REDUCTION OF CO_2 BY RESIDENTIAL WOOD HEATING AND TRADE-OFF CAUSED BY INCREASED POPULATION EXPOSURE TO PRIMARY $PM_{2.5}$ AND SLCF EMISSIONS

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S Y K E

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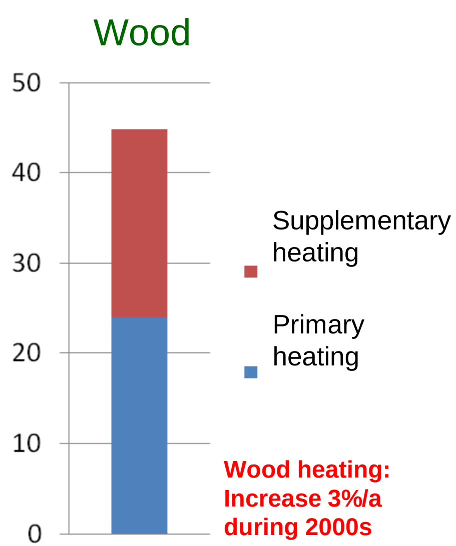
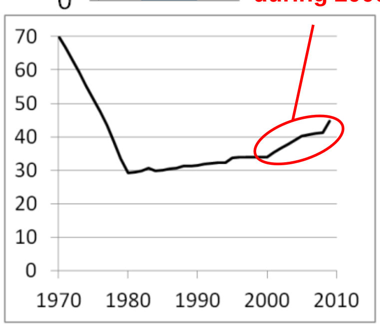
Residential heating in Finland

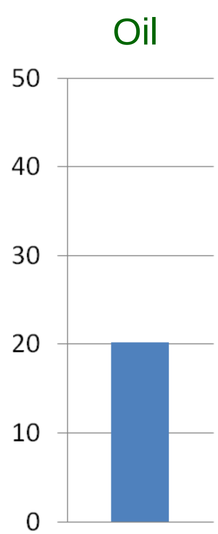
- Residential heating in this study = Heating of **detached houses** (excl. apartment houses)
- Detached houses are heated mainly by small kW-range boilers (wood and oil) and electricity. In addition, wood is widely used in stoves as supplementary heating in electricity-heated houses.

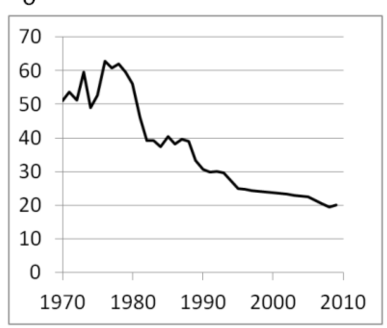
Energy use of the heating of detached houses in 2009 (above) and 1970-2009 (below) (unit PJ)

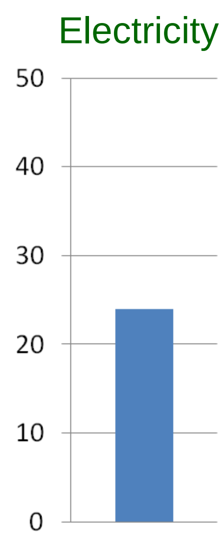


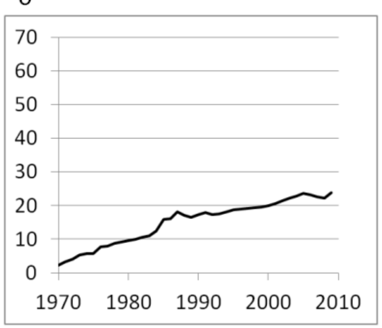


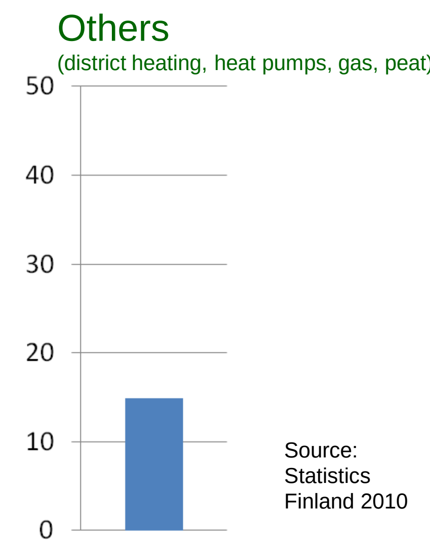
Residential wood heating in 2009 44.8 PJ
= 43% of the total residential heating energy use in Finland
= 3.5% of the total Finnish primary energy use

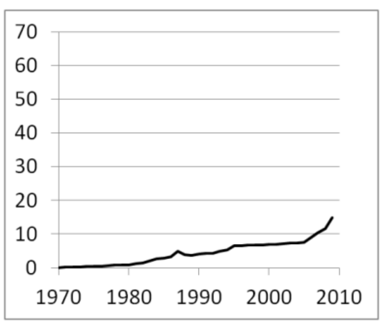










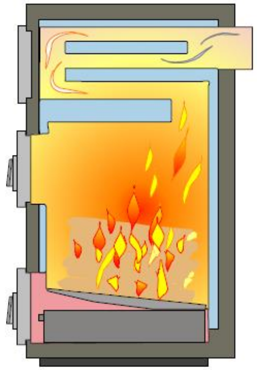


Source: Statistics Finland 2010

Residential wood heating in Finland

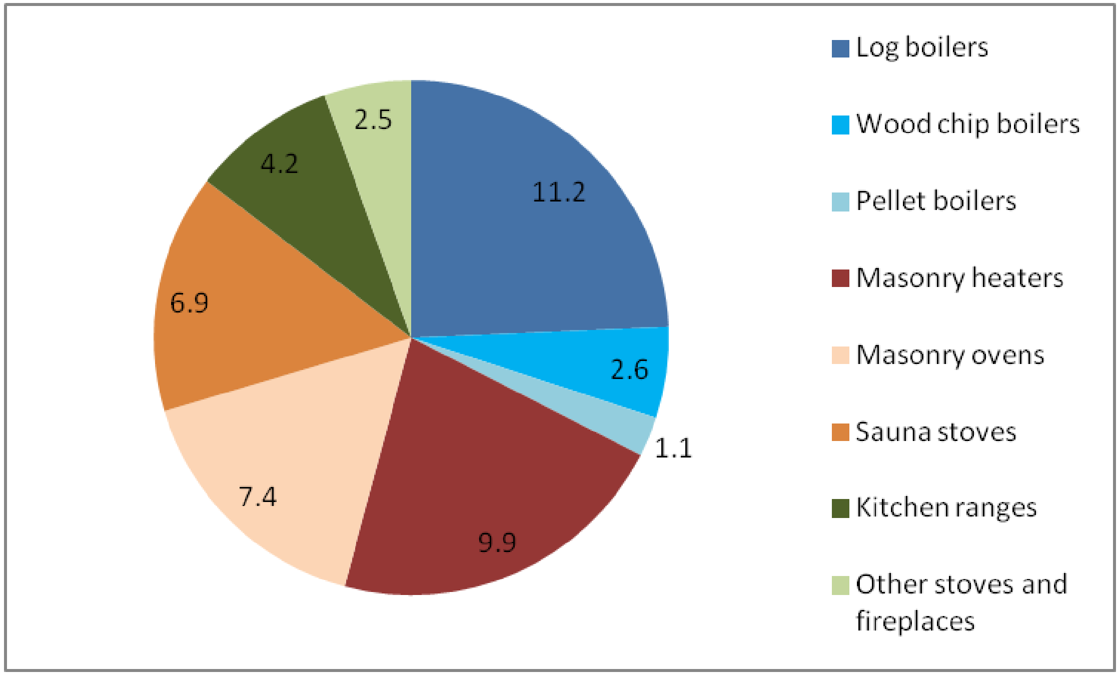
Combustion appliances

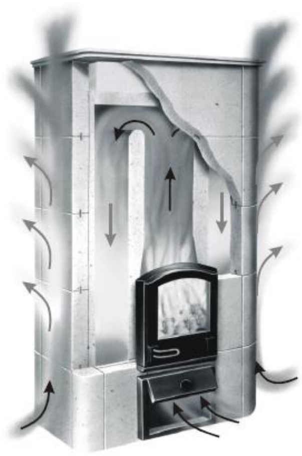
- Most common combustion appliance types are
  - Updraught-type log boilers, relatively simple in structure
  - Masonry heaters with large heat accumulating stone mass



Log boiler

Residential wood use by combustion appliance type in 2008 (in PJ)





Masonry heater

Source:
Finnish Forest
Research Institute 2010

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Residential wood heating in Finland

Potential way to reduce CO_2 emissions

- Wood is a renewable fuel, i.e. its CO_2 emissions can be considered zero
  - If RWH replaces heating by fossil fuels (or electricity heating if electricity is produced using fossil fuels), it has a **potential for CO_2 reductions**
- Wood is indigenous, often available from user's own or relative's forest, cheap
  - Improves **energy security**

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Residential wood heating in Finland

Emissions of primary $PM_{2.5}$ and negative health impacts

- RWH causes considerable **emissions and population exposure to $PM_{2.5}$**
- Emissions from RWH **8.4 kilotons/a** in 2008 (**26% of Finnish total** primary $PM_{2.5}$ emissions)
- Emission factors:
  - Wide range from pellet boilers (30 mg/MJ) to open fireplaces and iron stoves (800 mg/MJ)
  - Most common appliances:
    - Log boilers (80 mg/MJ)
    - Masonry heaters, conventional/modern (120/80 mg/MJ)
    - Compared to residential oil boiler (2 mg/MJ)

Source:
Karvosenoja et al. 2008. Evaluation of the emissions and uncertainties of $PM_{2.5}$ originated from vehicular traffic and domestic wood combustion in Finland. Boreal Environ. Res. 13:465-474.

