ACTION C3: SOCIO ECONOMIC AND ENVIRONMENTAL IMPACT

12/2024

PROJECT: HARMONIZING RELIABLE TEST PROCEDURES REPRESENTING REAL-LIFE AIR POLLUTION FROM SOLID FUEL HEATING APPLIANCES

Real-LIFE emissions, Life preparatory project 2020

Project Number: LIFE20 PRE/FI/000006

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Summary

This activity has been dedicated to the evaluation of the costs of implementation of the recommendations made in Actions A, and the scientific benefits of using realistic emission factors on the evaluation of air quality based on atmospheric modeling.

In the cost estimation, the aim was to calculate the added cost of implementation of the Real-life test protocol and the Extended ENPME method following three different scenarios:

- Scenario 1: Real-LIFE test protocol only,
- Scenario 2: Real-LIFE test protocol and extended ENPME method measurement used every other batch,
- Scenario 3: Real-LIFE test protocol and extended ENPME method measurement used for each batch.

The estimations included investments, maintenance, consumables, and labour costs. Three levels of labour costs were tested 100 €/h, 150 €/h and 200 €/h. Comparisons was made to the implementation of the EN16510-1:2022 standard.

The second part of this action aimed at evaluating the benefits of using more realistic emission factors (EF) for environmental studies, particularly focusing on residential wood combustion (RWC). Chemical Transport Models (CTMs), such as the CHIMERE model, simulate pollutant concentrations using meteorological and emission data. These models are essential for estimating the impact of primary particles from RWC on air quality. Traditional emission inventories used to exclude condensables, leading to significant underestimation of particulate matter (PM) concentrations. Including condensables in emission inventories has been shown to improve the accuracy of these models. For instance, a joint exercise conducted in 2021 used 11 models and two emission inventories (REF1 and REF2). REF2, which included condensables, resulted in significantly higher PM concentrations and improved model performance.

A theoretical scenario was analysed as an example for France, projecting the impact of replacing older appliances with advanced ones by 2030 as part of a plan to reduce emissions by 30% in average in France and 50% in the most polluted area between 2020 and 2030. The scenario indicated that emissions would be decreased significantly by 2030 and that the reduction of 30% could be reached. However, a much higher replacing rate would be needed to reach the 50% objective in the most polluted areas.

In conclusion, using realistic EFs, including condensables, is essential for accurate air quality modelling and achieving emission reduction targets. This approach not only improves model accuracy but also supports effective environmental policy and planning.

1. Economic Impact

1.1 Principle and objectives

The objectives of the study were to estimate the added costs of implementation of the recommendations made in Actions A in terms of:

- testing protocol
- and TPM measurement method applied in comparison with the implementation of the EN 16510 standard.

The standard EN 16510-1:2022 requires combustion tests at nominal load while three batches need to be measured for final evaluation.

The recommended testing protocol, so called the Real-LIFE protocol has been described in actions A3 and A5 and is presented in the following picture.

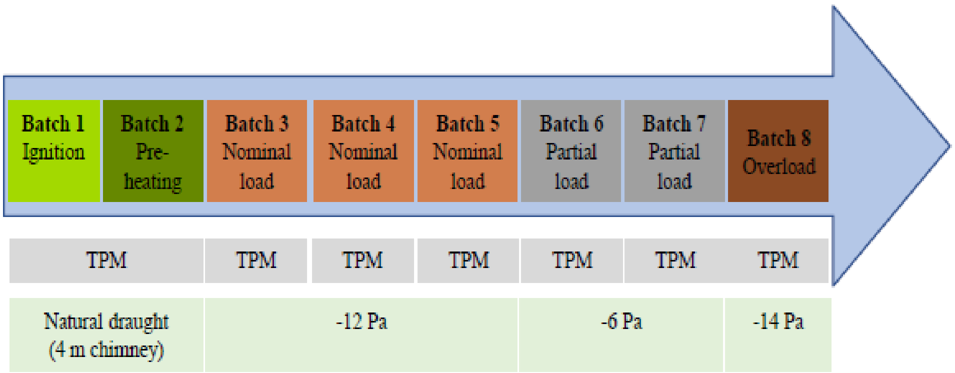

Figure 1: Schematic of the Real-LIFE testing protocol

The recommended TPM measurement method has been described in actions A3 and A4. It consists of an extended version of the ENPME method, the novel ENPME-dual-filter-method where a dilution step using a porous tube, combined to a second filter placed under ambient conditions of temperature and aiming at collecting the condensable fraction, are added to the ENPME method.

