging from 11% (-47 kt) to 55% (-247 kt), depending on whether only SHB or all 'non-controlled' appliances are replaced (Table 1). These reduction levels correspond to the cases in which the scrappage mechanism aims to replace 100% of 'non-controlled' appliances. A reduction in the replacement target reduces the gap between the scrappage scenarios and the 'Ecodesign' scenario proportionally. The average reduction of PM10 emissions for the period 2018-2030 (last row in Table 1) would range between 22 kt for the 'Scrappage SHB' scenario (green area in Figure 1) and 126 kt for the 'Scrappage All' scenario (green plus red areas in Figure 1).

Table 1 and Table A1 of the Annex show the reductions in the emissions in 2020 by each Member State (MS) after the introduction of the scrappage mechanism. In the 'Scrappage All' scenarios, the additional reduction in the emissions of PM10 is estimated to be below 40% in only 8 MS. In Greece, Hungary, Italy, Poland, Portugal, Slovakia, Slovenia and the United Kingdom, the reduction in the emissions is above 60%. In contrast, in the 'Scrappage SHB' scenario, the additional reduction in the emissions of PM10 is estimated to be above 20% in only 3 MS: Slovenia (-74%), Poland (-21%), and Ireland (-26%).

In absolute values, in the 'Scrappage All' scenario most of the reduction in the emissions comes from the replacement of firewood- and coal-fired stoves, and fireplaces. Poland is the MS which contributes most to the overall reduction (39%), followed by France (12%), Romania (8.5%) and Italy (8%). In the 'Scrappage SHB' scenario, the reduction in PM10 emissions from Polish SHB represents around 61% of the total effect of the scrappage mechanism in the whole EU-27.

3.2. Investment costs and macroeconomic impacts

Figure 2 summarises the additional annualised investment costs derived from the 'Ecodesign' scenario[8] and from the scrappage policy scenarios. In the 'Ecodesign' scenario, the annual additional costs amount to almost EUR 5.9 billion[9] for the year 2020, EUR 14.1 billion for 2025 and EUR 21.4 billion for 2025. Investment costs reach a maximum of EUR 24.1 billion in 2032 and decrease slightly to EUR 23.5 billion in 2045. The average annualised cost derived from the 'Ecodesign' scenario between 2018 and 2030 amounts to EUR 12.3 billion/year. Note in any case that these costs are not to be interpreted as the overall net costs of the policy, as they do not take into account the substitution effects and fuel savings delivered by the improved energy efficiency of Ecodesign-compliant installations. The investment costs are to be interpreted as an upper limit since substitution effects are not taken into account.

The implementation of a scrappage mechanism increases the average annualised costs between 2018 and 2030 by as much as EUR 314 million (+2.6%) for the case in which the entire stock of 'non-controlled' SHB is replaced and by EUR 12.3 billion/year (+52%) when all the stock of 'non-controlled' appliances is replaced.

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[8] See footnote 2.

[9] All the economic variables are expressed in constant 2005 euros.

Figure 2. Change in annualised investment costs (million €) for different policy scenarios, EU-27, 2020-2045
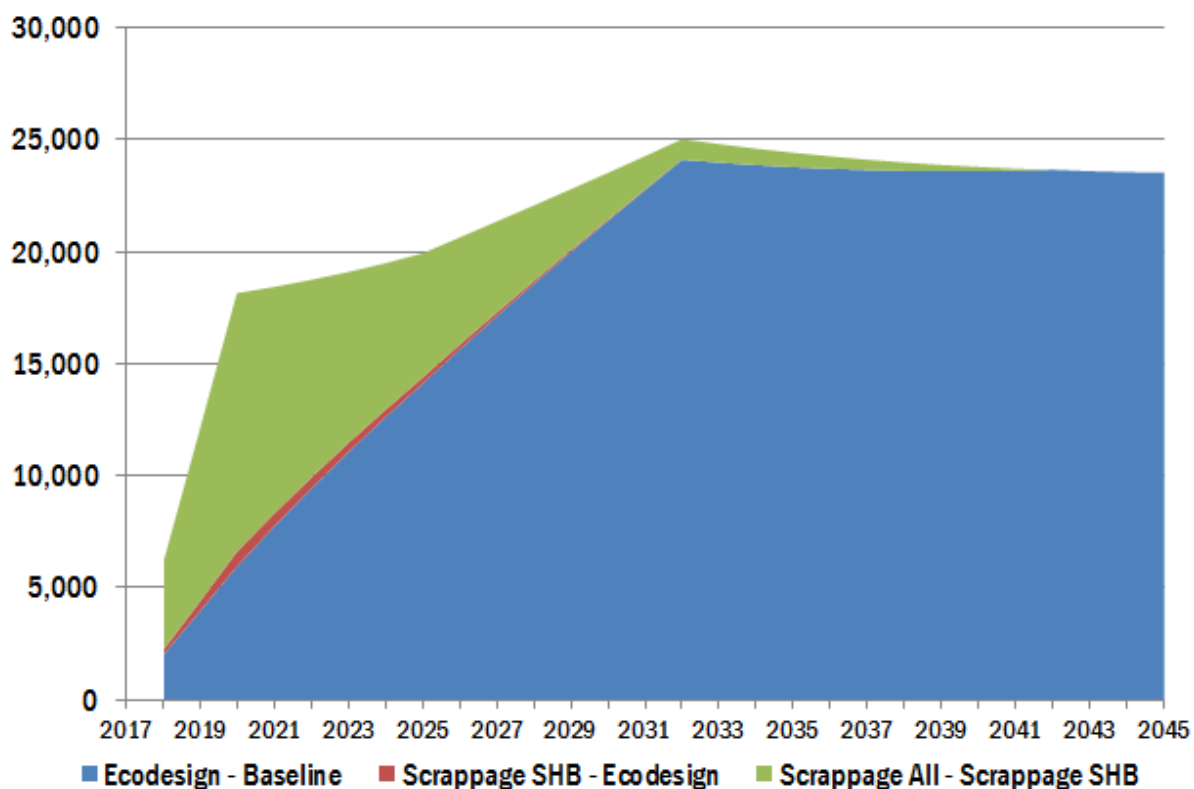
Source: GAINS and own elaboration.
Note: Each area presents the change in the annualised investment costs between two scenarios. Costs correspond to the cases in which the whole stock of 'non-controlled' appliances and SHB is replaced.

The previous figures on investment costs refer to the average annualised cost of the scrappage mechanism between 2018 and 2030. However, according to the definition of the scrappage mechanism, the expenditure in new appliances would be executed between the years 2018 and 2020. In these three years, the investment in new appliances would total EUR 146 billion in the 'Scrappage All' scenario and EUR 18.8 billion in the 'Scrappage SHB' scenario. In addition, government would have to compensate households for the early replacement of old appliances.

It is obvious that the mechanism of the scrappage policy would not target all the appliances regardless of their age. In practice, the policy target would be defined somewhere along the *cost-abatement curve* (Figure 3). This curve shows the total investment costs and subsidies between 2018 and 2020 associated with a certain level of reduction in PM10 emissions. For instance, for the 'Scrappage All' scenario, the investment cost associated with reaching 50% of the total emissions that can be abated with the scrappage programme is EUR 73 billion and the associated subsides are EUR 22.9 billion, equivalent to 31% of the investment costs (yellow circle in left-hand part of Figure 3). However, it is important to highlight that, in practice, subsidies do not usually exceed 20% of the investment costs (Michelsen and Madlener, 2012). According to the data reported in Figure 3 (red circles and dashed red lines), in the 'Scrappage All' scenario it would be feasible to get around 32% of the maximum emission reduction that can be achieved via scrappage by subsidising 20% of the investment costs. In the case of the 'Scrappage SHB'

scenario, a subsidy covering 20% of the investment costs would achieve 4.9% of the maximum emission reduction.