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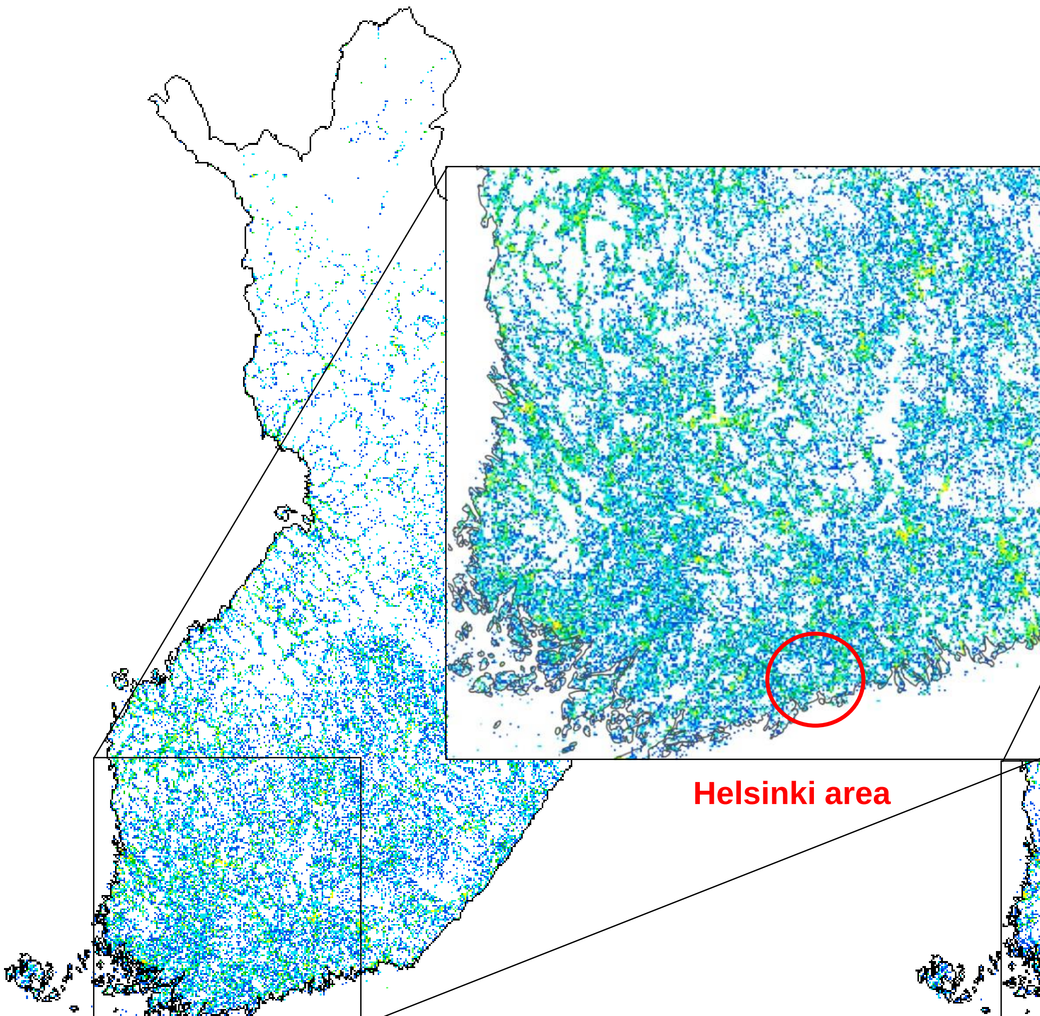
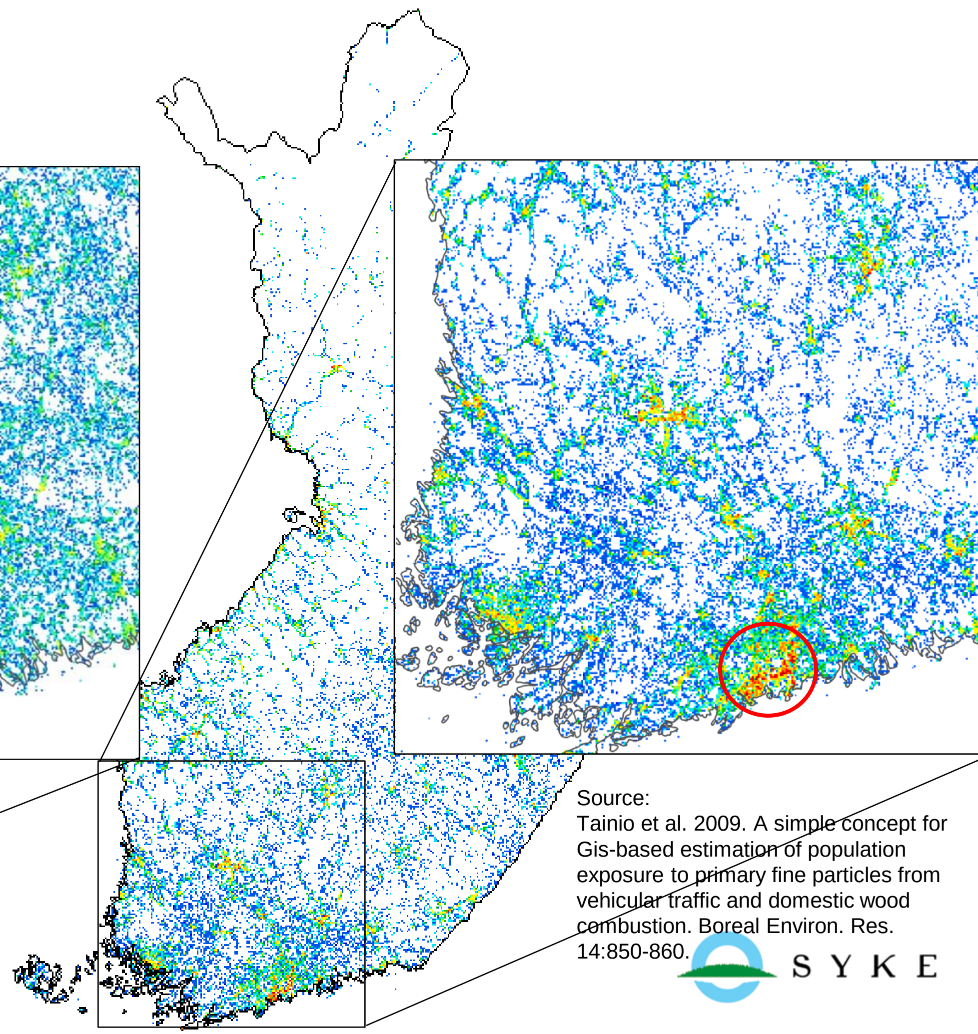
Residential wood heating in Finland

Emissions of primary $PM_{2.5}$ – Spatial distribution

Primary wood heating (boilers)



Supplementary wood heating (stoves)



Source:
Tainio et al. 2009. A simple concept for Gis-based estimation of population exposure to primary fine particles from vehicular traffic and domestic wood combustion. Boreal Environ. Res. 14:850-860.

Residential wood heating in Finland

Emissions of PM - short-lived climate forcers (SLCF)

- Particles in the atmosphere influence the climate
- **Black carbon (BC) –containing particles increase radiative forcing** and thus warm the climate

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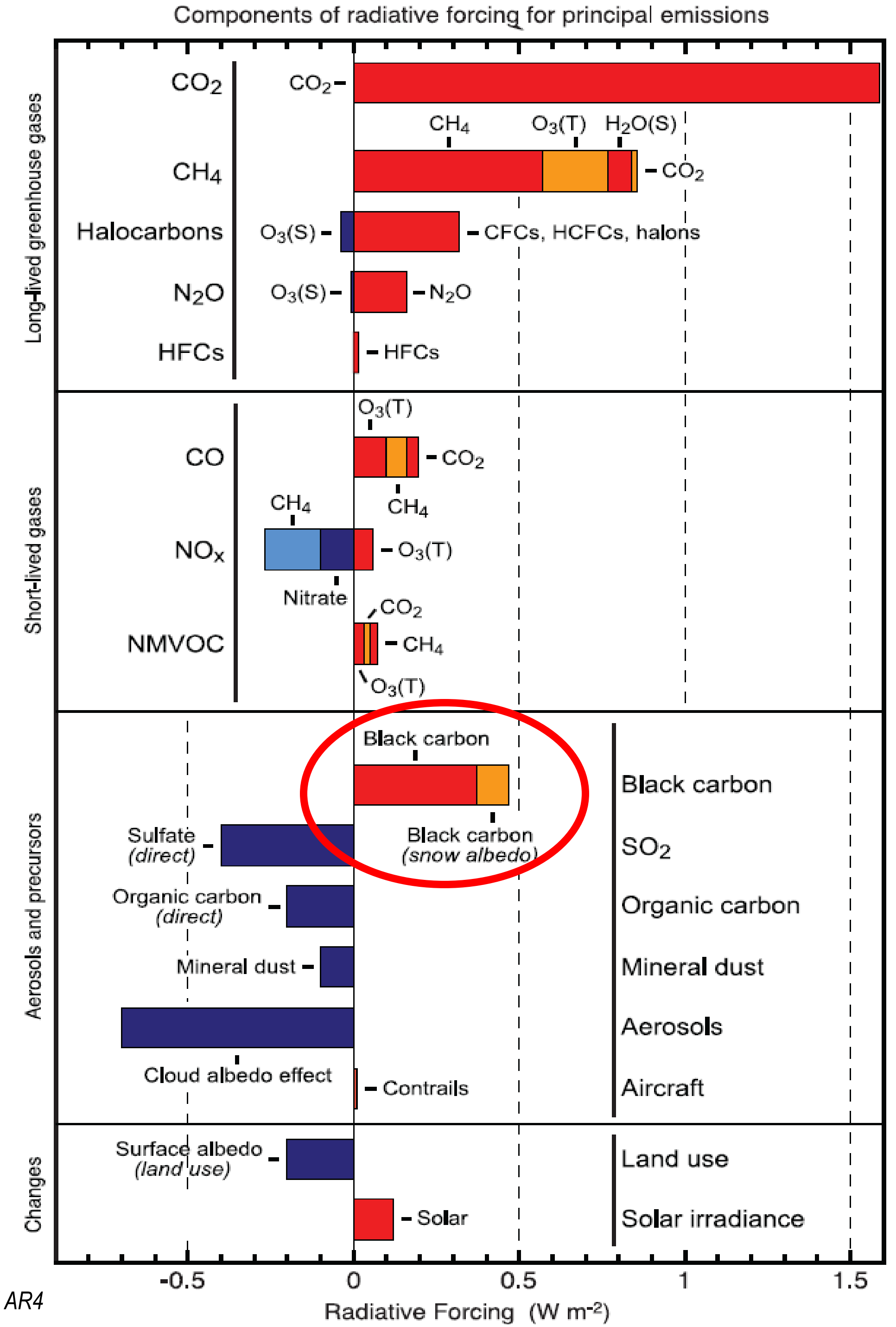
Change of radiative forcing by components

- Black carbon (BC), i.e. soot, is the most important aerosol warming the atmosphere
- Multiple effects of BC:
  - Direct warming effect – absorbs sun radiation
  - (Cloud formation)
  - Changes in snow and ice albedo (especially in the Arctic))
- BC life time in the atmosphere only days to weeks!