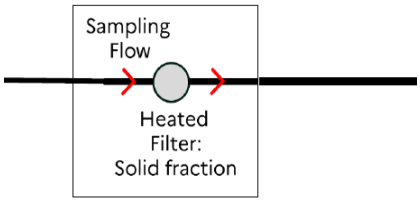

Figure 2: Schematic of the ENPME method at 180 °C

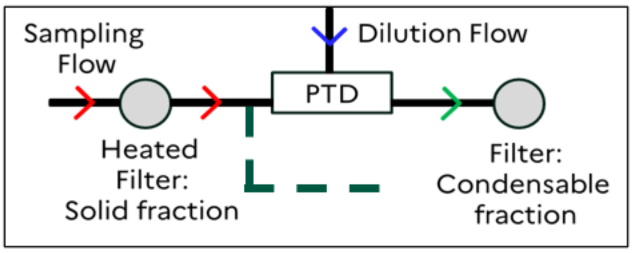

Figure 3: Schematic of the extended ENPME method with a porous tube diluter (PTD) and filter holder behind the ENPME at 180 °C

The principle of the evaluation was the following:

- The evaluation concerns the added costs for the laboratory that performs the test and does not include the margin applied by the laboratory, as a result it does not represent the added costs that the manufacturer would have to pay to get a stove tested according to the proposed Real-LIFE methodology.
- The added costs have been calculated per stove tested,

- Three cases have been evaluated:
  - Case 1: The stove is tested by implementing the Real-LIFE protocol while only sampling TPM only with ENPME at 180 °C. Only one additional filter holder is needed for quick filter change between the batches.
  - Case 2: The stove is tested by implementing the Real-LIFE protocol associated to measurements using the extended ENPME method every other batch (batches 1+2, batch 4, batch 6 and batch 8)
  - Case 3: The stove is tested by implementing the Real-LIFE protocol associated to measurements using the extended ENPME every batch while installing two parallel sampling lines for switching between the batches.
- The evaluation considers depreciation of additional investments, costs for maintenance and repair, consumables, and man-hour costs (extra day of sampling, extra man-hour necessary). The details of the costs considered are presented in Table 1.

Table 1: Details of the costs considered for the evaluation.

Additional investment compared to current reference method in EN 16510-1:2022:
Additional CO_2 analyser for dilution ratio determination (€)
Additional filter holders (€)
Additional ENPME Probe (€)
Porous Tube Diluter, PTD (€)
Additional sampling line configuration parts (€)
Annual costs for maintenance and repair (€/a)
Additional consumable costs:
Additional costs for filters (€/d)
Additional costs for fuel (€/d)
Labour costs
Additional labour requirement (h/testing day)
Additional number of testing days compared to current reference method in EN 16510-1:2022

Some assumptions have been made (Table 2) to calculate the added costs regarding:

- the duration of use of the measurement equipment purchased to implement the new methodology,
- the interest rate applied,
- the capital recovery factor,
- the maintenance and repair cost per year expressed as percent of the cost of the equipment,
- The number of tested appliances on the test bench per year
- the unit cost of consumables: filters and fuel
- the average labour price (€/h)

Table 2: Assumptions made to calculate the added costs

Duration of use of measurement equipment	15 years
Interest rate	4.5%
Capital recovery factor	0.093
Maintenance and repair (%/a)	4.0%
Number of tested appliances on the test bench per year	40
Average rate of wood used per batch	2.5 kg
Cost of consumables	Between 2 and 6 €/filter according to diameter
	0.43 €/kg of wood
Average labour price (€/h)	100€/hour
	150€/hour
	200€/hour
Risk of having to repeat the test	Case 1: 50%
	Case 2: 60%
	Case 3: 70%

Three levels of average labour price have been considered to represent the diversity of existing average labour prices within Europe ranging between 100 €/h and 200 €/h.

1.2 Added costs evaluation

The details of the calculation performed with an average labor costs of 100€/h are presented below.

