REDUCTION OF CO$_2$ BY RESIDENTIAL WOOD HEATING AND TRADE-OFF CAUSED BY INCREASED POPULATION EXPOSURE TO PRIMARY PM$_{2.5}$ AND SLCF EMISSIONS

Niko Karvosenoja (1), Maria Holmberg (1), Pekka Vanhala (1), Ville-Veikko Paunu (1), Marko Tainio (2,3), Jaakko Kukkonen (4), Kaarle Kupiainen (1,5)

(1) Finnish Environment Institute (SYKE)
(2) Systems Research Institute (SRI) Polish Academy of Sciences
(3) National Institute for Health and Welfare (THL), Finland
(4) Finnish Meteorological Institute
(5) International Institute for Applied Systems Analysis (IIASA)

8th International Conference on Air Quality - Science and Application, Athens, 19-23 March 2012
Contents

Background – Residential wood heating (RWH) in Finland
  • Significance, combustion appliances, spatial distribution
  • RWH as a measure to reduce CO₂ emissions
  • RWH as a source of fine particles (PM₂.₅): emissions, health impacts
  • RWH as a source of short-lived climate-forcers (SLCF), especially black carbon (BC)

Future of RWH in Finland – Scenarios to increase RWH
  • Potential to reduce CO₂ emissions
  • Impacts on primary PM₂.₅ emissions and population exposure
  • Impacts on SLCF emissions and the climate

Discussion – Results in European perspective

Conclusions
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)**

**Wood**
- Supplementary heating
- Primary heating

Wood heating: Increase 3%/a during 2000s

**Oil**

**Electricity**

**Others**
- (district heating, heat pumps, gas, peat)

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

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

- Log boilers: 11.2 PJ
- Wood chip boilers: 4.2 PJ
- Pellet boilers: 2.6 PJ
- Masonry heaters: 6.9 PJ
- Masonry ovens: 7.4 PJ
- Sauna stoves: 9.9 PJ
- Kitchen ranges: 2.5 PJ
- Other stoves and fireplaces: 1.1 PJ

Source: Finnish Forest Research Institute 2010
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
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:
Residential wood heating in Finland

Emissions of primary PM$_{2.5}$ – Spatial distribution

Primary wood heating (boilers)  Supplementary wood heating (stoves)

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
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)**

- Wood log boiler
- Conventional masonry heater
- Modern masonry heater
- Pellet boiler
- Residential oil boiler

*POM = particulate organic matter*
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?
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
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
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”)


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.
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)

* Population weighted concentration
Results - population exposure to PPM$_{2.5}$ in 2020

Baseline to PRIM (Substitution of oil heating by pellets)

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

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

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

* Population weighted concentration

Urban
Non-urban
Results - population exposure to PPM$_{2.5}$ in 2020

Baseline: supplementary wood heating (stoves)

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)
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/m^3
(of which in urban areas 133 ng/m^3)

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

* Population weighted concentration
Results - population exposure to \( \text{PPM}_{2.5} \) in 2020

Baseline to SUPPL (Saving of electricity)

\( \text{PPM}_{2.5} \) concentration **decrease** caused by 1.9 TWh saving of electricity due to increased stove use

Population exposure* to \( \text{PPM}_{2.5} \) **decrease** 0.27 ng/m\(^3\)

* 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)
Results – Health costs vs CO₂ reduction gains
Change in health costs and CO₂ 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/m³ ΔPM₂.₅ concentration; 1 500 000 € per mortality case
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.
Results – Health costs vs CO\textsubscript{2} reduction gains

Change in health costs and CO\textsubscript{2} emission ”gains” compared to Baseline

Health costs of the population exposure to PPM\textsubscript{2.5} were compared with benefits gained by avoiding CO\textsubscript{2} emissions, at different price levels of CO\textsubscript{2} emission allowance.

Baseline to SUPPL
(50% increase in stove use)

- CO\textsubscript{2} emission allowance price levels:
  - Low = 8 €/ton(CO\textsubscript{2}) (current 2012 future price)
  - Medium = 15 €/ton(CO\textsubscript{2}) (average of 2009-1010)
  - High = 30 €/ton(CO\textsubscript{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\textsuperscript{3} ΔPM\textsubscript{2.5} concentration; 1 500 000 € per mortality case.
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
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 CO₂ 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 unambiguously climate friendly**

**Change in GWP100**
*Global Warming potential as calculated over 100 years*

- Net: -0.296 Mtons CO₂-eq

**Change in GWP20**
*Global Warming potential as calculated over 20 years*

- Net: 0.235 Mtons CO₂-eq
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.
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 CO₂ emission reduction**

• However, they **increase population exposure and health impacts of PPM₂.₅ emissions**. For urban areas, calculated **health costs exceeded the CO₂ reduction gains** when compared against CO₂ 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 unambiguously 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
Thank You

www.environment.fi/syke/pm-modeling

This work was supported by projects
“Mitigation of Arctic warming by controlling European black carbon emissions (MACEB)” and
“Climate change, air quality and housing - future challenges to public health (CLAIH)”

funded by
LIFE+ 09 Environment Policy and Governance
and the Academy of Finland