CLEARING THE SMOKE

A cost-benefit analysis of wood stove filters in the EU

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INTRODUCTION

Residential wood burning is the **largest source of fine particle pollution (PM2.5)** from energy use in the European Union. Despite increasing awareness of the devastating health and environmental consequences, current EU regulations fall short of tackling emissions at the source.

The EU **Ecodesign standards for solid fuel stoves** (Lot 20) set limits on emissions but do not require newly sold stoves to incorporate proven emission filtration technologies, such as **electrostatic precipitators**, which can significantly reduce particulate emissions.

This paper estimates the costs and benefits of requiring electrostatic precipitators in all new wood stoves sold on the EU market. **Denmark (DK) and Slovakia (SK)** are used as illustrative case studies, demonstrating both the feasibility and necessity of such a requirement. The analysis covers **densely populated urban areas, smaller towns, and rural regions**, recognising that biomass use tends to be more intensive in rural areas, in both countries. Denmark and Slovakia were selected because they are of similar size but differ significantly in per capita income, allowing an examination of the impacts for both wealthier and less wealthy EU member states.

Additionally, external costs related to air pollution (health impacts only) and climate pollution have been calculated per gigajoule (GJ) of heating energy for new wood stoves (with and without precipitators) and heat pumps. Using estimated average energy consumption across different areas in the two countries, the paper presents an **analysis of the total cost of ownership** for stoves equipped with precipitation technology.

COSTS

Table 1 presents the **Gross National Product (GNP)** of Denmark and Slovakia, highlighting the differences in their economic capacities, while Table 2 provides cost estimates for electrostatic precipitators in wood stoves for these two Member States.

The average annual gross salaries in Denmark and Slovakia are approximately €70,000 and €20,000, respectively. This means that **the annual cost of electrostatic precipitators represents only around 0.2–0.5% of these incomes** (as shown in Table 2) and is already offset by savings on alternative fuels such as gas or oil. Consequently, making electrostatic precipitators mandatory for new wood stoves would not constitute a significant financial burden.

Table 1: GNP for Denmark and Slovakia

	Denmark	Slovakia
GNP per capita (2024) [1)]	€60,510	€19,130
Average salary [2)]	€70,000	€20,000

1) https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10/default/table
2) https://ec.europa.eu/eurostat/databrowser/view/nama_10_fte/default/table?lang=en

Table 2: **Costs for electrostatic precipitators**

		Denmark	Slovakia
Estimated price of precipitator (mass production)		€1,000 [1]	€1,000 [1]
Estimated installation price of precipitator		€200 [2]	€60 [7]
Electricity costs per year [3]	Urban: 44 kWh	€16 [4]	€8 [4]
	Towns: 99 kWh	€36 [4]	€18 [4]
	Rural: 180 kWh	€65 [4]	€32 [4]
Extra maintenance costs per year (chimney sweep)		€70 [5]	€21 [7]
Total cost of ownership [6]	Urban	€2,920	€1,640
	Towns	€3,320	€1,840
	Rural	€3,900	€2,120
Ownership costs per year [6]	**Urban**	**€146**	**€82**
	Towns	**€166**	**€92**
	Rural	**€195**	**€106**

1) *The current price (https://www.pejseringen.dk/exodraft-braendeovnsfilter) of an electrostatic precipitator being sold in very low quantities is 2,300 euro. If required by Ecodesign regulations, mass production is expected to reduce the price to max. 1,000 euro (confirmed by the producer Exodraft and by https://cea-europe.org/wp-content/uploads/2024/11/CEA_Studie_20241125.pdf).*
2) *Depending on the access to the chimney (here it is assumed that the chimney can be reached e.g., by using a simple ladder).*
3) *Assuming that the filter (stove) is used 400/1,200/2,400 hours per year in urban/towns/rural areas (in use 70W / standby: 2W).*
4) *https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics*
5) *Performed by the chimney sweeper once a year during mandatory inspection (assumed reachable e.g., by using a simple ladder).*
6) *Assuming that the lifetime of the precipitator is 20 years: https://www.epa.gov/sites/default/files/2020-07/documents/cs6ch3.pdf*
7) *Assumed 30 % of the price in Denmark since average salary in Slovakia is around 30 % of the average salary in Denmark.*

BENEFITS

Over its lifetime, a well-maintained, high-quality electrostatic precipitator is assumed to **remove an average of 70% of fine particulate matter (PM2.5).** The calculations below are based on the use of dry wood and proper stove operation – conditions that are essential for achieving optimal performance. It is therefore crucial that this information be clearly displayed on product labelling to guide users.

If these conditions are not met –for example, if wet or inappropriate fuel is used, or if the stove is poorly operated– air pollution levels increase significantly. In such cases, the benefits of the precipitator would in fact be greater than those estimated here, as more particles would be captured.