Figure 3. Total additional investment costs and subsidies (million €), and share of investment covered by subsidies according to the share of PM10 emissions abated for different scrappage scenarios, EU-27, 2018-2020
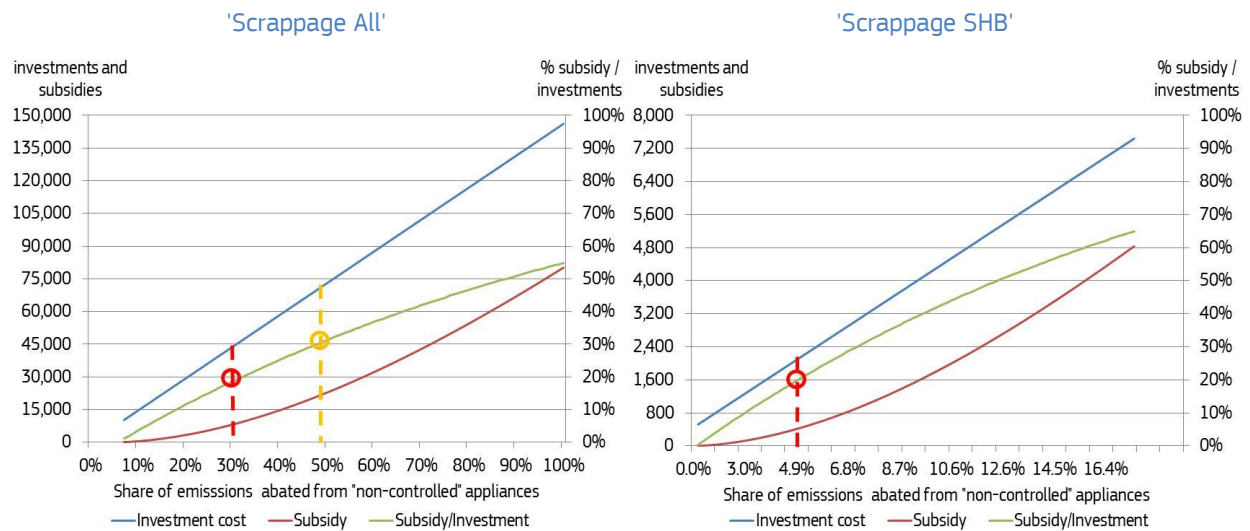
Source: own elaboration.
Note1: In both scenarios 100% abated emissions corresponds to the maximum average annual reduction in PM10 emissions that can be obtained in the period 2018-2030 by the replacement of all 'non-controlled' appliances (i.e. 126 kt).
Note2: Costs refer to the total additional investment costs between 2018 and 2020 compared to the costs of the 'Ecodesign' scenario.

For the case of a subsidy covering 20% of the investment costs of the scrappage of all types of 'non-controlled' appliances, average PM10 emissions in the period 2018-2030 are estimated to be reduced by 7% (-22 kt) with respect the average emissions of the 'Ecodesign' scenario in the period 2018-2030, and the emissions of the year 2020 by 18% (-79 kt). In such a case, total investment costs and subsidies during the three years in which the scrappage system operates would amount to EUR 47 billion and EUR 9.4 billion respectively. For the period 2018-2030, the average annualised costs would total EUR 1.5 billion (+17%) and subsidies EUR 521 million (Table 2). A similar subsidy-to-costs ratio in the 'Scrappage SHB' mechanism could reduce the average emissions of the period 2018-2030 by 2.1 kt (-0.7%), while limiting the increase in total investment costs and subsidies with respect to the 'Ecodesign' scenarios to EUR 2.1 billion and EUR 411 million respectively. In terms of average annualised costs, investment costs and subsides would total EUR 56 million (+0.5%) and EUR 25.6 million respectively.

In a 'Scrappage All' scenario in which subsidies cover 20% of costs, the countries with the highest growth in abatement costs are Slovenia (+32%), Slovakia (+29%), Hungary (25%) and Italy (24%) (see Table 2). In Poland, which shows the largest reduction in PM10 emissions in absolute terms, costs are estimated to increase by 21%. Poland would represent 34% of the total replacement costs of the EU-27, followed by France (12%), and Italy (10%). In the case of Poland, high costs are related to the replacement of a large number of firewood and hard coal stoves, and hard-coal-fired SHB, while in Italy and France the main reason for high costs is the replacement of firewood stoves, which have

high unit costs and long lifetimes. This group of countries also concentrates most of the subsidies (Poland 32%, France 15%, and Italy 12%).

Table 2. Average annualised subsidies and investment costs and average annual emissions abated of a scrappage mechanism subsidising 20%, 2018-2030

	Scrappage All					Scrappage SHB				
	Subsidy	Investment cost		Emissions		Subsidy	Investment cost		Emissions	
	Million €	Million €	change	t	change	Million €	Million €	change	t	change
Austria	3.0	7.7	2.9%	-57.9	-1.4%	0.1	0.1	0.1%	-1.3	0.0%
Belgium	6.6	19.9	10.7%	-203.4	-8.3%	0.1	0.3	0.2%	-15.6	-0.6%
Bulgaria	11.8	29.0	11.1%	-479.7	-6.8%	0.6	2.2	0.8%	-110.8	-1.6%
Cyprus	0.1	0.1	20.5%	-1.6	-3.8%	0.0	0.0	0.5%	-0.1	-0.2%
Czech Rep.	15.5	66.8	16.9%	-905.3	-9.6%	1.9	3.5	1.1%	149.9	1.6%
Denmark	10.5	24.8	9.7%	-537.1	-6.2%	0.4	0.7	0.3%	-60.8	-0.7%
Estonia	3.7	9.8	10.8%	-219.9	-8.4%	0.1	0.3	0.4%	-51.8	-2.0%
Finland	2.8	8.0	2.1%	-242.0	-5.2%	0.3	0.8	0.2%	-125.9	-2.7%
France	76.3	181.0	6.0%	434.5	0.8%	0.7	1.1	0.0%	49.5	0.1%
Germany	17.0	58.0	3.9%	-587.6	-2.9%	0.2	0.7	0.0%	-31.6	-0.2%
Greece	14.7	30.6	18.9%	-500.4	-8.7%	0.4	0.7	0.4%	-14.0	-0.2%
Hungary	14.6	42.7	25.3%	-579.1	-8.8%	1.4	2.4	1.7%	136.2	2.1%
Ireland	5.3	27.1	16.9%	-89.8	-3.5%	0.6	0.8	0.7%	135.6	5.2%
Italy	61.1	153.2	24.0%	-2 678.5	-14.7%	0.0	0.1	0.0%	-5.7	0.0%
Latvia	11.7	37.1	13.1%	-585.3	-8.1%	0.2	0.2	0.1%	24.2	0.3%
Lithuania	5.8	15.1	12.5%	-209.0	-7.0%	0.6	0.9	0.9%	-3.6	-0.1%
Luxembourg	0.2	0.5	10.8%	-8.6	-9.0%	0.0	0.0	0.2%	-0.4	-0.5%
Malta	0.0	0.0	0.0%	0.0	0.0%	0.0	0.0	0.0%	0.0	0.0%
Netherlands	0.4	1.7	0.9%	-17.5	-1.0%	0.0	0.0	0.0%	0.0	0.0%
Poland	167.3	509.8	20.6%	-9 999.2	-10.7%	13.5	28.0	1.3%	-1 619.0	-1.7%
Portugal	18.3	48.6	16.4%	-959.3	-11.3%	1.0	2.6	0.9%	-118.0	-1.4%
Romania	40.5	99.3	9.1%	-1 644.1	-6.5%	0.9	4.5	0.3%	-219.6	-0.9%
Slovakia	3.8	15.9	29.3%	-318.2	-18.9%	0.1	0.2	0.3%	-8.7	-0.5%
Slovenia	2.4	4.5	31.7%	-147.3	-9.1%	1.5	2.9	20.2%	-96.0	-5.9%
Spain	13.4	48.8	7.2%	-755.4	-6.3%	0.1	0.2	0.0%	-0.6	0.0%
Sweden	0.1	1.4	1.4%	-13.2	-0.6%	0.0	0.0	0.0%	0.0	0.0%
United Kingdom	13.9	46.7	18.5%	-550.9	-10.9%	1.0	2.3	1.0%	-64.5	-1.3%
EU-27	**520.6**	**1 488.5**	**11.4%**	**-21 856.0**	**-7.1%**	**25.6**	**55.6**	**0.5%**	**-2 052.4**	**-0.7%**