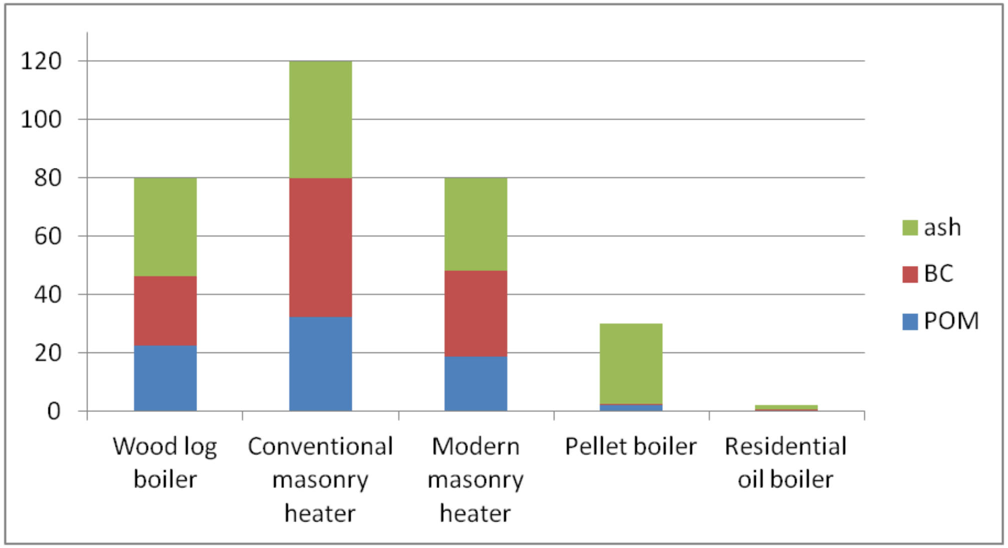
source: IPCC, 2007 AR4

Residential wood heating in Finland

Emissions of PM - short-lived climate forcers (SLCF)

- Particles in the atmosphere influence the climate
- **Black carbon (BC) –containing particles increase radiative forcing** and thus warm the climate
- Wood combustion in stoves, masonry heaters and log boilers produce considerable amounts of BC emissions

Composition of $PM_{2.5}$ emission factors (mg/MJ)



*POM = particulate organic matter

Future of RWH in Finland

IS IT DESIRABLE TO PROMOTE THE INCREASE OF RESIDENTIAL WOOD HEATING?

Potential to increase RWH - Two most likely ways identified:

1. Increase of **primary** wood heating: Replacement of residential oil heating by wood pellet heating
2. Increase of **supplementary** wood heating: Increasing wood use in existing stoves in electricity-heated houses (thus saving electricity)

- How much CO_2 can be reduced?
- What does it mean for $PM_{2.5}$ emissions and human health impacts?
- What does it mean for SLCF emissions and climate impacts?

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Future of RWH in Finland

Three different pathways for the year 2020 were considered

1. **Baseline**: No substantial increase in RWH. This is in line with the basic pathway of the Finnish official Climate Strategy

2. Increase of primary RWH (**PRIM) scenario**: Total substitution of residential oil heating by pellet heating (15 PJ primary energy)

3. Increase of supplementary RWH (**SUPPL) scenario**: 50% increase in wood stove (masonry heater) use (8.5 PJ primary energy) and respective saving in electricity (6.8 PJ = 1.9 TWh) compared to Baseline

Results

Reduction of CO_2 emissions in 2020

Baseline to PRIM (Substitution of oil heating by pellets)

CO_2 emissions decrease **1.11 Mtons/a**

Baseline to SUPPL (50% increase in stove use and respective saving in electricity)

CO_2 emissions decrease **0.54 Mtons/a**

Sum of both

1.65 Mtons/a = 5.5% reduction to the Finnish total non-ETS (Emission Trading Scheme) emissions in 2020

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Results

Change in primary $PM_{2.5}$ emissions in 2020

Baseline to PRIM (Substitution of oil heating by pellets)

Pellet heating emissions increase 450 tons/a; oil heating emissions decrease 30 tons/a

-> Net increase in $PPM_{2.5}$ emissions **420 tons/a**

Baseline to SUPPL (50% increase in stove use and respective saving in electricity)

Masonry heaters emissions increase 899 tons/a; electricity production emissions decrease 27 tons/a

-> Net increase in $PPM_{2.5}$ emissions **872 tons/a**

Sum of both

1292 tons/a = 4.6% increase to Finnish total primary $PM_{2.5}$ emissions in 2020

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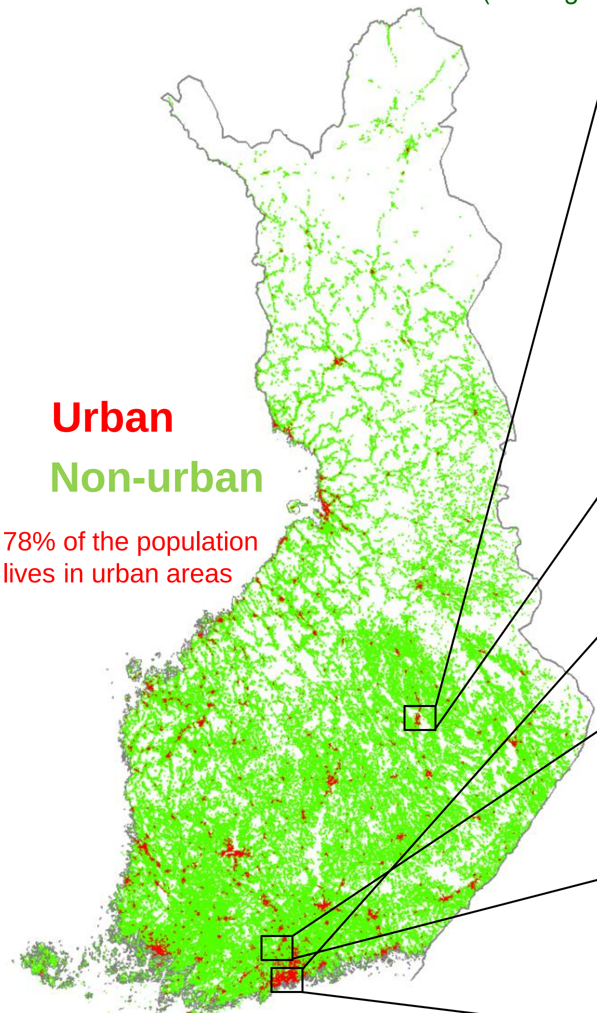
Results - population exposure to $PPM_{2.5}$ in 2020

- $PPM_{2.5}$ **emission and dispersion modeling** at 1 km spatial resolution were run for each heating scenario using The Finnish Regional Emission Scenario (FRES) model (Karvosenoja 2008). Source-receptor matrices for $PPM_{2.5}$ dispersion were based on UDM-FMI model.
- In addition, population exposure impacts were studied **separately for urban and non-urban areas** at 250 m resolution ("a conglomeration of grid cells is defined urban when it is densely built with a minimum of 200 inhabitants")

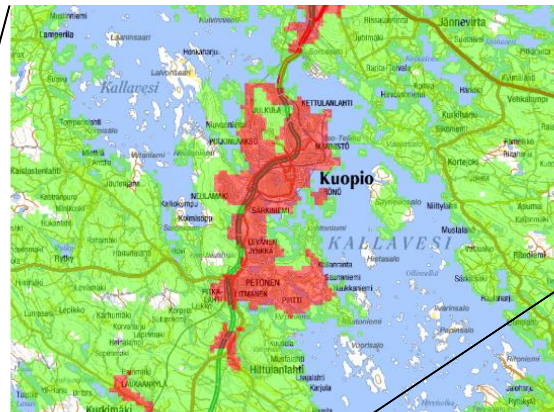
Karvosenoja N. 2008. Emission scenario model for regional air pollution. Monographs Boreal Environ. Res. 32.



Urban

Non-urban

78% of the population lives in urban areas



Kuopio
93 000 inhab.

Nurmijärvi
40 000 inhab.
(mainly detached houses, commuting to Helsinki area)

Helsinki Metropolitan area
1.1 Million inhab.

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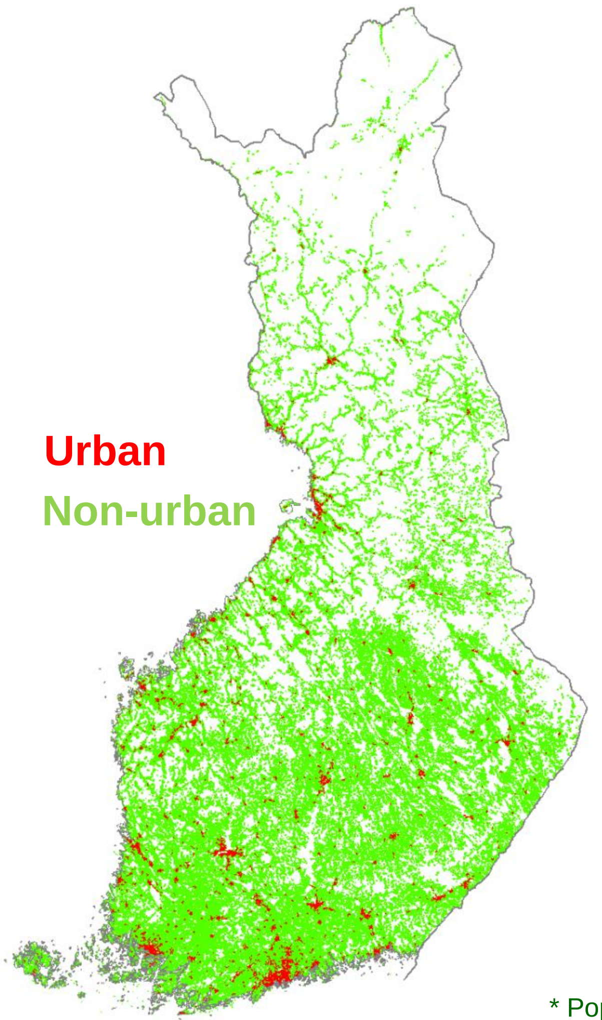
Results - population exposure to $PPM_{2.5}$ in 2020

