Cost-benefit: Electrostatic precipitators for solid fuel stoves and boilers

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Background

Residential heating with wood, coke, and coal in small stoves and boilers is a significant pollution source in many countries.

The smoke contains same toxic particles and carcinogenic PAHs as tobacco smoke and increases the risk of cancer, blood clots, cardiovascular diseases, lung diseases, etc.

Thereby the pollution contributes to mortality and morbidity - and imposes an expensive health burden on society. However, this expensive burden may make the requirement to equip and operate new residential stoves and boilers with an electrostatic precipitator a positive investment for society.

Purpose

The main purpose of this study was to perform a cost-benefit screening of the following scenario: the ongoing revision of the EU Ecodesign regulations for wood stoves and boilers leads to an outcome where electrostatic precipitators (or similar tech) will be mandatory for new appliances. Furthermore, climate pollution and externalities (health costs) of air pollution were calculated per Gigajoule (GJ) of house heating for an existing Ecodesign wood stove (with and without precipitator) and compared to the use of a heat pump.

Methods

Model calculations were conducted for densely populated urban areas, smaller towns, and rural areas, as the latter typically have more intense use of biomass than the former, in Denmark and Slovakia, two EU countries that have same size but quite different per-capita average income to illustrate the consequences in both wealthier and less wealthy countries in the EU. Costs of precipitators in case of mass production were estimated to be 1,000 euro. Specific fuel use and health externalities for densely populated urban areas, smaller towns, and rural areas in Denmark and Slovakia were used. Pollution health externalities in Denmark and global warming per GJ of heating for existing Ecodesign wood stoves (with and without precipitators) - and using heat pumps - were calculated for four key air pollutants: $PM_{2.5}$, NOx, NH_3, and SO_2, and four climate pollutants: CO_2, CH_4, N_2O, and black carbon (BC).

Results & Discussion

Annual cost of electrostatic precipitators represents only 0.2-0.5% of the incomes in Denmark and Slovakia. As a result, making electrostatic precipitators mandatory for new stoves and boilers would not pose a general financial burden: but some families may need financial support to buy precipitators.

The benefit to cost ratio of requiring electrostatic precipitators for residential stoves is 2.7-19.4 and for boilers 3.2-74.6 thus making it a beneficial – and in many cases a very beneficial – investment for society if new Ecodesign regulations mandate the use of electrostatic precipitators for solid fuel appliances .

Even though externalities are highest per kg $PM_{2.5}$ in densely populated urban areas, the benefits to cost ratios are highest for stoves in rural areas because of significantly higher fuel use per stove (more pollution per stove) and because $PM_{2.5}$ spread far from the source thereby causing regional exposure.

The general health costs of air pollution from a new wood stove meeting current Ecodesign regulations in Denmark are approximately 180 times higher per GJ of household heating than those from even a coal-powered electric heat pump.

Even if electrostatic precipitators are made mandatory in the Ecodesign regulation, new wood stoves would still result in about 70 times higher health costs per GJ of heating compared to a coal-powered heat pump.

Hence, much better insulated homes in combination with heat pumps (residential and large central) is both the cheapest and most efficient way to clean heating for society.

Cost-benefit analysis for stoves per household of requiring electrostatic precipitators (per year)

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

Cost-benefit analysis for boilers per household of requiring electrostatic precipitators (per year)

		Denmark	Slovakia
Boiler contribution to house heating	Urban	57 GJ (16 MWh)	
	Towns	72 GJ (20 MWh)	
	Rural	86 GJ (24 MWh)	
Wood pellet boiler: Health (euro per year) benefits of precipitators	Urban	741	741
	Towns	576	864
	Rural	516	946
Log wood boiler (no accumulation tank): Health benefits (euro per year) of precipitators	Urban	4,731	4,959
	Towns	3,960	5,616
	Rural	3,268	6,278
Log wood boiler (with accumulation tank): Health benefits (euro per year) of precipitators	Urban	912	969
	Towns	720	1,080
	Rural	602	1,204
Ownership costs in euros per year	Urban	144	80
	Towns	148	82
	Rural	152	84
Wood pellet boiler: benefit to cost ratio	**Urban**	**5,0**	**9,3**
	Towns	**4,0**	**10,2**
	Rural	**3,2**	**11,1**
Log wood boiler (no acc. tank): benefit to cost ratio	**Urban**	**32,9**	**62,1**
	Towns	**26,8**	**68,5**
	Rural	**21,5**	**74,6**
Log wood boiler (acc. tank): benefit to cost ratio	**Urban**	**6,3**	**12,1**
	Towns	**4,9**	**13,2**
	Rural	**4,0**	**14,3**

Air pollution health costs in Denmark per GJ of heating for existing 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	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.

Global warming per GJ of house heating for existing Ecodesign wood stoves and heat pumps

			CO_2 [1]	CH_4	N_2O	BC [2]	Total GW GWP20/100
Official GWP20 / GWP100			**1 / 1**	**84 / 28**	**264 / 298**	**3,200/900**	
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	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.

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Acknowledgement

This study was funded by the Clean Air Fund and the European Climate Foundation to deliver input to the ongoing revision of the Ecodesign regulation for new residential stoves and boilers using solid fuels in the EU. However, all views and opinions expressed are those of the authors only and do not necessarily reflect those of the funders.