Table 3 presents the health benefits (i.e. societal gains) per gigajoule (GJ) of heating, resulting from reduced fine particle (PM2.5) emissions when using precipitators in wood stoves. These **health benefits are likely underestimated**, as electrostatic precipitators also remove ultrafine particles, larger particulates, and harmful substances such as dioxins, polycyclic aromatic hydrocarbons (PAHs), and heavy metals attached to the particles. However, only the benefits of PM2.5 reduction are included in the analysis, as there are currently no externality values for other particle sizes, and the extent to which these additional substances are filtered out remains uncertain. As a result, the model does not account for these further benefits.

Table 3: **Health benefits of electrostatic precipitators per GJ of house heating (per year)**

		Denmark	Slovakia
Health cost per kg of $PM_{2.5}$ [1]	Urban: > 3,000 citizens/km^2	€325 euro	€338 [5]
	Towns: 1,500-3,000 citizens/km^2	€213 euro	€303 [5]
	Rural: < 100 citizens/km^2	€149 euro	€283 [4]

Emissions from a new stove without precipitator	$PM_{2.5}$ emission [2]		0.347 kg	
	Health costs	Urban	€113	€117
		Towns	€74	€105
		Rural	€52	€98
Emissions from a new stove with precipitator	$PM_{2.5}$ emission [3]		0.104 kg	
	Health costs	Urban	€34	€35
		Towns	€22	€32
		Rural	€16	€29
Health benefits (avoided costs) of precipitators (euro)		**Urban**	**€79**	**€82**
		Towns	**€52**	**€74**
		Rural	**€36**	**€69**

1) https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2023/N2023_54.pdf (Multiplying with 1.09 to get 2025 prices).
2) Assuming 85% energy efficiency and using emission factors of https://dce2.au.dk/pub/SR435.pdf (Ecodesign stoves = 295 g/GJ).
3) Assuming an average fine particle removal of 70% over the lifetime by the precipitator.
4) Assuming that the rural $PM_{2.5}$ emission from stoves in Slovakia has a cost being 1.9 higher than rural stoves in Denmark due to the much higher regional population density in central Europe https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/etc-atni-report-04-2020-costs-of-air-pollution-from-european-industrial-facilities-200820132017
5) Assuming that the cost increase from rural areas to more densely populated areas (towns and urban) in Slovakia are 31% of corresponding cost increase in Denmark since the Slovakian GNP is 31% of the Danish GNP (table 1).

COST-BENEFIT ANALYSIS

Table 4 presents a cost-benefit analysis comparing the annual ownership costs per household with the health benefits gained from reducing fine particle pollution through the use of electrostatic precipitators.

As shown in Table 4, mandating the use of electrostatic precipitators under revised Ecodesign regulations would be a socially cost-beneficial investment (ratios above 1 mean the benefits outweigh the costs), particularly if countries actively support their uptake – or promote cleaner heating alternatives, as discussed below.

Table 4: Cost-benefit analysis per household of requiring electrostatic precipitators (per year)

		Denmark	Slovakia
Stove contribution to house heating [1]	Urban	5 GJ (1.4 MWh)	
	Towns	15 GJ (4.2 MWh)	
	Rural	30 GJ (8.4 MWh)	
Health benefits of precipitators [2]	Urban	**€395**	**€410**
	Towns	**€776**	**€1,104**
	Rural	**€1,086**	**€2,063**
Ownership costs [3]	Urban	€146	€82
	Towns	€166	€92
	Rural	€195	€106
Benefit-to-cost ratio *(Values above 1 indicate net benefits)*	**Urban**	**2,7**	**5,0**
	Towns	**4,7**	**12,0**
	Rural	**5,6**	**19,4**

1) Assuming 400/1,200/2,400 hours of precipitator (stove) use a year in Urban/towns/rural areas and a typical new stove.
2) Calculated from health benefits due to less pollution for stoves with precipitators in table 3 (e.g. 5GJ · 79€/GJ = 395€).
3) From annual costs calculations (table 2).

EXTERNALITIES: WOOD STOVES VS HEAT PUMPS

The next table presents the average health costs in Denmark resulting from air pollutants emitted by new wood stoves that comply with current Ecodesign regulations (with and without electrostatic precipitators), compared to air-to-air heat pumps, which can often serve as alternatives to wood stoves. These heat pumps are assessed using electricity from various energy sources. Table 6 shows the corresponding climate impacts.

As illustrated in Table 5, the **health costs** from air pollution caused by a new Ecodesign-compliant **wood stove are approximately 180 times higher than those of a heat pump** powered by coal-based electricity. These figures exclude further damages to ecosystems, agriculture, forests, and building materials.

If electrostatic precipitators were made mandatory, the health costs would still be around **70 times higher** per GJ compared to a coal-powered heat pump.