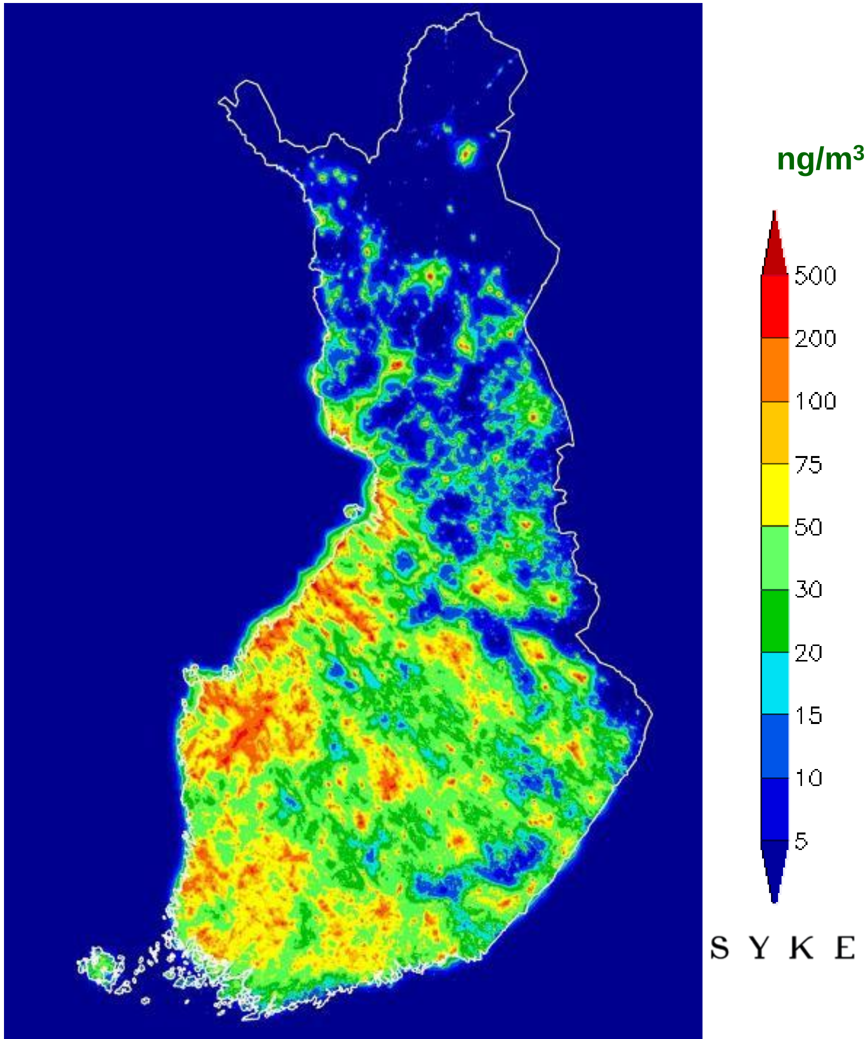
Baseline: primary wood heating (boilers)



Population exposure* to $PPM_{2.5}$ 183 ng/m^3

(of which in urban areas 141 ng/m^3)

$PPM_{2.5}$ concentration caused by primary RWH (24 PJ)



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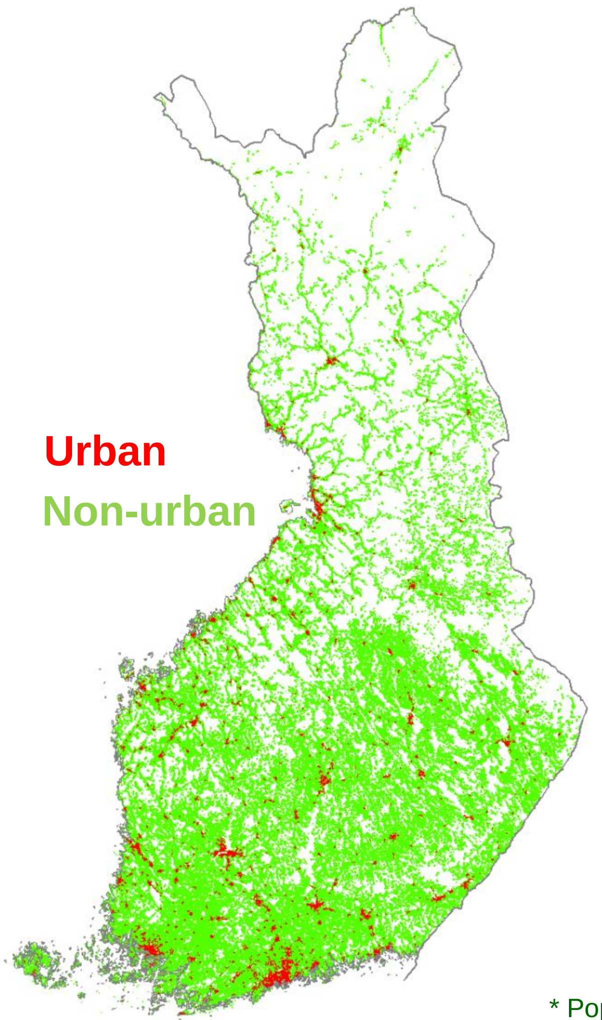
* Population weighted concentration

Results - population exposure to $PPM_{2.5}$ in 2020

Baseline to PRIM (Substitution of oil heating by pellets)

Urban

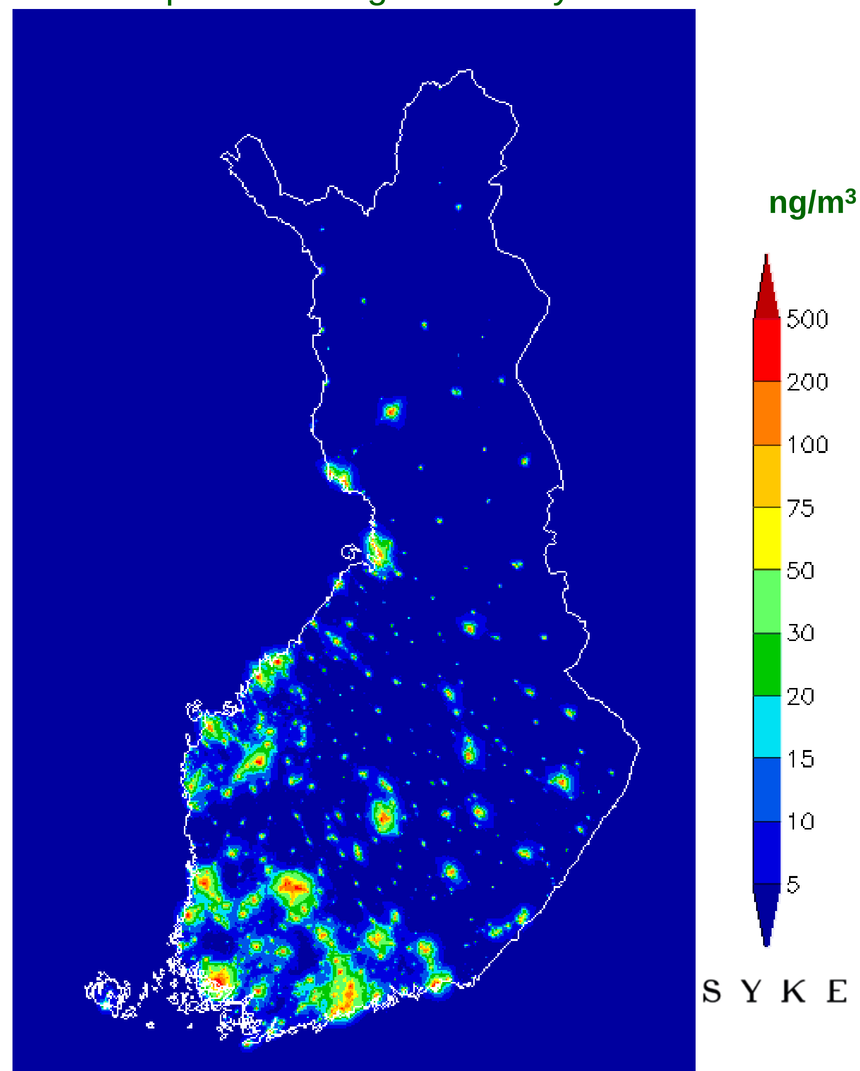
Non-urban



Population exposure* to $PPM_{2.5}$ **increase** 91 ng/m^3

(of which in urban areas 89 ng/m^3)

$PPM_{2.5}$ concentration **increase** caused by 15 PJ additional pellet heating in formerly oil-heated houses



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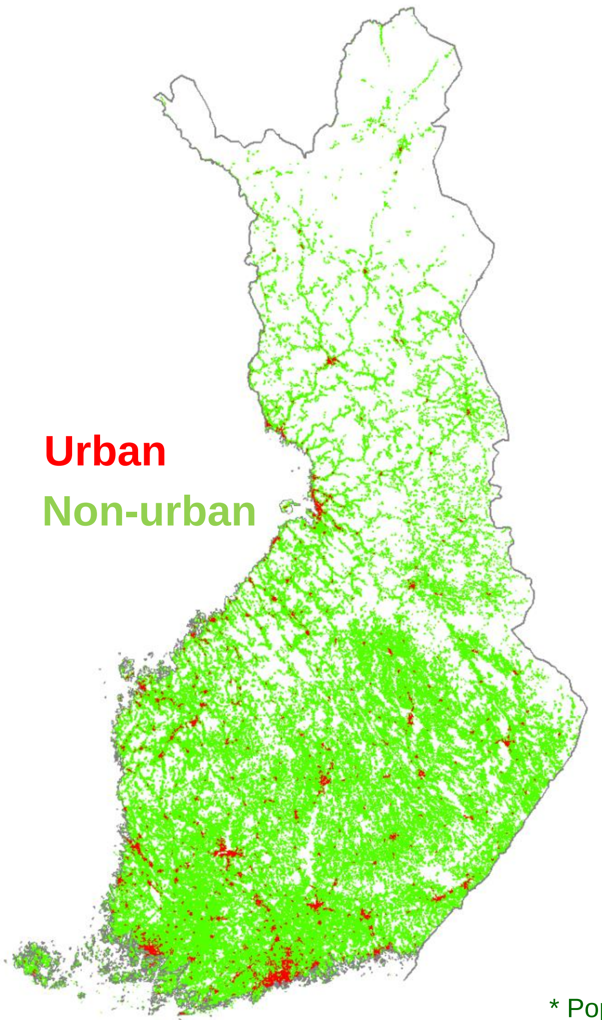
* Population weighted concentration