Source: own elaboration.
Note: Additional costs and subsidies refer to the average annualised values of the period between 2018 and 2020 compared to the costs of the 'Ecodesign' scenario. Emissions refer to the average annual emissions of the period 2018-2030 compared to those of the 'Ecodesign' scenario.

On the other hand, in the 'Scrappage SHB' scenario with subsidies limited to cover 20% of the investment costs, the mechanism would result in an increase in control costs of over 5% compared to the 'Ecodesign' scenario only in Poland (+20%), where 50% of the investment costs and 53% of the subsidies would be concentrated.

Investment in the different technologies defined in each scenario has an impact on the aggregated gross value added (GVA) of each of the MS in several ways. On the one hand, production of Ecodesign-compliant appliances generates an increase in the value added of the sectors involved in their production. This impact on GVA translates into an increase in the income of households, which in turn causes further increases in the final demand. On the other hand, the increase in public transfers to households is compensated by a reduction in its expenditure, which will have a negative impact in terms of GVA.

Investment in the technologies of the 'Ecodesign' scenario would increase the GVA of the EU-27 economy by EUR 14 billion/year (+0.05%) in the period 2018-2030. A scrappage mechanism with a subsidy covering 20% of the investment costs is estimated to increase

the GVA by EUR 2.3 billion/year when the programme is targeted at all types of 'non-controlled' appliances and by EUR 106 million/year when the mechanism applies only to SHB (Table 3).

Table 3. Average annual change in the Gross Value Added of a scrappage mechanism subsidising 20% of investment costs

	Scrappage All		Scrappage SHB	
	Million €	%	Million €	%
Austria	34.9	10.52%	1.6	0.49%
Belgium	40.3	21.54%	1.2	0.64%
Bulgaria	3.8	11.43%	0.0	0.14%
Cyprus	0.0	0.00%	0.0	0.56%
Czech Rep.	30.8	8.42%	4.2	1.15%
Denmark	55.3	18.37%	2.0	0.66%
Estonia	0.0	0.00%	0.0	0.00%
Finland	16.2	4.98%	1.3	0.41%
France	280.8	11.60%	4.5	0.19%
Germany	276.5	10.76%	11.5	0.45%
Greece	62.3	37.24%	1.6	0.93%
Hungary	47.5	23.17%	4.3	2.10%
Ireland	17.1	15.79%	1.8	1.66%
Italy	337.1	26.75%	4.7	0.37%
Latvia	1.0	0.48%	0.0	0.00%
Lithuania	16.6	18.53%	1.6	1.82%
Luxembourg	2.3	13.16%	0.1	0.53%
Malta	0.0	0.00%	0.0	0.20%
Netherlands	25.3	13.22%	1.1	0.60%
Poland	719.9	30.52%	44.6	1.89%
Portugal	32.9	15.83%	0.0	0.00%
Romania	93.4	9.72%	0.0	0.00%
Slovakia	25.2	23.45%	0.7	0.68%
Slovenia	15.0	36.10%	8.5	20.49%
Spain	77.7	11.34%	2.2	0.32%
Sweden	16.0	7.78%	0.9	0.44%
United Kingdom	110.1	18.97%	7.0	1.20%
EU-27	**2 338.1**	**16.70%**	**105.6**	**0.76%**

Source: GAINS and own elaboration.
Note: Average annual change in the Gross Value Added refers to the average annual change in the Gross Value Added of the period between 2018 and 2020 compared to the average annual change in the Gross Value Added of the 'Ecodesign' scenario.

By MS, in both scenarios the impact of the scrappage policy would be positive in terms of value added. In the 'Scrappage All' scenario, Poland (EUR 720 million/year), Italy (EUR 337 million/year), France (EUR 281 million/year), and Germany (EUR 277 million/year) would be the countries with the largest gains in terms of GVA. In the 'Scrappage SHB' scenario, 41% of the increase in the GVA takes place in Poland, 11% in Germany, 8.5% in Slovenia and 7% in the United Kingdom. In most MS the increase in the value added is mainly driven by the change in the domestic stock of appliances. However, in the case of Germany, the impact is mostly due to the growth in the investment in heating appliances abroad.

3.3. Cost-benefit analysis

Table 4 and Figure 4 depict, for the period 2018-2030, the average annual emissions abated by type of appliance replaced, and the associated costs and monetised health benefits.[10] The 'Scrappage All' scheme could achieve the maximum possible reduction in the emissions of PM10 (-126 kt) by replacing all the 'non-controlled' appliances with new ones. The total investment costs of this system would be EUR 6.4 billion, with an average PM abatement cost of EUR 50 682/t.

Table 4. Average annual emissions abated (tonnes/year), average annualised costs and health benefits (million €/year), and PM abatement costs (€/tonne) of the scrappage programme by type of appliance, EU-27, 2018-2030

			100% of appliances scrapped				
			Emissions	Costs	Abatement cost	Health benefits low case	Health benefits high case
			(tonnes/year)	(million €/year)	(€/tonne)	(million €/year)	(million €/year)
Scrappage All	**Scrappage SHB**	SHB-M-HC2	48.3	0.6	12 987	1.1	3.3
		SHB-M-HC1	15 016.5	196.9	13 113	351.4	1 013.6
		SHB-M-FWD	7 384.1	116.8	15 823	172.8	498.4
		STOVE-H-FWD	62 368.2	3 224.0	51 693	1 459.4	4 209.9
		FPLACE-FWD	24 707.5	1 557.9	63 055	578.2	1 667.8
		STOVE-H-HC1	15 510.0	1 116.9	72 013	362.9	1 046.9
		STOVE-H-HC2	527.9	38.2	72 360	12.4	35.6
		SHB-M-DC	103.3	15.8	153 358	2.4	7.0
		STOVE-H-DC	181.6	110.9	610 653	4.2	12.3
		Total	**125 847.4**	**6 378.1**	**50 682***	**2 944.8**	**8 494.7**

Source: GAINS and own elaboration.
Note1: Costs refer to the average annualised values of the period between 2018 and 2020 compared to the costs of the 'Ecodesign' scenario. Emissions abated and related benefits refer to the average levels of 2018-2030 compared to those of the 'Ecodesign' scenario.
Note2: The marginal benefit adopted for the calculation of health benefits corresponds to the median value of a life year (VOLY), i.e. EUR 23 400/t PM10 assuming a share of 90% of PM2.5 in PM10), for the low case and to the mean value of statistical life (VSL), i.e. EUR 67 500/t PM10, for the high case. These values have been derived from the figures reported in AEA Technology Environment (2005) for PM2.5 (EUR 26 000/t PM2.5 and EUR 75 000/t PM2.5), and assuming a share of 90% of PM2.5 in PM10.
Note3: See Table A2 in the Annex for a description of appliances.
Note4: * = average cost.