Table 5: Air pollution health costs in Denmark per GJ of heating for Ecodesign stoves and heat pumps

			$PM_{2.5}$	NOx	NH_3	SO_2	Total cost
Average cost in euro per kg (wood stoves/power plants) [1]			**140/74**	**57/24**	**38/--**	**25/24**	**---**
New wood stoves [2]	Wood	Kg	0.347	0.094	0.043	0.013 [4]	**55.7 euro**
		Euro	48.6	5.3	1.5	0.3	
New wood stove with precipitator [3]	Wood	Kg	0.104	0.094	0.043	0.013	**21.6 euro**
		Euro	14.5	5.3	1.5	0.3	
Heat pumps [4] (1/3 of power plant)	Coal	Kg	0.001	0.006	0	0.004	**0.31 euro**
		Euro	0.07	0.14	0	0.10	
	Gas	Kg	<0.001	0.009	0	<0.001	**0.22 euro**
		Euro	---	0.22	---	---	
	Wood	Kg	<0.001	0.011	0	<0.001	**0.26 euro**
		Euro	---	0.26	0	---	
	Wind/sun/hydro/nuke	Kg/euro	0	0	0	0	**0**

1) https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2023/N2023_54.pdf *(Multiplying with 1.09 to get 2025 prices).*
2) https://dce2.au.dk/pub/SR435.pdf *assuming 85% efficiency (Stoves (2015-2016) p. 114 are fulfilling the present Ecodesign regulations).*
3) *Assuming that precipitators on new stoves in the Ecodesign directive remove about 70% of $PM_{2.5}$*
4) https://envs.au.dk/fileadmin/envs/Emission_inventories/Emission_factors/Emf_internet_energy_GHG.htm *and 300% heat efficiency.*

Table 6 also shows that, even when assuming carbon neutrality for wood-based CO_2 emissions, **wood stoves result in significantly greater global warming than heat pumps powered by coal**. Electrostatic precipitators help reduce black carbon emissions, thereby significantly lowering the climate impact of wood stoves

Table 6: Global warming per GJ of house heating for Ecodesign wood stoves and heat pumps

			CO_2 [1]	CH_4	N_2O	BC [2]	**Total GW**
Official GWP20 / GWP100			**1 / 1**	**84 / 28**	**264 / 298**	**3,200/900**	GWP20/100
New wood stove	Wood	Kg	0-121 [5]	0.1 [5]	0.005 [5]	0.052 [3]	**175-296 / 51-172**
		GWP20/100	0-121	8.4/2.8	1.3 / 1.5	166 / 47	
New wood stove with precipitator [4]	Wood	Kg	0-121	0.1	0.005	0.016 [4]	**61-182 / 18-139**
		GWP20/100	0-121	8.4/2.8	1.3 / 1.5	51 / 14	
Heat pump [5] (1/3 of power plant)	Coal	Kg	32	<0.001	<0.001	<0.001	**32 / 32**
		GWP20/100	32	---	---	---	
	Gas	Kg	19	<0.001	<0.001	<0.001	**19 / 19**
		GWP20/100	19	---	---	---	
	Wood	Kg	0-33	0.001	<0.001	<0.001	**0-33 / 0-33**

		GWP20/100	0-33	0.1/---	---	---	
	Wind/sun/ hydro/Nuke	Kg	0	0	0	0	**0**
		GWP20/100	0	0	0	0	**0**

1) CO_2 interval for wood: Wood considered CO_2-neutral ("0") and taking the actual full CO_2-emisson from wood burning into account ("121").
2) BC: Black Carbon.
3) https://dce2.au.dk/pub/SR435.pdf assuming 85% energy efficiency. (Stoves 2015-2016 p. 114 fulfill the present Ecodesign regulations).
4) Assuming that precipitators on new stoves in the Ecodesign directive remove about 70% of BC: https://sites.uef.fi/real-life-emissions/wp-content/uploads/sites/321/2024/10/Presentation_Olli_LIFE_10-10-2024_-4.pdf
5) https://envs.au.dk/fileadmin/envs/Emission_inventories/Emission_factors/Emf_internet_energy_GHG.htm with 300% heat efficiency.

CONCLUSIONS

Our analysis finds that:

- **Filters cut harmful particle emissions by 70%**, reducing the health burden of wood stoves by hundreds of euros per year per household.
- **Health benefits outweigh costs up to 19 to 1**, especially in rural areas where wood burning pollution is widespread.
- For most households, **filters would cost less than 0.5% of annual income**, and even less when offset by savings from switching off gas or oil.
- Even filtered wood stoves still pollute **70 times more than heat pumps** per unit of energy.

Including a requirement for electrostatic precipitators in the revised Ecodesign regulations for wood stoves is **unlikely to place a significant economic burden on households**, even in less affluent EU countries. However, **some households may require financial support** to cover the upfront installation costs. Several Member States already offer schemes to support the renovation of domestic biomass heating systems, which could be extended to cover this technology.

Mandating the use of precipitators in new wood stoves would bring substantial societal benefits, with the **health and environmental gains far outweighing the costs**. Electrostatic precipitators significantly reduce air pollution and climate impacts from stoves that already comply with current Ecodesign standards.

Nonetheless, even with precipitators, wood stoves still generate around 70 times higher health-related costs than heat pumps – even when the electricity used by the latter is coal-based. From a societal perspective, energy renovation and the deployment of heat pumps should therefore take clear precedence over residential wood burning.

Further information

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