Results - population exposure to $PPM_{2.5}$ in 2020

Baseline: supplementary wood heating (stoves)

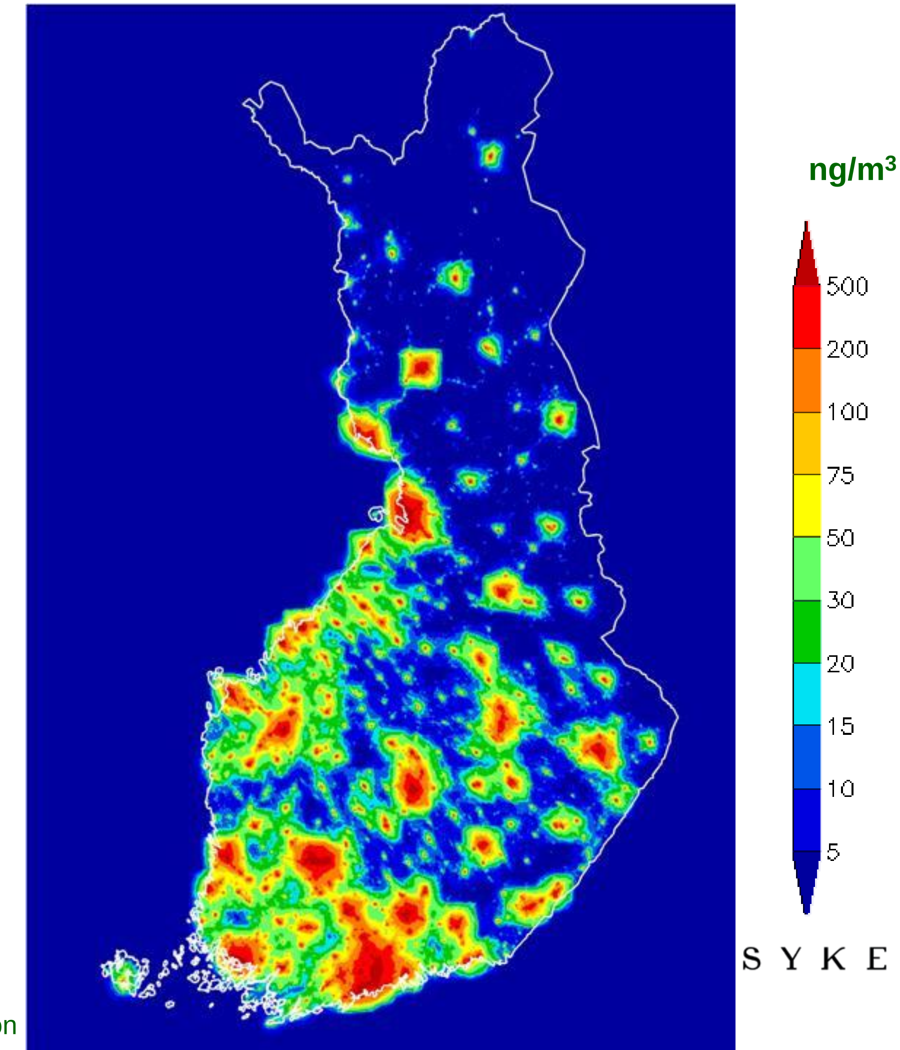
Urban
Non-urban



Population exposure* to $PPM_{2.5}$ 375 ng/m^3

(of which in urban areas 355 ng/m^3)

$PPM_{2.5}$ concentration caused by supplementary RWH (17 PJ)



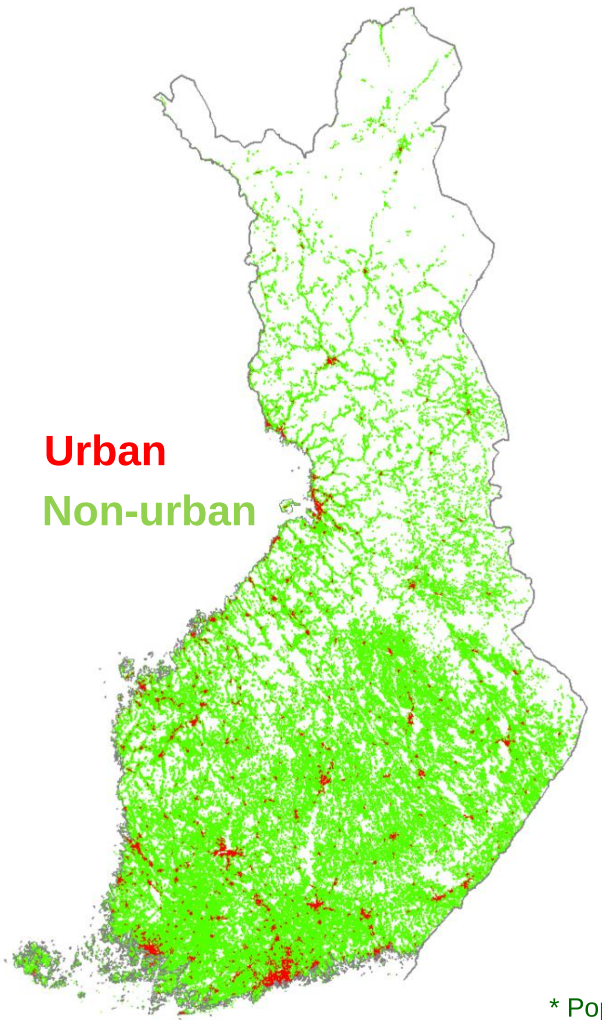
* Population weighted concentration

Results - population exposure to $PPM_{2.5}$ in 2020

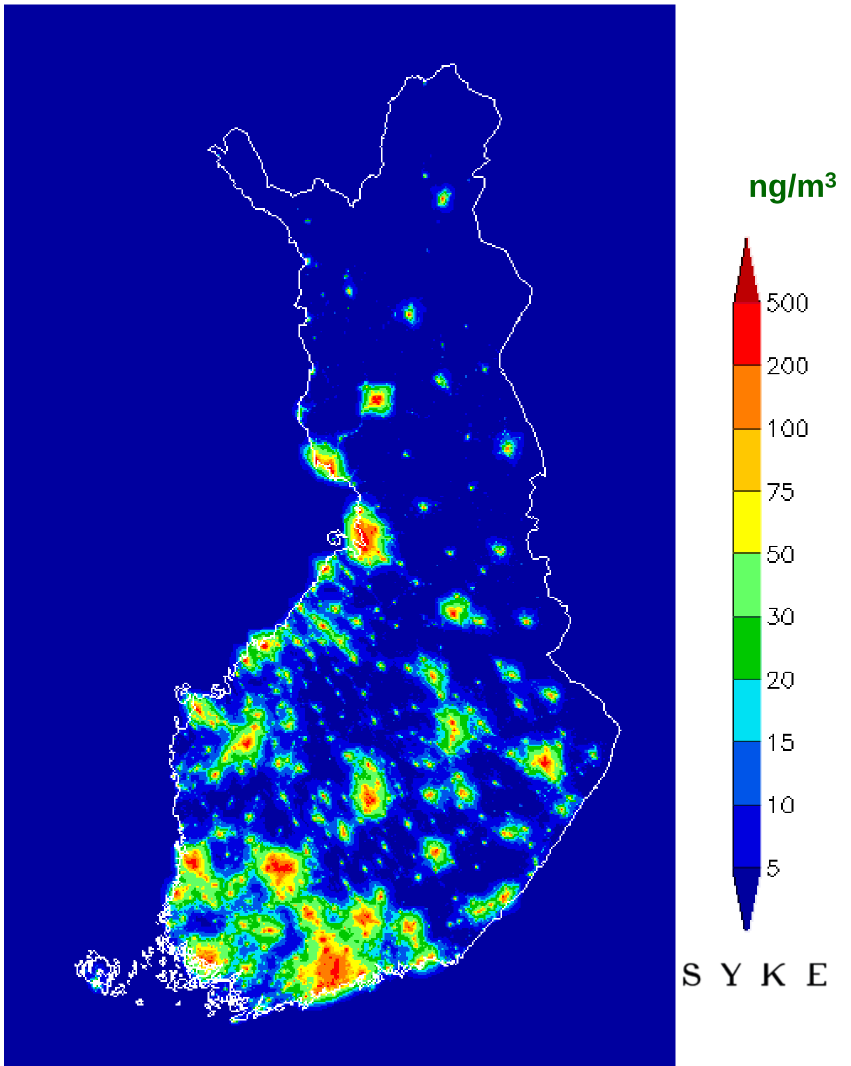
Baseline to SUPPL (50% increase in masonry heater use)

Population exposure* to $PPM_{2.5}$ **increase** 141 ng/m³

(of which in urban areas 133 ng/m³)



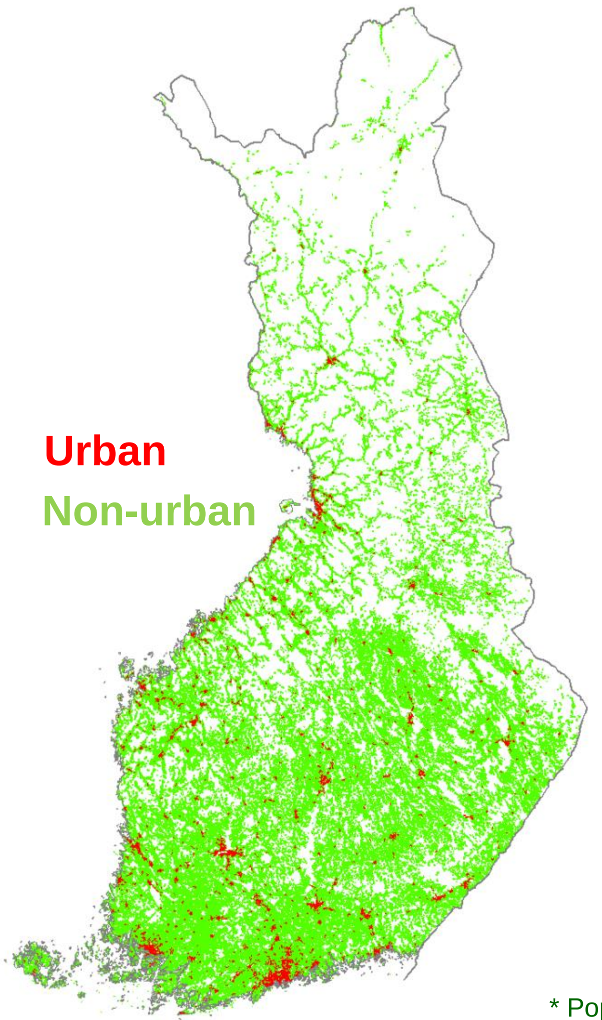
$PPM_{2.5}$ concentration **increase** caused by 8.5 PJ additional stove heating in electricity-heated houses