Since the 'Scrappage SHB' mechanism only covers a subset of the appliances included in the 'Scrappage All' mechanism, the emission reductions are lower. However, the 'Scrappage SHB' mechanism can achieve 18% of the maximum reduction of the 'Scrappage All'

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[10] Health benefits refer to the monetary value of the reduction in chronic mortality in lost years of life valued according to the median value of a life year (VOLY) for the low case and to the mean value of statistical life (VSL) for the high case. The marginal benefit adopted in this study ranges from EUR 23 400/t PM10 for the low case to EUR 67 500/t PM10 for the high case, and has been derived from the figures reported in AEA Technology Environment (2005) for PM2.5 (EUR 26 000/t PM2.5 and EUR 75 000/t PM2.5), assuming a share of 90% of PM2.5 in PM10. Note that these marginal benefit values are taken from the CAFE analysis underpinning the 2005 Thematic Strategy on Air Pollution and are not fully updated and only provide an indicative range.

mechanism while cutting total abatement costs and subsidies by a factor of 20 (i.e. limiting investment costs and subsidies to 4.9% of the costs of the 'Scrappage All' scenario).

Figure 4. Average marginal costs and marginal benefits of the scrappage programme, EU-27, 2018-2030
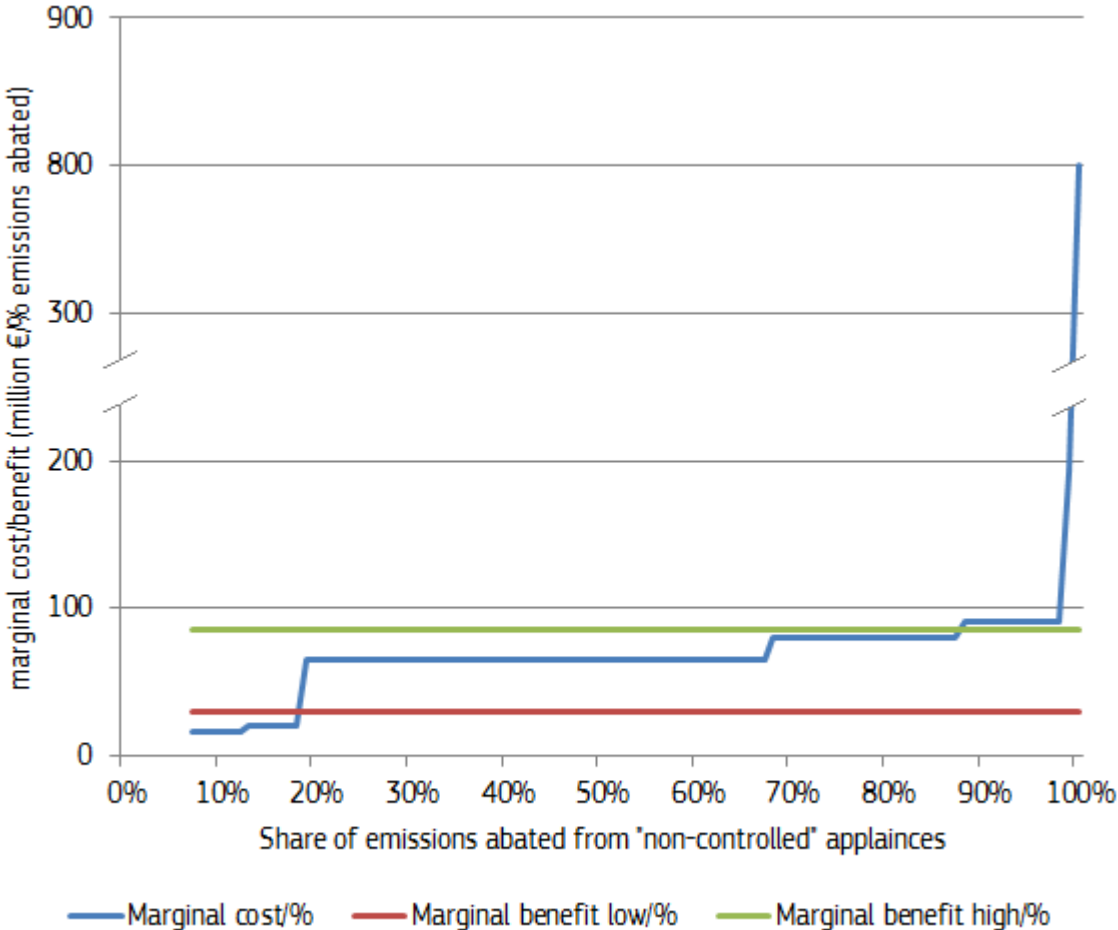
Source: own elaboration.
Note1: 100% abated emissions corresponds to the maximum reduction in PM10 emissions that can be obtained by the replacement of all 'non-controlled' appliances (i.e. 141 kt, representing 95% of the emissions from 'non-controlled' appliances).
Note2: The marginal benefit adopted for the calculation of health benefits corresponds to the median value of a life year (VOLY), i.e. EUR 23 400/t PM10 assuming a share of 90% of PM2.5 in PM10), for the low case and to the mean value of statistical life (VSL), i.e. EUR 67 500/t PM10, for the high case. These values have been derived from the figures reported in AEA Technology Environment (2005) for PM2.5 (EUR 26 000/t PM2.5 and EUR 75 000/t PM2.5), and assuming a share of 90% of PM2.5 in PM10.

Figure 4 shows the marginal cost and marginal benefit curves in terms of million euros per percentage of emissions abated. For the case of the median value of a life year (VOLY) (low case), the marginal benefit equals the marginal costs at a level at which 18% of the maximum reduction in the emissions from 'non-controlled' appliances is achieved. This level of pollution would imply the accelerated scrappage of SHB. Taking the mean value of statistical life (VSL) (high case) as a reference, the marginal benefit equals the marginal costs at a level at which 87% of the maximum reduction in the emissions from 'non-

controlled' appliances is achieved including, in addition to the replacement of SHB, the substitution of firewood-fired stoves and fireplaces. In that case, the replacement of SHB would contribute to 20% of the reduction and 6% of the costs, while the replacement of stoves and fireplaces would contribute to 80% of the emissions reduction and 94% of the costs.