Estimation of added costs for method change form EN16510 to the novel ENPME-dual-filter-method with porous tube dilution and using the novel test protocol

General assumptions:			
Duration of use of measurement equipment	15	years	
Interest rate	4,5%		
Capital recovery factor	0,09311		
Maintenance and repair	4,0%	%/a	
Additional investment compared to current reference method in EN 16510:	*Case 1*	*Case 2*	*Case 3*
Additional CO_2 analyser (€)		6 000	9 000
Additional filter holders (€)	2000	6 000	8 000
Additional EN-PME Probe (€)		7 088	7 088
Porous Tube Diluter, PTD (€)		4 000	8 000
Additional sampling line configuration parts (€)		750	1 500
What else ....?Pumps		1 000	1 000
Total added investment (€)	*2 000*	*24 838*	*34 588*
Compilation of all fixed costs per lab day :	*Case 1*	*Case 2*	*Case 3*
Annual fixed costs for added investments (€/a)	186	2 313	3 221
Annual costs for maintenance and repair (€/a)	7	93	129
Total fixed costs per year (€/a)	*194*	*2 405*	*3 349*
Calculated daily fixed costs for added investments (€/d)	4,8	60	84
Further assumptions:			
Number of stoves tested in the lab per year on one test bench	40	40	40
Additional labour requirement (h/testing day)	3	3,5	4
Average labour price (€/h)	100	100	100
Additional number of testing days compared to current reference method in EN 16510:	0,5	0,60	0,70
Additional consumable costs:			
Additional costs for filters (€/d)	30,0	83,2	81,6
Additional costs for fuel (€/d)	8,1	8,6	9,1
Total consumable costs per test day (€/d)	*38,1*	91,8	90,7
Final compilation:			
Added fixed costs (€/stove test)	2,4	36,1	50,2
Added labour costs (€/stove test)	450	560	680
Added consumable costs (€/stove test)	57,1	146,9	154,3
Total of added costs (€/stove test)	***510***	***743***	***884***

A synthesis of the main added costs determined for the three cases is presented in the following sections.

1.2.1 Case 1: Change of protocol from EN 16510-1:2022 protocol to Real-LIFE protocol

For case 1, the added costs are due to the implementation of the Real-LIFE protocol alone.

The equipment required in this case is one additional filter holder to be able to take sample during all batches of the protocol without long interruptions between the batches. This filter holder can be preheated in between.

No extended ENPME method is implemented.

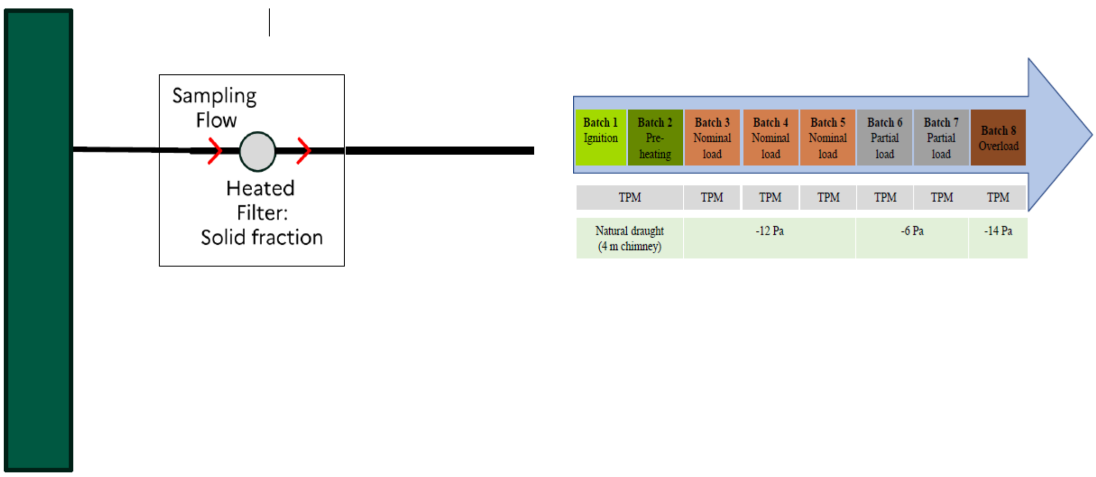

Figure 4: Schematic Case 1 ENPME Method + Real-LIFE protocol

Table 3: Input data used and added costs determined for case 1

Input data		Total added cost (€/stove tested) compared to EN 16510 implementation
Investments costs about 2000 € Risk of having to repeat the tests 50% 0,5 extra day of sampling 3h extra man-hour necessary/day of sampling 5 extra filters per sampling day 5 more batches performed per day	Average labour price 100 €/h	510
	Average labour price 150 €/h	735
	Average labour price 200 €/h	960