* Population weighted concentration

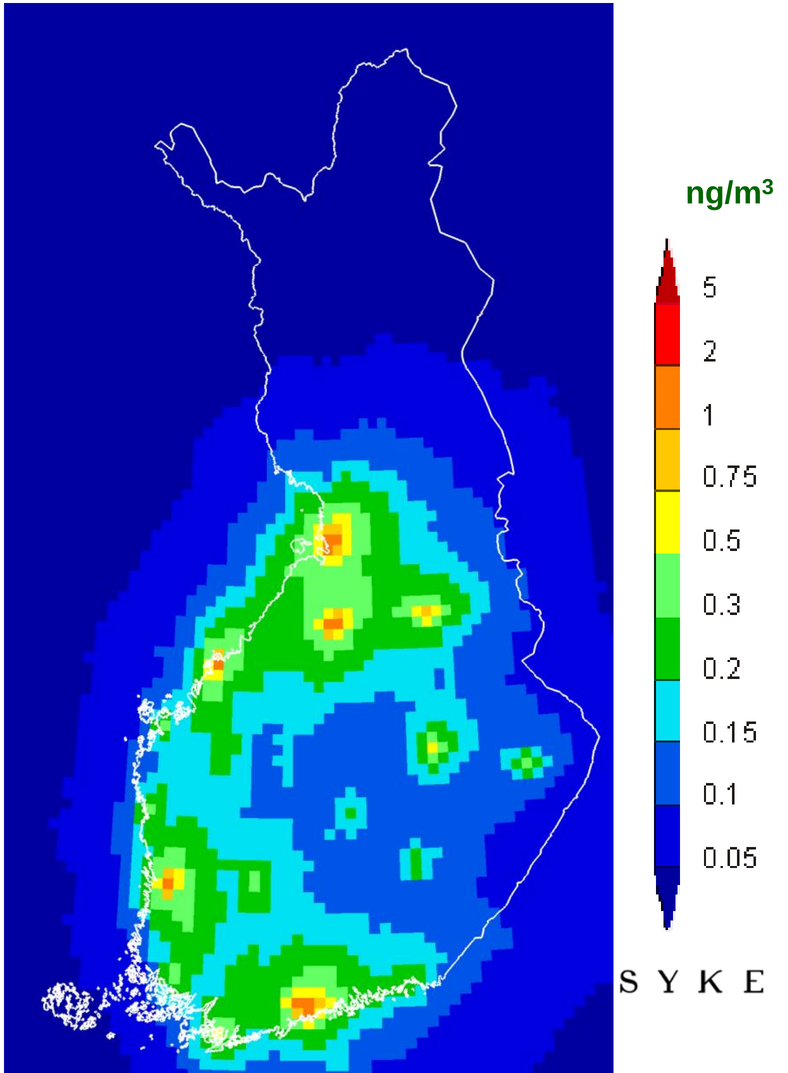
Results - population exposure to $PPM_{2.5}$ in 2020

Baseline to SUPPL (Saving of electricity)



Population exposure*
to $PPM_{2.5}$ **decrease**
0.27 ng/m³

$PPM_{2.5}$ concentration **decrease** caused by 1.9 TWh saving of electricity due to increased stove use

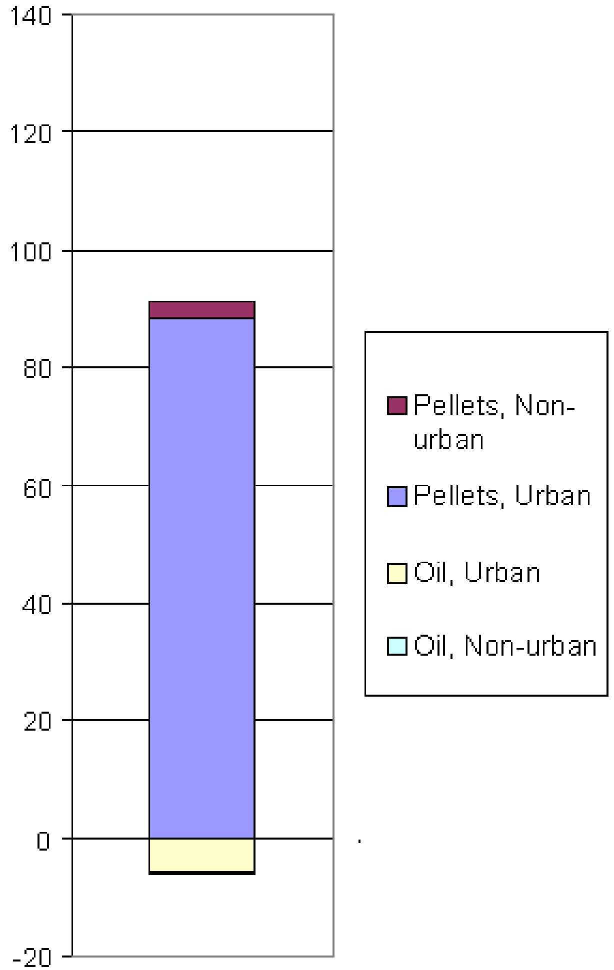


* Population weighted concentration

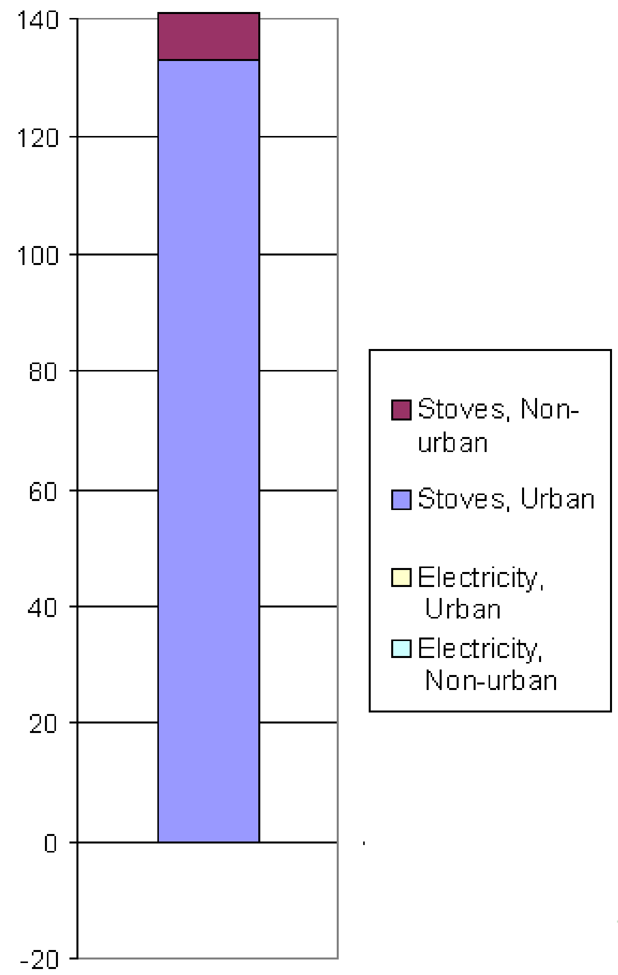
Results - population exposure to $PPM_{2.5}$ in 2020

Summary - Change in population exposure compared to Baseline

Baseline to PRIM
(Substitution of oil heating by pellets)



Baseline to SUPPL
(50% increase in stove use)



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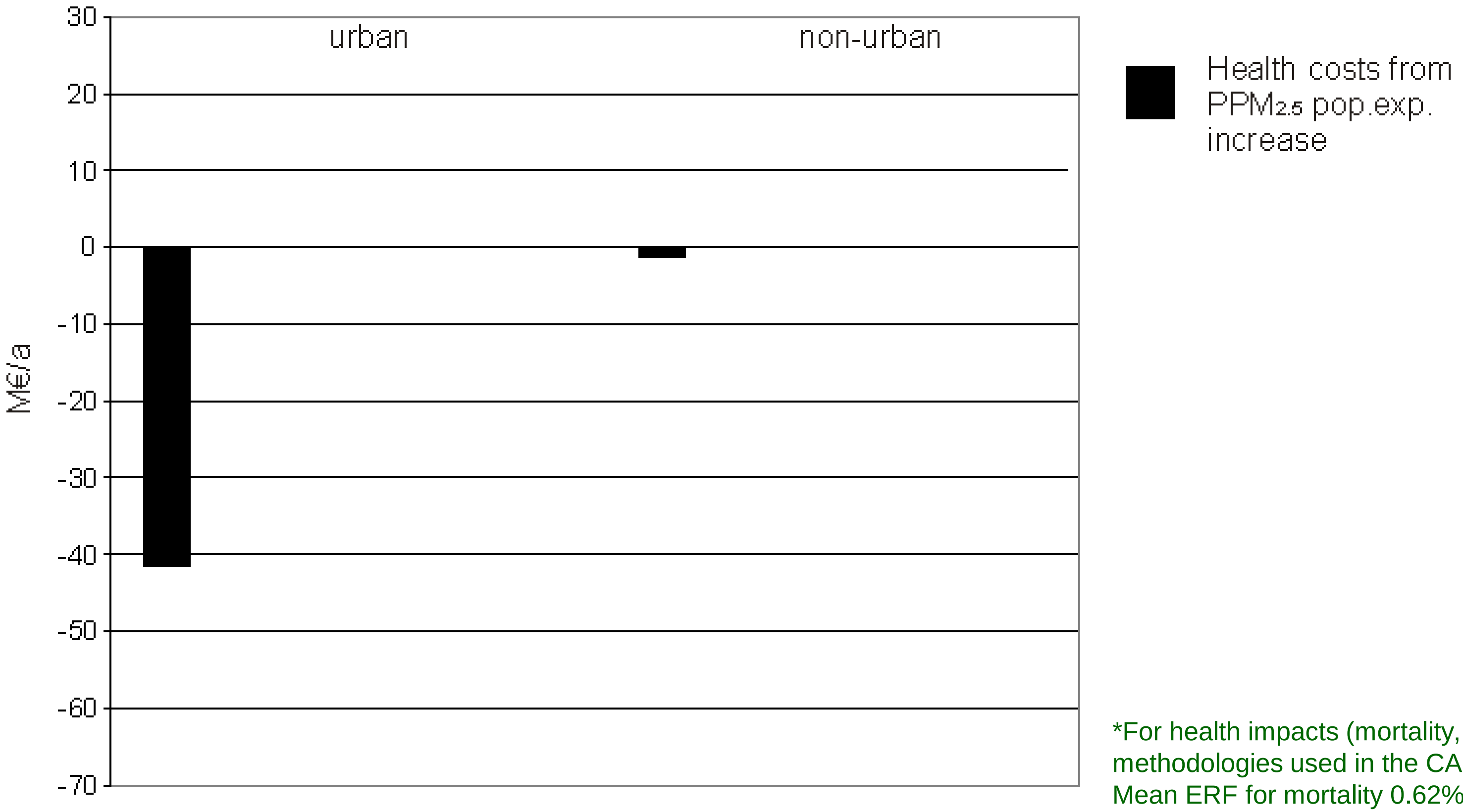
Results – Health costs vs CO_2 reduction gains