Comparing investment costs and health benefits (see Table 4), and focusing on the most conservative value of life, in the year 2025, the costs derived from the 'Scrappage All' scenario total EUR 6.4 billion, exceeding the health benefits by EUR 3.4 billion. In contrast, for the 'Scrappage SHB' the health benefits (EUR 525 million) are greater than the costs (EUR 314 million). In the case of the highest value of life, the health benefits exceed the costs by EUR 2.1 billion in the 'Scrappage All' scenario and by EUR 1.2 billion in the 'Scrappage SHB' scenario.[11]

When subsidies are limited to covering up to 20% of the investment costs, in the 'Scrappage All' scenario the average annualised investment costs are reduced to a total of EUR 2 billion/year and the health benefits range between EUR 0.9 billion and EUR 2.7 billion per year. Under the 'Scrappage SHB' scheme with subsidies limited to 20%, the investment costs average EUR 88 million/year and the health benefits range between EUR 147 million and EUR 424 million.

Focusing on the 'Scrappage SHB' scenario, it is worth highlighting that the replacement of the whole stock of 'non-controlled' SHB can achieve a significant share of the reduction in emissions while limiting investment costs and subsidies. However, the subsidies of such a mechanism could be very onerous. Thus, if we take the 'Scrappage SHB' scenario as a starting point and limit the subsidies to 20% of the investment costs, it would reduce the emissions abated by a factor of 3.6 (from 22.4 kt to 6.4 kt), decrease the total investment costs of the mechanism by a factor of 3.6 (from EUR 7.4 billion to EUR 2.1 billion) and cut the total subsidies by a factor of 11.8 (from EUR 4.8 billion to EUR 411 million). However, although this policy scenario is estimated to significantly reduce the subsidies, it would increase the level of emissions of the whole period, and thus reduce the health benefits derived from the abatement of PM10 emissions.

4. CONCLUSIONS

This document explores the potential for the use of a market-based instrument to contribute to reducing the emissions of particulate matter of less than 10 micrometres (PM10) from household heating appliances in the framework of the review of the Thematic Strategy on Air Pollution (TSAP). The study is focused on the assessment of the economic and environmental impacts of possible scrappage policies for promoting the accelerated replacement of existing heating appliances with cleaner ones. Under these policy programmes, households replacing an old appliance with a cleaner one would receive a subsidy from the government. This subsidy would compensate households for the residual value of the scrapped appliance and the opportunity costs of the early investment in a new one.

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[11] Note that total health benefits are calculated using average damage functions, while real health impacts of emissions depend on many specific factors (e.g. exposure to emissions from household boilers is likely to occur in densely populated areas and lead to higher-than-average health costs).

Two different scenarios were analysed: a 'Scrappage All' scenario where all the different types of conventional appliances that do not incorporate any emission control technology ('non-controlled' appliances) are replaced, and a 'Scrappage SHB' scenario where only 'non-controlled' firewood- and hard-coal-fired manual single house boilers (SHB) are replaced. It was assumed that the scrappage programme is in force for three years (between 2018 and 2020). For each of these scenarios, the study further focused on the effects of different levels of replacement of the 'non-controlled' appliances and the size of subsidies relative to the investment costs.

Results for the EU-27 show that a scrappage programme designed to replace all types of 'non-controlled' appliances, and with subsidies limited to 20% of the investment costs, could contribute to the reduction of the emissions of PM10 from household heating appliances in 2020 by 18% (-79 kt), with a reduction of 7.4% (-22 kt/year) with respect to the average emissions of the period 2018-2030. This early replacement would increase average annual investment costs of the period 2018-2030 by 11% (+ EUR 1.5 billion/year). Total subsidies to compensate households for the early replacement would amount to EUR 9.4 billion during the period 2018-2020. Health benefits of this policy scenario would total between EUR 0.9 billion and EUR 2.7 billion per year. This scheme would increase the Gross Value Added (GVA) by EUR 2.3 billion/year.

The scrappage mechanism that only targets SHB, and with subsidies limited to 20% of the costs, could achieve 9% of the reduction resulting from the previous 'Scrappage All' scenario, while cutting the abatement costs and subsidies to 3.7% and 4.9% respectively. This mechanism would reduce PM10 emissions in 2020 by 3% (-13.3 kt) and the average emissions of the period 2018-2030 by 0.7% (-2.1 kt), and the costs would increase by 0.5% (EUR 55.6 million/year). Total subsidies during the period 2018-2020 would sum to EUR 411 million. Health benefits would range from EUR 147 million and EUR 424 million per year. Around 50% of the investment costs and subsidies, and 61% of the reduction in PM10 emissions, would be generated by the accelerated replacement of SHB in Poland. This scrappage mechanism would increase the GVA by EUR 106 million/year; 42% of the total increase in the GVA would be in Poland, 11% in Germany, 8.5% in Slovenia and 7% in the United Kingdom.

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Table A1. PM10 emissions (tonnes) in the Ecodesign scenario and emissions abated by scrappage scenario, 2020 and average emissions 2018-2030

	2020					Average 2018-2030				
	Total emissions	Emissions abated				Total emissions	Emissions abated			
	Ecodesign	Scrappage All	Scrappage All 20%	Scrappage SHB	Scrappage SHB 20%	Ecodesign	Scrappage All	Scrappage All 20%	Scrappage SHB	Scrappage SHB 20%
Austria	5 167	-670	-214	-105	-29	4 021	-334	-58	-47	-1
Belgium	3 419	-1 556	-498	-161	-45	2 453	-872	-203	-85	-16
Bulgaria	10 978	-5 817	-1 861	-851	-238	7 026	-2 885	-480	-477	-111
Cyprus	56	-23	-7	-2	-1	43	-12	-2	-1	0
Czech Rep.	13 526	-7 898	-2 527	-2 588	-725	9 389	-4 198	-905	-964	150
Denmark	12 515	-7 046	-2 255	-1 588	-445	8 659	-3 493	-537	-744	-61
Estonia	3 795	-2 019	-646	-552	-155	2 627	-1 093	-220	-289	-52
Finland	6 499	-1 790	-573	-1 234	-345	4 642	-1 009	-242	-657	-126
France	79 214	-30 707	-9 826	-923	-258	52 093	-12 941	434	-348	49
Germany	23 684	-3 788	-1 212	-225	-63	20 327	-2 228	-588	-128	-32
Greece	9 270	-6 825	-2 184	-491	-138	5 780	-3 397	-500	-225	-14
Hungary	10 142	-8 021	-2 567	-1 903	-533	6 615	-3 900	-579	-683	136
Ireland	3 585	-1 615	-517	-916	-256	2 600	-750	-90	-258	136
Italy	26 034	-19 823	-6 343	-29	-8	18 205	-11 801	-2 678	-18	-6
Latvia	10 551	-5 729	-1 833	-229	-64	7 213	-2 983	-585	-74	24
Lithuania	4 472	-2 354	-753	-718	-201	2 991	-1 215	-209	-313	-4
Luxembourg	138	-68	-22	-5	-1	96	-39	-9	-3	0
Malta	2	0	0	0	0	2	0	0	0	0
Netherlands	1 982	-88	-28	0	0	1 665	-57	-17	0	0
Poland	140 247	-97 558	-31 218	-28 942	-8 104	93 443	-49 980	-9 999	-14 073	-1 619
Portugal	12 641	-8 847	-2 831	-1 318	-369	8 468	-4 705	-959	-685	-118
Romania	39 386	-20 940	-6 701	-1 120	-314	25 320	-10 335	-1 644	-702	-220
Slovakia	2 428	-1 950	-624	-70	-19	1 686	-1 124	-318	-39	-9
Slovenia	2 611	-2 058	-659	-1 923	-539	1 620	-984	-147	-924	-96
Spain	16 858	-5 410	-1 731	-156	-44	12 057	-3 007	-755	-68	-1
Sweden	2 779	-17	-6	0	0	2 218	-20	-13	0	0
United Kingdom	7 162	-4 600	-1 472	-1 353	-379	5 047	-2 487	-551	-647	-65
EU-27	**449 141**	**-247 216**	**-79 109**	**-47 401**	**-13 272**	**306 305**	**-125 847**	**-21 856**	**-22 449**	**-2 052**