1.2.2 Case 2: Change of protocol from EN 16510-1:2022 protocol to Real-LIFE protocol + ENPME extended method every other batch

For case 2 the added costs are due to the implementation of the Real-LIFE protocol and the ENPME extended method every other batch.

For implementing the protocol, the equipment required is one additional filter holder to be able to take sample during every batch of the protocol.

The equipment required for implementing the extended ENPME extended method every other batch is:

- Two additional CO_2 analysers for the determination of the dilution ratio and the CO_2 concentration in the air added to the porous tube diluter.
- Two additional filter holders for the extended ENPME method
- One additional ENPME probe
- One porous Tube Diluter, PTD
- Additional sampling line configuration parts
- One additional pump

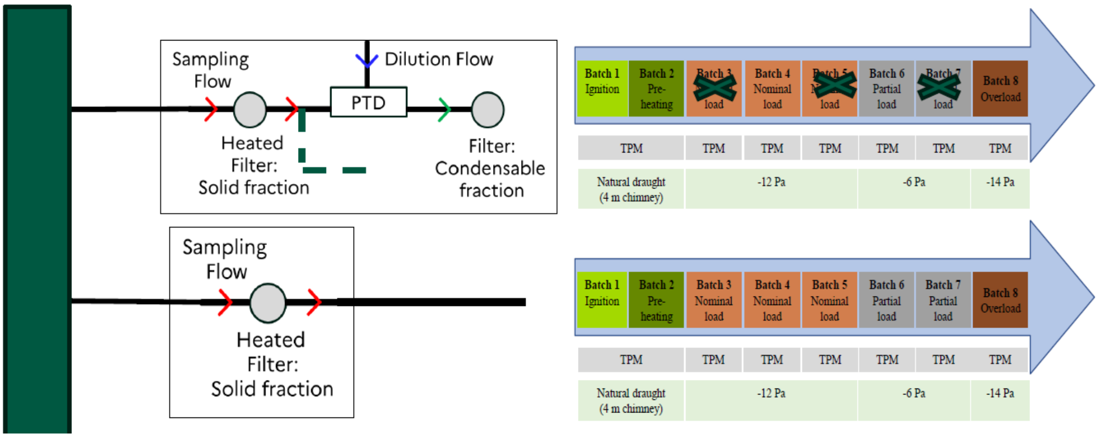

Figure 5: TPM sampling for case 2, upper sampling line with extended ENPME for every second batch and lower sampling line with ENPME only but for every single batch during Real-LIFE protocol.

Table 4: Input data used and added costs determined for case 2

Input data		Total added cost (€/stove tested) compared to EN 16510 implementation
Investments costs about 24838 € Risk of having to repeat the tests 60% 0,5 extra day of sampling 3,5h extra man-hour necessary/day of sampling 13 extra filters per sampling day 5 more batches performed per day	Average labour price 100 €/h	743
	Average labour price 150 €/h	1023
	Average labour price 200 €/h	1303

1.2.3 Case 3: Change of protocol from EN 16510-1:2022 protocol to Real-LIFE protocol + ENPME extended method for every batch

For case 3 the added costs are due to the implementation of the Real-LIFE protocol and the ENPME extended method every batch.

For implementing the protocol, the equipment required is one additional filter holder to be able take sample during every batch of the protocol.