Change in health costs and CO_2 emission ”gains” compared to Baseline

Baseline to PRIM

(Substitution of oil heating by pellets)



*For health impacts (mortality, morbidity) and costs, methodologies used in the CAFE program (Hurley et al. 2005). Mean ERF for mortality 0.62% change per 1 µg/m^3 $\Delta PM_{2.5}$ concentration; 1 500 000 € per mortality case

SYKE

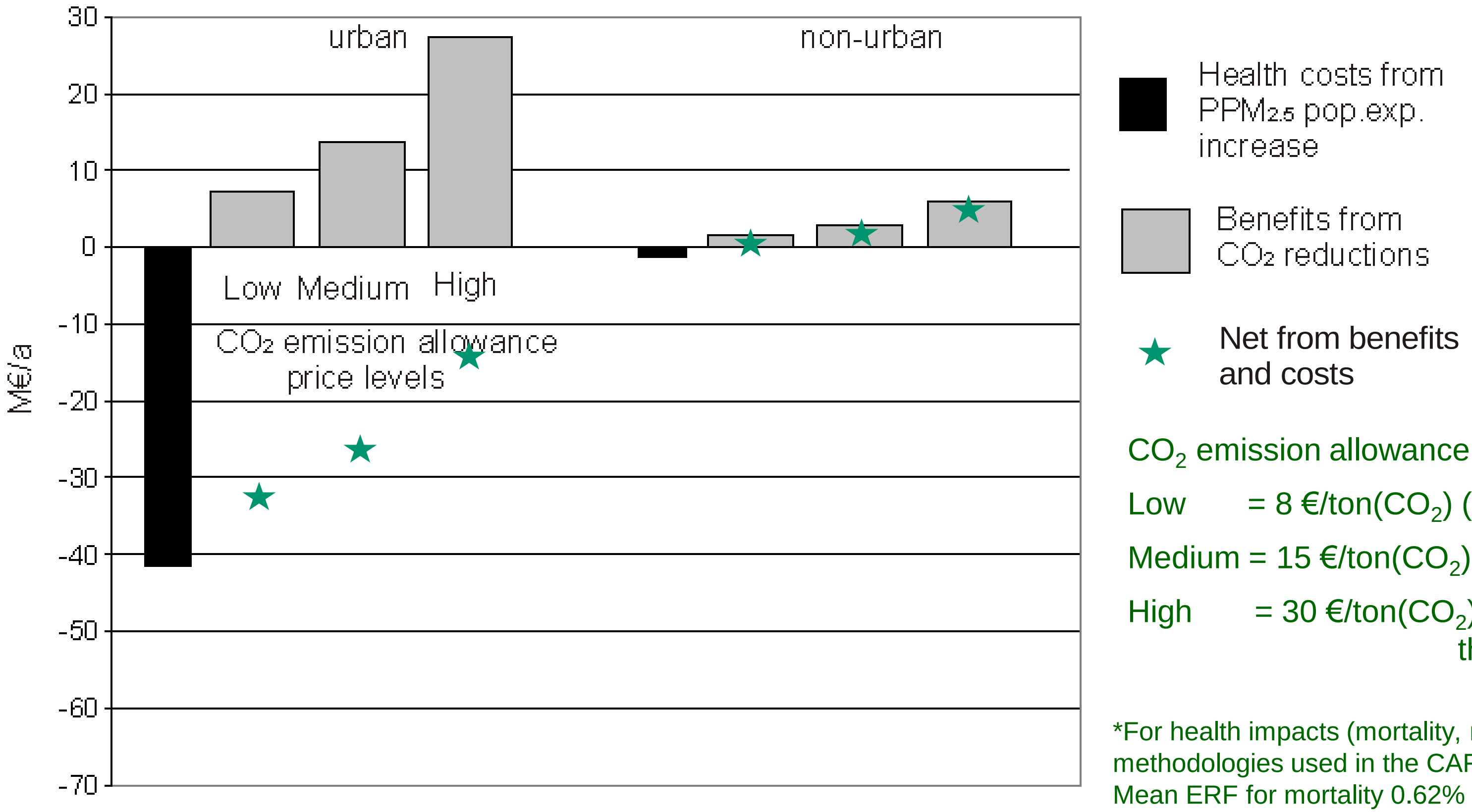
Results – Health costs vs CO_2 reduction gains

Change in health costs and CO_2 emission ”gains” compared to Baseline

Health costs of the population exposure to $PPM_{2.5}$ were compared with benefits gained by avoiding CO_2 emissions, at different price levels of CO_2 emission allowance

Baseline to PRIM

(Substitution of oil heating by pellets)



CO_2 emission allowance price levels:

Low = 8 €/ton(CO_2) (current 2012 future price)

Medium = 15 €/ton(CO_2) (average of 2009-1010)

High = 30 €/ton(CO_2) (highest price under the EU ETS second phase)

*For health impacts (mortality, morbidity) and costs, methodologies used in the CAFE program (Hurley et al. 2005). Mean ERF for mortality 0.62% change per 1 µg/m^3 $\Delta PM_{2.5}$ concentration; 1 500 000 € per mortality case

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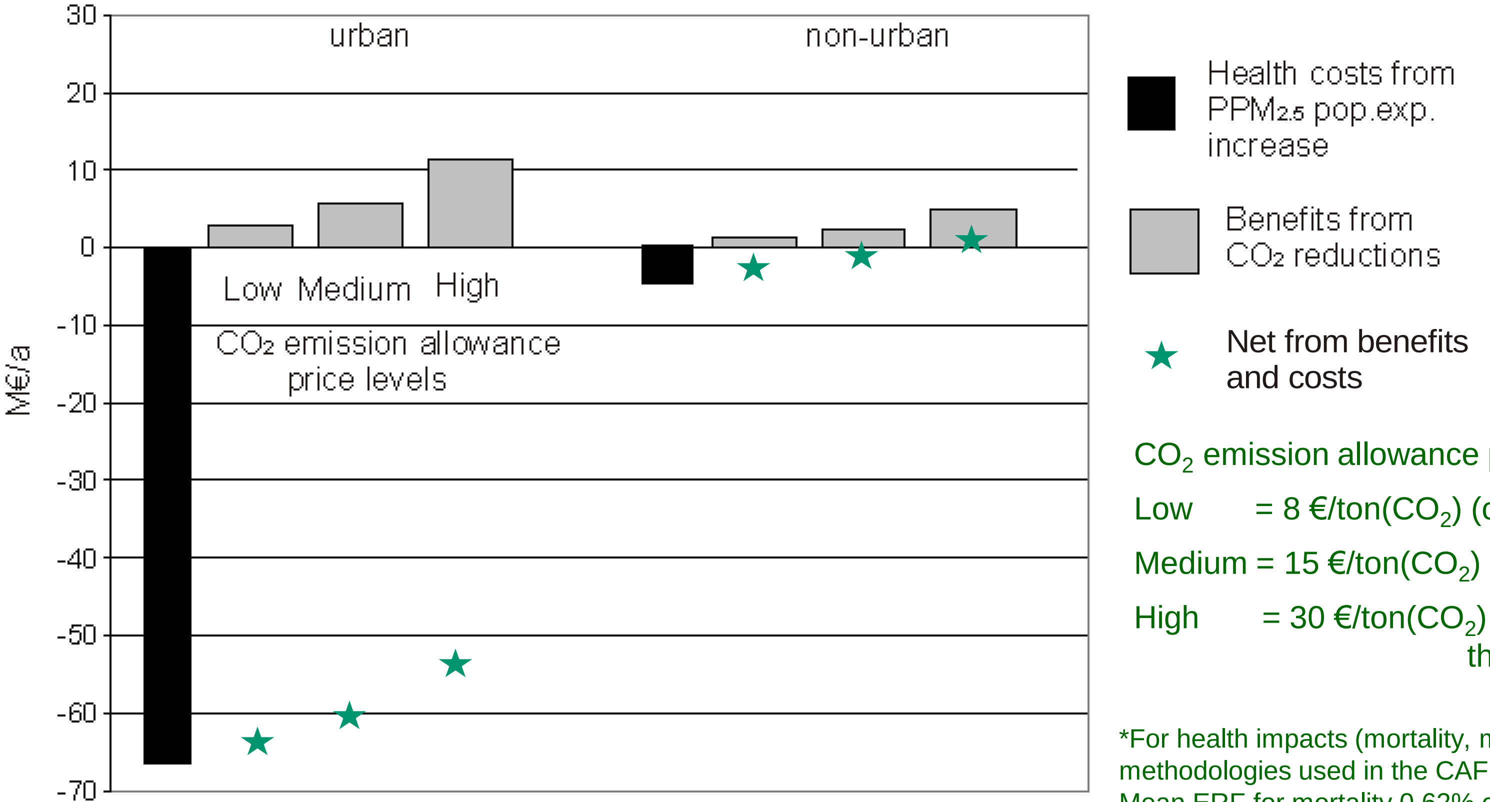
Baseline to SUPPL
(50% increase in stove use)