Table A2. List of appliances, fuels and abatement technologies

Acronym	Appliance	Fuel
FPLACE-FWD	Fireplace	Firewood
SHB_M-DC	Single house boiler manual	Derived coal
SHB_M-FWD	Single house boiler manual	Firewood
SHB_M-HC1	Single house boiler manual	Hard coal grade 1
SHB_M-HC2	Single house boiler manual	Hard coal grade 2
STOVE_H-DC	Stove	Derived coal
STOVE_H-FWD	Stove	Firewood
STOVE_H-HC1	Stove	Hard coal grade 1
STOVE_H-HC2	Stove	Hard coal grade 2

Table A3. PM 10 emissions (tonnes) from 'non-controlled' appliances by type and country in the 'Ecodesign' scenario, 2020

Appliance Type	FPLACE-FWD	SHB-M-DC	SHB-M-FWD	SHB-M-HC1	SHB-M-HC2	STOVE-H-DC	STOVE-H-FWD	STOVE-H-HC1	STOVE-H-HC2	Total
Austria	42	45		116		23	511	26		762
Belgium	396	1	180			9	1 103			1 690
Bulgaria	446	61	276	670		82	4 257	361		6 154
Cyprus	12		2				9			24
Czech Rep.	897	14	1 070	1 807		129	4 196	325		8 437
Denmark	996		1 626	18			4 607	34		7 281
Estonia	566	0	562	10		2	908	43		2 092
Finland	418		1 280				173			1 871
France	9 659	2	388	638		17	20 070	1 224		31 997
Germany	1 111	219	212	38	6		2 267	304	45	4 203
Greece	1 327	0	543	7		3	5 226	28		7 134
Hungary	655	3	675	1 440		24	5 289	403		8 488
Ireland	43	15	2	1 011		82	116	546		1 816
Italy	11 493			32			9 055	6		20 585
Latvia	750		196	60			4 866	103		5 975
Lithuania	539	1	667	136		10	1 009	163		2 523
Luxembourg	24	0	6			1	41	0		72
Malta										
Netherlands	37						57			94
Poland	3 606	20	2 822	28 043	160	160	41 402	24 824	1 800	102 836
Portugal	1 624		1 476				6 201			9 301
Romania	1 952		1 206	48			18 628	26		21 860
Slovakia	139	0	69	9		1	1 729	88		2 035
Slovenia			2 155				144			2 299
Spain	569			172			4 333	619		5 693
Sweden							19			19
United Kingdom	720	3	654	852		18	1 466	1 287		5 000
EU-27	38 020	386	16 067	35 107	166	560	137 681	30 408	1 845	260 239

Source: GAINS and own elaboration

Note: the appliances covered by the 'Scrappage SHB 'scenario are firewood-fired manual single house boilers (SHB-M-FWD) and hard-coal-fired manual single house boilers (SHB-M-HC1 and SHB-M-HC2).

SCENARIO DESCRIPTION

'Baseline' scenario

For the years 2020, 2025 and 2030 the emission levels and the investment costs are directly derived from GAINS. Data for the other years in the 2020-2045 series is calculated as follows:

1. For the rest of the years between 2020 and 2045, the energy use[14] is extrapolated on the basis of the energy growth rate by country r, appliance a, fuel f, technology c and year t (indicating 2020, 2025 and 2030) calculated as follows:

   a. for each five year period (e.g. 2020-2025), if the energy use in the starting (ts) and end (te) years is non-zero, we compute the growth rate according to the corresponding average annual growth rate calculated as:

$$nrg\_growth(r,a,f,c) = \left[\frac{nrg\_BL(r,a,f,c,te)}{nrg\_BL(r,a,f,c,ts)} \right]^{\frac{1}{5}} - 1 \qquad (1)$$

   where nrg_BL is the energy consumption by region, appliance, fuel, technology and year in the 'Baseline' scenario;

   b. if the energy use is zero for ts and non-zero for te or vice versa, we assume a linear growth in the energy mix between the two years.

2. The emissions of PM10 for each country, appliance, fuel and technology are calculated by multiplying the corresponding energy consumption by the relevant emission coefficients from GAINS, i.e.:

$$PM\_BL(r,a,f,c,t) = nrg\_BL(r,a,f,c,t) \times PMcoef\_BL(r,a,f,c) \qquad (2)$$

3. In order to estimate the annual costs, we multiply the energy use obtained from Step 1 by the annualised total costs per unit of energy used:

$$cost\_yr\_BL(r,a,f,c,t) = nrg\_BL(r,a,f,c,t) \times cost\_BL(r,a,f,c) \qquad (3)$$

   It is important to note that the unit costs reported by GAINS include only additional costs, compared to the value of 'non-controlled' appliances. For instance, for new appliances, GAINS unit costs only include the additional cost of a new appliance compared to a conventional one and for 'non-controlled' appliances costs are zero. In contrast, in our modelling exercise, costs of appliances include total costs.

4. The next steps consist of converting the discounted annual costs into current change in the stock of appliances to be introduced as external shocks into the FIDELIO model:

$$addstock\_BL(r,a,f,t) = \sum_{c} cost\_yr\_BL(r,a,f,c,t) \times \frac{1}{A} \qquad (4)$$

In (4) $\frac{1}{A}$ denotes the annualisation factor as used in GAINS, which is defined as:

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[14] Table A4 shows a summary of the energy use by type of appliance for the different scenarios.

$$A \equiv \frac{(1+i)^l i}{(1+i)^l - 1} \qquad (5)$$

where l is the lifetime[15] of the appliance and i is the interest rate (4%), which reflects the long-term risk-free interest rate.[16] In this case, since there is no early replacement of appliances, the net addition to the stock of appliances would be equal to the gross one.

'Ecodesign' scenario

The 'Ecodesign' scenario takes the energy use of the 'Baseline' scenario as a starting point. On top of this energy use, it is assumed that from 2018 onwards the stock of 'non-controlled' fireplaces, automatic and manual single house boilers and stoves would be gradually replaced by new appliances complying with more stringent standards. This substitution is assumed to be linear, according to the depreciation rates of each appliance. As a consequence, the energy use of old appliances decreases over time and is compensated by an equivalent increase in the energy use of 'ecodesigned' appliances. By the year 2045 the whole stock of appliances would have been replaced.

1. The change in the energy use of existing appliances between 2018 and 2045 is defined as:

$$changenrg\_ED(r,a,f,c,2018) = -nrg\_BL(r,a,f,c,t)\left(1 - \frac{td+1}{l(a)}\right) \qquad (6)$$

Where $l(a)$ is the lifetime of each appliance (including fireplaces, automatic and manual single house boilers, and stoves) and td is the number of years elapsed since the approbation of the new emission standards ($td = 1,..., l(a)-1$).