The equipment required for implementing the extended EN PME extended method every batch is:

- Three additional CO_2 analysers (one CO_2 analyser for determination of CO_2 concentration in dilution air and two CO_2 analyser behind the porous tube dilution).
- Three additional filter holders
- One additional ENPME probe
- Two porous Tube Diluter, PTD
- Additional sampling line configuration parts
- one additional pump for extra sampling train

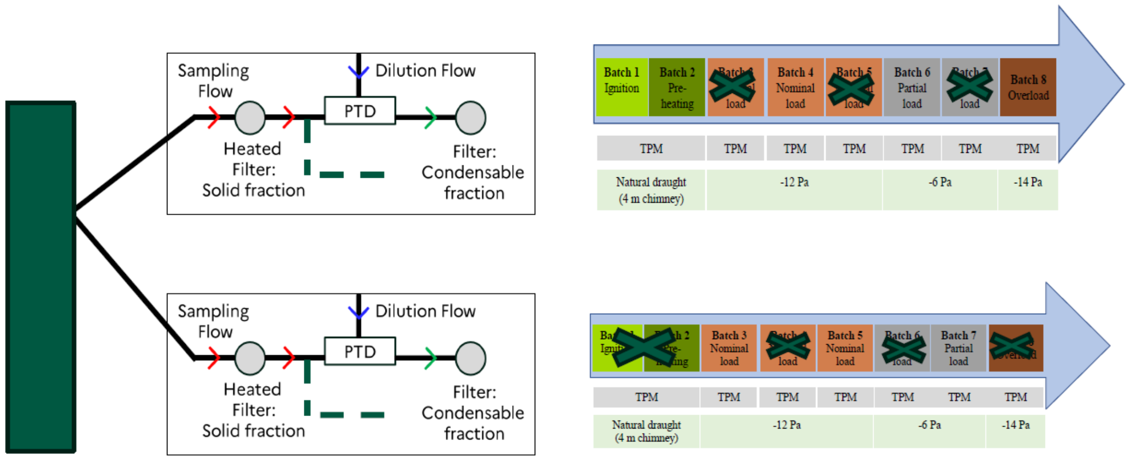

Figure 6: TPM sampling for case 3, two sampling lines with extended ENPME for every batch during Real-LIFE protocol.

Table 5: Input data used and added costs determined for case 3

Input data		Total added cost (€/stove tested) compared to EN 16510 implementation
Investments costs about 34588 € Risk of having to repeat the tests 70% 0,5 extra day of sampling 3,5h extra man-hour necessary/day of sampling 12 extra filters per sampling day 5 more batches performed per day	Average labour price 100 €/h	884
	Average labour price 150 €/h	1224
	Average labour price 200 €/h	1564

2. Environmental impact

In this task, we aimed at evaluating the benefits for environmental studies of using realistic emission factors (EF). The estimation of the effect of the atmospheric emissions of primary particles from residential wood burning can be achieved by using Chemical Transport Models (CTM). CTMs are 3D models that simulate concentrations of various pollutants (such as O3, NO2 or PM) based on meteorological and emission data. They are deterministic models, representing the main physicochemical processes occurring in the atmosphere.

As an example, the air quality model CHIMERE (Menut et al., 2020) is co-developed by the CNRS (the French National Council for Scientific Research) and INERIS (French National Institute for Industrial Environment and Risks). It is a scientific program that gathers a set of equations representing the transport and transformation of chemical species to simulate the temporal evolution of air pollutants over a range of spatial scales, from the regional scale (several thousand kilometers) to the urban scale (spatial resolution of a few kilometers).

The model integrates a chemical mechanism containing more than one hundred chemical reactions. It simulates the formation and evolution of airborne particles with diameters ranging from a few nanometers to 40 µm. Simulated particles consist of primary PM (anthropic or natural) emitted directly into the air and of secondary PM that are formed by chemical reactions in the atmosphere (nitrate, ammonium, sulfate and secondary organic aerosols).

One important input to simulate the particle concentrations from residential wood burning (RWB) is use an inventory emission. The emission inventory EMEP traditionally used by CTMs to simulate air quality over Europe is based on reporting from the different countries. For some countries, the emission factors included condensables. However, most countries used emission factors that did not include condensables. Denier von der Gon et. (2015)[1] showed that this discrepancy in emission factors was problematic to estimate the impact of RWB emissions on air quality with CTMs and was responsible of a strong underestimation of simulated PM concentrations by CTMs. They proposed a revised RWB inventory based on a harmonized methodology over Europe and estimated that emissions should be higher by a factor of 2–3 but with substantial inter-country variation.