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Results – Climate impacts of GHG and SLCF in 2020

- Impacts of GHG and SLCF emissions on GWP100 and GWP20 were calculated for each heating scenario based on methodology reported in UNEP/WMO 2011 with references

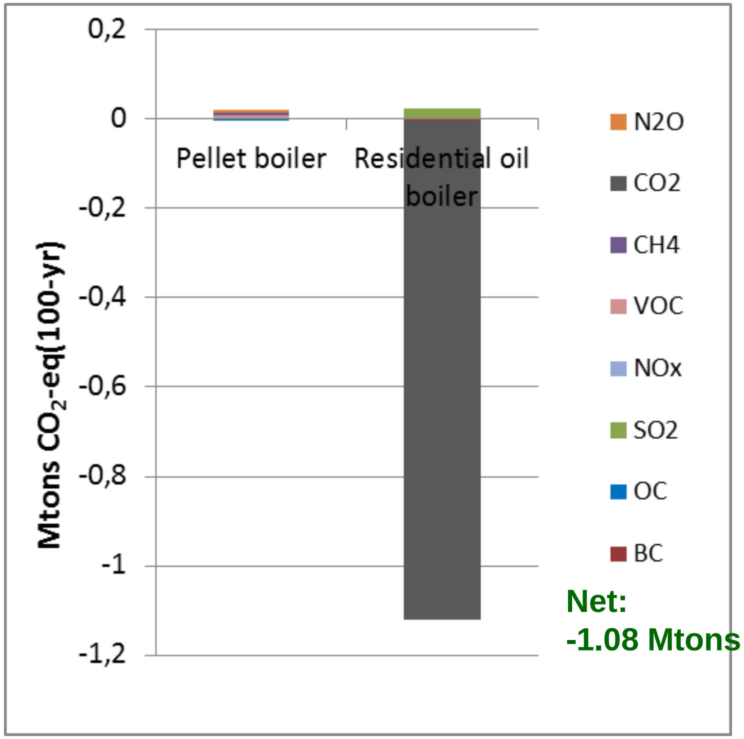
Baseline to PRIM

(Substitution of oil heating by pellets)

- Pellet combustion causes relatively low emissions of BC and other SLCFs
- Switching from fossil oil to wood pellets **bring explicit climate benefits**

Change in GWP100

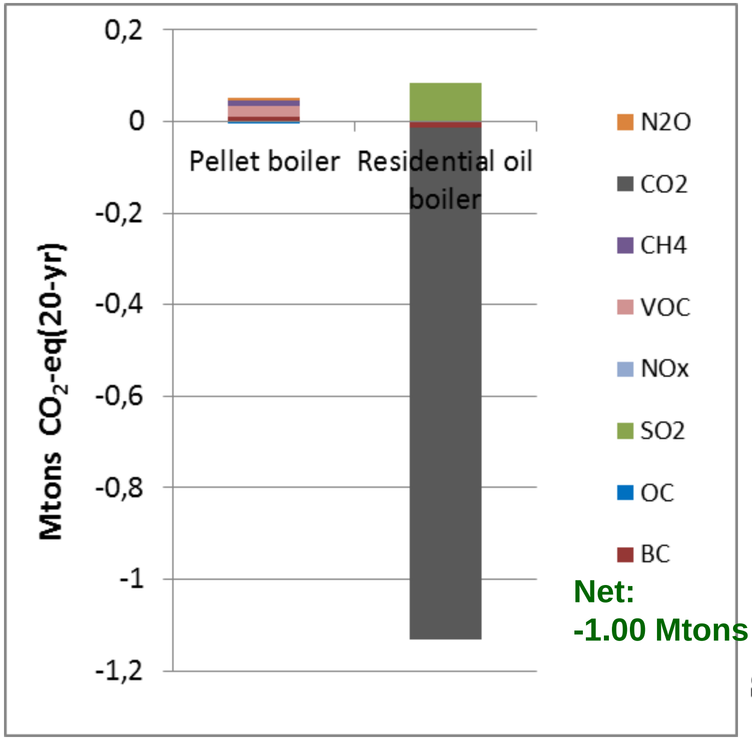
*Global Warming potential as calculated over 100 years



Net:
-1.08 Mtons CO_2-eq

Change in GWP20

*Global Warming potential as calculated over 20 years



Net:
-1.00 Mtons CO_2-eq

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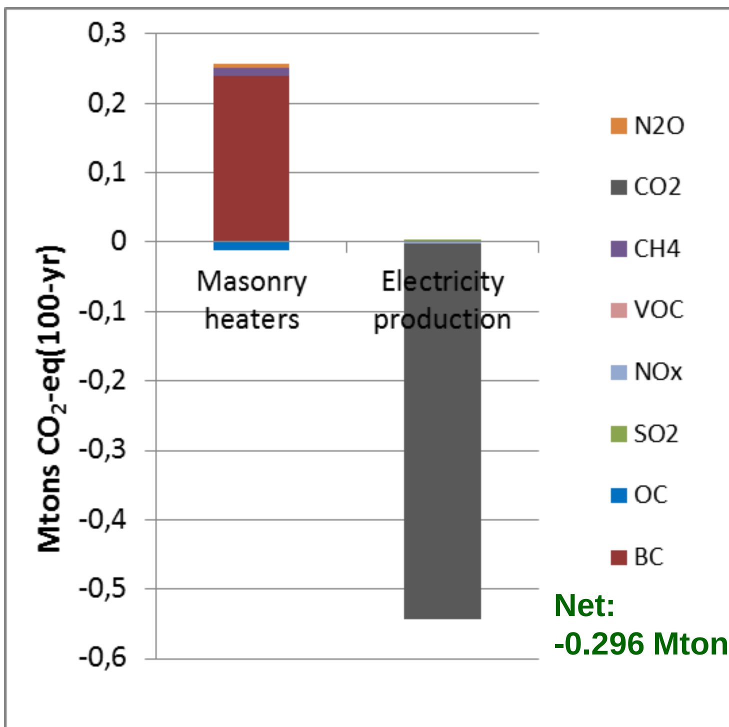
Results – Climate impacts of GHG and SLCF in 2020

Baseline to SUPPL (50% increase in stove use)

- Combustion in masonry heaters causes significant BC emissions
- Net impact depends strongly on time period: If GWP is calculated over 100 years, the CO_2 reduction due to electricity saving exceeds the impacts of increased BC emissions from stoves. However, if calculated over 20 years, the situation is vice versa.
- **PRELIMINARY RESULTS!** However, it can be concluded that saving electricity by supplementary wood heating in stoves is **not unambigiously climate friendly**

Change in GWP100

*Global Warming potential as calculated over 100 years

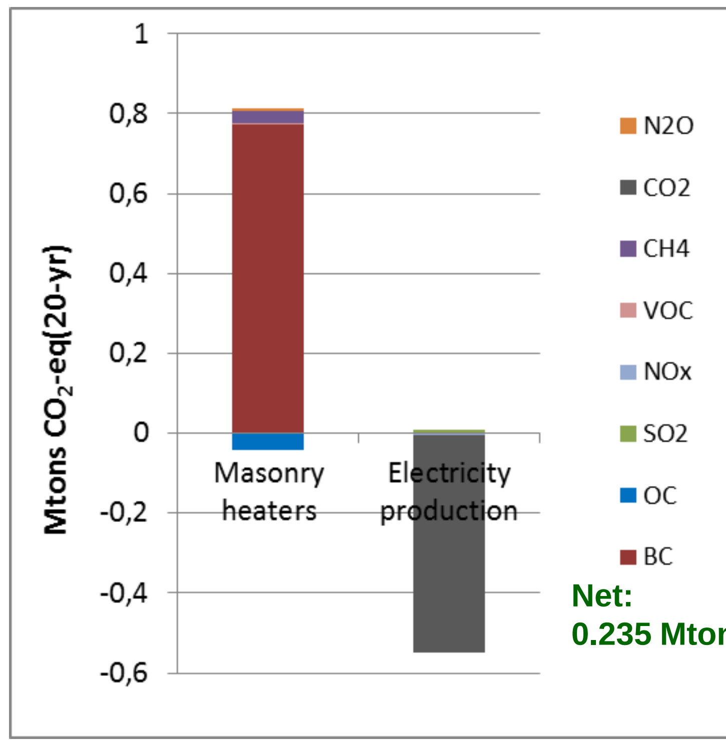


Net:
-0.296 Mtons CO_2-eq

Change in GWP20

*Global Warming potential as calculated over 20 years

*Electricity production average e.f. 287 g(CO_2)/kWh



Net:
0.235 Mtons CO_2-eq

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Discussion – European relevance

- RWH is common and increasing in many other European countries as well
- $PPM_{2.5}$ emission factors of studied appliances are relatively low (pellet boilers 30 mg/MJ; masonry heaters 80-120 mg/MJ) compared to e.g. conventional iron stoves in many countries (typically 200-1000 mg/MJ)
- Population densities in Finnish urban areas relatively low compared to Central Europe

⟶ **Population exposure impacts might be higher** for other European urban areas than estimated in this study

- Also other European stove types produce considerable BC emissions (although they are highly stove type and use pattern –specific)
- Emission-to-GWP estimates for SLCFs were based on global averages

⟶ **SLCF climate impact results** of this study potentially **relevant** for other European countries

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Conclusions

- Two most probable ways to increase RWH in the future (substitution of residential oil heating by pellet heating and increasing supplementary stove heating in electricity-heated houses) have **significant potential for CO_2 emission reduction**
- However, they **increase population exposure and health impacts of $PPM_{2.5}$** emissions. For urban areas, calculated **health costs exceeded the CO_2 reduction gains** when compared against CO_2 emission allowance prices.
- From human health perspective, **promotion of RWH should be prioritized to non-urban areas**
- When climate impacts of both GHG and SLCF emissions are taken into account, electricity saving due to **increased supplementary stove heating is not unambigiously climate friendly**. Switching from residential oil heating to wood pellets bring explicit climate benefits.
- From both health and climate perspectives, **advanced RWH technologies ensuring controlled combustion process should be promoted**
- The results of this study demonstrate the **need for an integrated assessment** that allows for both the various positive and adverse effects in order to plan coherent climate and air pollution abatement strategies

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Thank You

www.environment.fi/syke/pm-modeling

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"Climate change, air quality and housing - future challenges to public health (CLAIH)"

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