For each type of appliance a, fuel f, country r and year t, the energy use of the stock of 'ecodesigned' appliances is equivalent to the sum of the reduction in the energy use of the appliances replaced:

$$changenrg\_ED(r,a,f,ed,2018) = -\sum_c changenrg\_ED(r,a,f,c,2018) \qquad (7)$$

2. The energy use of the 'Ecodesign' scenario will be:

$$nrg\_ED(r,a,f,c,t) = nrg\_BL(r,a,f,c,t) + changenrg\_ED(r,a,f,c,t)$$
$$nrg\_ED(r,a,f,ed,t) = nrg\_BL(r,a,f,c,t) + changenrg\_ED(r,a,f,ed,t) \qquad (8)$$
$$nrg\_ED(r,a,f,other,t) = nrg\_BL(r,a,f,other,t)$$

Where *other* represents those appliances not covered by the Ecodesign Directive.

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[15] The lifetime of appliances is 25 years for fireplaces, 15 years for single house boilers and 15 years for stoves.

[16] Note that when the interest rate approaches zero, the annualised factor approaches the inverse of the appliance lifetime, i.e. $\lim_{i\to 0} A = 1/l$. This simply reflects the fact that in the case of an (almost) zero interest rate, the annualised value of an appliance is constant and equal over the entire lifetime of the appliance.

3. The emissions are derived straightforwardly from the energy consumption of the 'Scrappage' scenario and the corresponding emission factors as for equation (2). For new appliances added to the stock from 2018 onwards, the coefficients correspond to the emission limit value (ELV) of the draft impact[17] assessment of the implementing measures for local space heaters and solid fuel boilers of the Directive setting the ecodesign requirements for energy-related products (Directive 2009/125/EC). For the other appliances, the emission factors are those reported by GAINS.

4. Finally, annualised costs and changes in the stock of appliances are calculated as for the 'Baseline' scenario. In the case of 'ecodesigned' appliances, costs are derived from the preparatory studies for Ecodesign Requirements of Directive 2009/125/EC for solid fuel small combustion installations (Bio Intelligence Service, 2009) and from GAINS.

'Scrappage' scenario

In order to assess the impact of the scrappage mechanism, the following procedure is applied:

1. For the year 2020, we recalculate for each country, appliance and fuel the energy use of the 'non-controlled' appliances to be replaced and the corresponding energy use of 'ecodesigned' appliances according to a given policy target (or share of appliances replaced):

$$nrg\_SC(r,a,f,noc,2020) = (1-g) \times nrg\_ED(r,a,f,noc,2020)$$
$$nrg\_SC(r,a,f,ed,2020) = nrg\_ED(r,a,f,ed,2020) + g \times nrg\_ED(r,a,f,noc,2020) \tag{9}$$

where *noc* denotes 'non-controlled' appliances eligible for the scrappage mechanism and $g \in (0,1)$ is a policy target which defines the share of appliances replaced. For other appliances not affected by the scrappage mechanism, the energy use would be equal to that of the 'Ecodesign' scenario.

2. The difference between the energy consumption in the 'Ecodesign' and 'Scrappage' scenarios for 2025 represents the change in the energy consumption due to the scrappage policy, i.e.:

$$\Delta nrg\_SC(r,a,f,c,2020) = nrg\_SC(r,a,f,c,2020) - nrg\_ED(r,a,f,c,2020) \tag{10}$$

It is assumed that these changes are equally distributed among the three years in which the scrappage mechanism is operative (2018-2020). Thus, the energy consumption of the 'Scrappage' scenario is given by:

$$nrg\_SC(r,a,f,c,2018) = nrg\_ED(c,a,f,c,2018) + 1/3 \times \Delta nrg\_SC(r,a,f,c,2020)$$
$$nrg\_SC(r,a,f,c,2019) = nrg\_ED(c,a,f,c,2019) + 2/3 \times \Delta nrg\_SC(r,a,f,c,2020) \tag{11}$$
$$nrg\_SC(r,a,f,c,2020) = nrg\_ED(c,a,f,c,2020) + \Delta nrg\_SC(r,a,f,c,2020)$$

From 2020 onwards, the energy use of 'non-controlled' and 'ecodesigned' appliances is calculated following the method described in equations (6) to (8).

3. Emissions and annualised costs are derived from the energy use of the 'Scrappage' scenario following the method described for the 'Ecodesign' scenario.

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[17] See footnote 2.

In the 'Scrappage' scenario we have two new elements in comparison to the 'Ecodesign' scenario. First, in order to calculate the net change in the stock of appliances, the residual value of the scrapped appliances must be deducted from the gross change in the stock of appliances. Second, households must be compensated with an appropriate subsidy for the early replacement.

4. We start by calculating the investment in new appliances replacing 'non-controlled' ones. This investment takes place during the period in which the scrappage mechanism is in force (i.e. 2018-2020). Since it is assumed that these changes are equally distributed over the four years, the annual investment in new appliances is given by:

$$inved\_SC(r,a,f,t) = 1/3 \times \Delta nrg\_SC(r,a,f,2020) \times cost\_SC(r,a,f,t) \times \frac{1}{A} \quad (12)$$

$$t \in [2018,2020]$$

5. The gross addition to the stock of appliances in the 'Scrappage' scenario is calculated as the investment in 'ecodesigned' appliances replacing 'non-controlled' ones plus the addition to the stock due to other appliances not affected by the scrappage mechanism:

$$gross\_addstock\_SC(r,a,f,t) = inved\_SC(r,a,f,t)$$

$$+ \sum_c [nrg\_SC(r,a,f,c,t) - \Delta nrg\_SC(r,a,f,c,t)] \times cost\_ED(r,a,f,c) \times \frac{1}{A} \quad (13)$$

6. In order to calculate the net addition to the stock of appliances, the residual value of replaced appliances must be deducted from the stock of appliances. This residual value is calculated for each appliance according to the following formula:

$$rval\_SC(r,a,f,t) = - \frac{1/3 \times \Delta nrg\_SC(r,a,f,noc,2025) \times cost\_ED(r,a,f,noc,t) \times \frac{1}{A}}{l-1} \sum_{s=0}^{g \times l - 1} \frac{s}{l} \quad (14)$$

The first term in the right-hand side of (14) represents the annual depreciation of the stock of appliances and the second term gives the weighted cumulative age of the appliances replaced.

7. The total net addition to the stock of appliances mechanism is then calculated as follows:

$$addstock\_scr(r,a,f,t) = gross\_addstock\_SC(r,a,f,t) - rval\_SC(r,a,f,t). \quad (15)$$

This net addition to the stocks is introduced into the FIDELIO model as a change factor in the equations of the stock of appliances.

In the period when the policy is in force, households replacing an old appliance with a cleaner one receive a subsidy from the government. This subsidy (transfer from government) is assumed to compensate households for the residual value of the scrapped appliance (*rval*) and for the opportunity costs of the early investment in a new one. Since in practice it is difficult to validate the age of the appliances, it is assumed that, in order to ensure that the replacement target is fully achieved, the subsidy should cover the residual value and the opportunity costs corresponding to the newest appliance covered by the target, regardless of the actual age of the appliance.

The size of the subsidy is calculated for each type of appliance as follows:[18]

$$subsidy(r,a,f,t) = \frac{rval\_SC(r,a,f,t)}{(1+i)^{(g\times l-1)}} + \frac{inved(r,a,f,NEW,t)\left[(1+i)^{(g\times l-1)}-1\right]}{(1+i)^{(g\times l-1)}} \quad (16)$$

The subsidy is introduced into the model as an increase in government transfers to households, which is compensated by an equivalent reduction in government expenditures (excluding transfers) to ensure budget neutrality. Finally, in order get a better view of the cost of the whole mechanism, the subsidy is annualised using the relevant factor given in (5).