In 2020, a workshop gathering experts on emission inventory, measurement on modeling was organized by MSC-W. In the report of the workshop[2], the experts concluded that "condensables should be included in future emission inventories and modelling. Residential Wood Combustion (RWC) emissions are a priority because of their known large contribution to PM emissions".

In order to evaluate the importance of accounting for condensables in emissions, a joint exercise between the Task Force on Modeling and Measurement (TFMM) of EMEP (European Monitoring and Evaluation Program) and CAMS (Copernicus Atmosphere Monitoring Service) was organized in 2021. PM concentrations were simulated with 11 models (EMEP, Lotos-Euros, EuradIM, IFS, MINNI, DEHM,

[1] Denier van der Gon, H. A. C., Bergström, R., Fountoukis, C., Johansson, C., Pandis, S. N., Simpson, D., and Visschedijk, A. J. H.: Particulate emissions from residential wood combustion in Europe – revised estimates and an evaluation, Atmos. Chem. Phys., 15, 6503–6519, https://doi.org/10.5194/acp-15-6503-2015, 2015.

[2] Simpson, D., Fagerli, H., Colette, A., Denier van der Gon, H., Dore, C., Hallquist, M., Christen Hansson, H., Maas, R., Rouil, L., Allemand, N., Bergström, R., Bessagnet, B., Couvidat, F., El Haddad, I., Genberg Safont, J., Goile, F., Grieshop, A., Fraboulet, I., Hallquist, A., Hamilton, J., Juhrich, K., Klimont, Z., Kregar, Z., Mawdsely, I., Megaritis, A., Ntziachristos, A., Pandis, S., Prévôt, A.S.H., Schindlbacher, S., Seljeskog,M. and Sir, N. How should condensables be included in PM emission inventories reported to EMEP/CLRTAP? Report of the expert workshop on condensable organics organised by MSC-W, Gothenburg, 17-19th March 2020.

MONARCH, MATCH, CHIMERE, SILAM, WRFCHEM) and two emission inventories: REF1, based on the official reporting and REF2 based on a estimation of RWB emissions including condensables by TNO.

As illustrated in figure 7, the simulated concentrations over winter 2017-2018 were significantly higher with REF2 emissions, especially over France, Belgium, Netherlands, Germany, Poland, Lithuania, Latvia, Estonia. The performance (bias, RMSE and correlation) of all models generally improved.

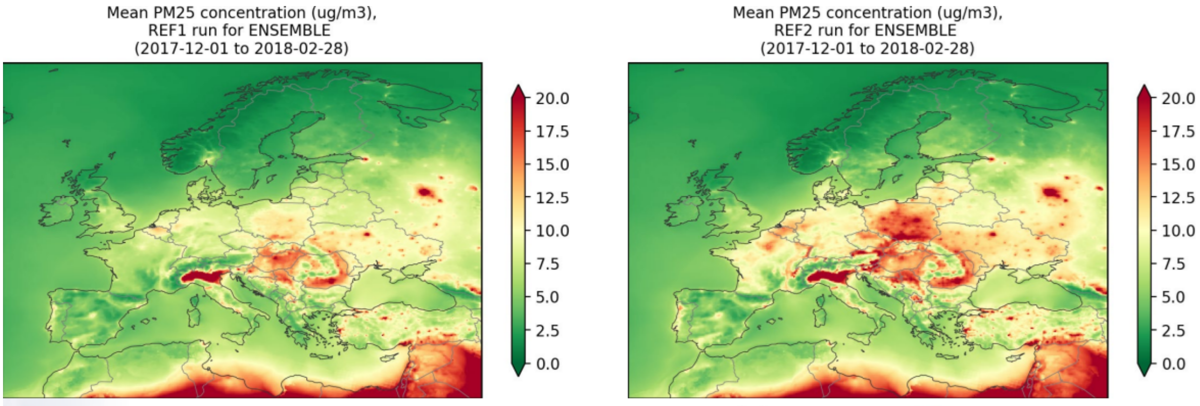

Figure 7: Averaged PM2.5 concentrations (in $\mu g/m^3$) simulated by the 11 models with the REF1 emissions (left) and REF2 emissions (right)[3]