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[18] The subsidy should be equal to the appliance residual value and the opportunity costs of net investments in new appliances, that is $subsidy = rval\_SC + (inved\_SC - subsidy)\left\{\left[(1+i)^{(g\times l-1)}-1\right]-1\right\}$, where for simplicity purposes we supressed all the indices. Note that $g \times l - 1$ denotes the remaining lifetime of the new appliance under the policy target g that defines the share of non-controlled appliances to be replaced, Simple algebraic transformations of the above expression then yield equation (20).

Table A4. Energy use by scenario and type of appliance (petajoules)

	Baseline				Ecodesign				Scrappage All				Scrappage All 20%				Scrappage SHB				Scrappage SHB 20%				Total
	ED	NOC-e	NOC-o	Other	ED	NOC-e	NOC-o	Other	ED	NOC-e	NOC-o	Other	ED	NOC-e	NOC-o	Other	ED	NOC-e	NOC-o	Other	ED	NOC-e	NOC-o	Other	
2018	0	632	8 359	2 921	117	591	8 339	2 864	279	430	8 339	2 864	169	540	8 339	2 864	166	542	8 339	2 864	131	578	8 339	2 864	11 912
2019	0	616	8 258	2 879	237	537	8 216	2 763	560	213	8 216	2 763	340	433	8 216	2 763	334	439	8 216	2 763	264	510	8 216	2 763	11 753
2020	0	601	8 159	2 843	359	486	8 095	2 663	845	0	8 095	2 663	514	331	8 095	2 663	506	339	8 095	2 663	400	445	8 095	2 663	11 603
2021	0	568	8 024	2 787	468	423	7 939	2 549	891	0	7 939	2 549	585	306	7 939	2 549	594	297	7 939	2 549	497	394	7 939	2 549	11 379
2022	0	535	7 892	2 734	574	365	7 786	2 438	938	0	7 786	2 438	656	282	7 786	2 438	680	258	7 786	2 438	591	347	7 786	2 438	11 162
2023	0	504	7 763	2 685	675	312	7 636	2 330	987	0	7 636	2 330	729	258	7 636	2 330	765	222	7 636	2 330	684	303	7 636	2 330	10 953
2024	0	475	7 637	2 639	774	263	7 489	2 226	1 037	0	7 489	2 226	804	234	7 489	2 226	848	189	7 489	2 226	775	263	7 489	2 226	10 752
2025	0	447	7 514	2 597	870	220	7 344	2 125	1 089	0	7 344	2 125	880	209	7 344	2 125	929	160	7 344	2 125	864	225	7 344	2 125	10 558
2026	0	431	7 433	2 558	966	185	7 241	2 030	1 151	0	7 241	2 030	966	185	7 241	2 030	1 015	137	7 241	2 030	958	194	7 241	2 030	10 422
2027	0	416	7 354	2 521	1 062	153	7 140	1 936	1 214	0	7 140	1 936	1 053	161	7 140	1 936	1 100	115	7 140	1 936	1 051	164	7 140	1 936	10 290
2028	0	402	7 276	2 485	1 156	122	7 040	1 845	1 278	0	7 040	1 845	1 142	137	7 040	1 845	1 184	94	7 040	1 845	1 144	135	7 040	1 845	10 163
2029	0	389	7 200	2 450	1 249	94	6 941	1 755	1 343	0	6 941	1 755	1 231	112	6 941	1 755	1 269	74	6 941	1 755	1 236	107	6 941	1 755	10 039
2030	0	376	7 125	2 418	1 341	68	6 843	1 666	1 409	0	6 843	1 666	1 321	88	6 843	1 666	1 354	56	6 843	1 666	1 330	80	6 843	1 666	9 919
2031	0	366	7 052	2 387	1 434	44	6 747	1 579	1 478	0	6 747	1 579	1 414	64	6 747	1 579	1 440	38	6 747	1 579	1 424	54	6 747	1 579	9 804
2032	0	356	6 980	2 357	1 528	21	6 652	1 493	1 548	0	6 652	1 493	1 509	40	6 652	1 493	1 528	21	6 652	1 493	1 519	29	6 652	1 493	9 693
2033	0	346	6 910	2 329	1 524	19	6 580	1 463	1 542	0	6 580	1 463	1 527	15	6 580	1 463	1 524	19	6 580	1 463	1 524	19	6 580	1 463	9 586
2034	0	338	6 841	2 303	1 521	17	6 509	1 434	1 538	0	6 509	1 434	1 524	14	6 509	1 434	1 521	17	6 509	1 434	1 521	17	6 509	1 434	9 482
2035	0	329	6 774	2 278	1 520	15	6 440	1 406	1 535	0	6 440	1 406	1 522	12	6 440	1 406	1 520	15	6 440	1 406	1 520	15	6 440	1 406	9 381
2036	0	321	6 708	2 254	1 521	12	6 372	1 379	1 533	0	6 372	1 379	1 522	11	6 372	1 379	1 521	12	6 372	1 379	1 521	12	6 372	1 379	9 284
2037	0	314	6 644	2 232	1 522	10	6 305	1 352	1 533	0	6 305	1 352	1 523	9	6 305	1 352	1 522	10	6 305	1 352	1 522	10	6 305	1 352	9 190
2038	0	307	6 581	2 211	1 525	8	6 239	1 327	1 534	0	6 239	1 327	1 526	8	6 239	1 327	1 525	8	6 239	1 327	1 525	8	6 239	1 327	9 099
2039	0	301	6 520	2 192	1 530	6	6 174	1 302	1 536	0	6 174	1 302	1 530	6	6 174	1 302	1 530	6	6 174	1 302	1 530	6	6 174	1 302	9 012
2040	0	295	6 459	2 174	1 535	4	6 111	1 277	1 540	0	6 111	1 277	1 535	5	6 111	1 277	1 535	4	6 111	1 277	1 535	4	6 111	1 277	8 928
2041	0	289	6 401	2 158	1 542	2	6 049	1 254	1 544	0	6 049	1 254	1 541	3	6 049	1 254	1 542	2	6 049	1 254	1 542	2	6 049	1 254	8 847
2042	0	284	6 343	2 143	1 551	0	5 988	1 231	1 551	0	5 988	1 231	1 549	2	5 988	1 231	1 551	0	5 988	1 231	1 551	0	5 988	1 231	8 770
2043	0	279	6 287	2 129	1 556	0	5 928	1 211	1 556	0	5 928	1 211	1 556	0	5 928	1 211	1 556	0	5 928	1 211	1 556	0	5 928	1 211	8 695
2044	0	274	6 232	2 117	1 563	0	5 870	1 192	1 563	0	5 870	1 192	1 563	0	5 870	1 192	1 563	0	5 870	1 192	1 563	0	5 870	1 192	8 624
2045	0	270	6 179	2 107	1 571	0	5 812	1 173	1 571	0	5 812	1 173	1 571	0	5 812	1 173	1 571	0	5 812	1 173	1 571	0	5 812	1 173	8 556

Note: ED: 'ecodesigned', NOC-e: 'non-controlled' eligible for scrappage, NOC-o: 'non-controlled' other.

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