In order to improve the results of CTM simulations, a method to estimate more realistic daily emissions was developed. This method consists in temporalizing the annual emissions provided by emissions inventory by using the daily temperature. This method called "Heating Degree Days" was developed in the project and was the subject of a publication (Guion et al., under review)[4]. Based on daily gas consumption data, we fitted some country-specific parameters to temporalize heating activities according to the outdoor temperature. When using this HDD approach, the simulations show better performance scores (temporal correlation and threshold exceedance detection) in winter, especially for PM indicating for that the model can evaluate the impact of wood burning emissions on air quality more realistically, With this method, we managed to improve the number of good detection of PM10 threshold exceedances (ambient concentrations of PM10 above 50 $\mu g/m^3$) by 32%. This method will be used in future projects on the impact assessment of wood burning emissions on air quality.

We initially planned to redo a similar exercise with the emission factors measured in the project to evaluate the effect of using the emission factors with the different protocols. However, most of devices tested in the project were recent devices (after 2022, referred to as "advanced appliances"). The number of older devices tested in the project was considered too low to derive representative emission factors. In the most recent version of the EMEP emission inventory, the most recent year available is 2022. It is therefore not possible to directly use the emission factors derived in the project as the inventory contains no "advanced appliances". Even if more recent appliances were available, several years would be needed before "advanced appliances" represent a significant share of appliances.

Instead of evaluating how different emission factors may impact the simulation of air quality, we estimated how the use of the factors measured in the project could be used to derive emission inventory. For that, we chose to focus on France. CITEPA is the organization responsible for reporting emissions. It estimates RWB emissions by combining EF with activity data per category of appliances. Table 6 shows the different categories of appliances and EFs used by CITEPA. As shown by the table, EF used by the CITEPA

[3] Colette, A. et al. Accounting for condensable fraction of residential combustion in CAMS Regional Production. CAMS 5th General Assembly, 8th June 2021. https://atmosphere.copernicus.eu/sites/default/files/custom-uploads/CAMS-5thGA/day1/Colette%20A_INERIS_European%20air%20quality.pdf

[4] https://doi.org/10.5194/egusphere-2024-2911, 2024.

are relatively similar to those provided in the EMEP guidebook. The EF for “advanced appliances” can be updated to use the EF measured in the project.

Table 6: Comparison of the EF per category used by CITEPA (left) and provided by the EMEP guidebook (right)

Categories/French EF Solid + Condensables (g/GJ)	Categories/French EF Solid fraction (g/GJ)	Categories/EMEP Guidebook Solid+condensable (g/GJ)
Conventionals (before 2005)/590	Conventionals (before 2005)/253	Conventional/800
Efficient 1 – (2005-2015) / 417	Efficient 1 – (2005-2015) / 331	Highly efficient / 400
Efficient 2 – (2015-2021) / 282	Efficient 2 – (2015-2021) / 144	
Advanced (starting from 2022) / 128	Advanced (starting from 2022) / 76	Advanced / 100

For the purposes of illustration, we performed a theoretical scenario where we extrapolated the current trend of wood energy consumption by “Performant 1” appliances (from 2017 to 2022) to the year 2030. We assumed that the energy is instead consumed by “advanced appliances”. As no significant trend was observed on open fireplaces, we assumed that the energy consumption for these appliances is constant. It should be noted that the trends in energy consumption may be due to changes in practices and not to changes in appliances. This scenario is therefore theoretical and does not necessarily reflect current evolution or measures. In our scenario, 3.2% per year of the wood energy consumed would be replaced by advanced appliances. It should be noted that according to a recent study published in summer 2024 from the ADEME French agency the renewal rate of heating appliances in 2022-2023 should be around 2%[5]. While this number corresponds to a change in the number of appliances and not in terms of energy consumption (i.e. in terms of use of appliances), it could suggest that our scenario could overestimate the decrease in emissions.

For simplification purposes, we assume that there are no wood pellets in the new appliances and that they consist entirely of fireplaces.

In 2020, old appliances (before 2005) represent 28% of wood energy consumption but they represent 48% of PM emissions (estimation with EF from the Real-Life protocol), the rest of the emissions being due to appliances between 2005 and 2015. In 2030, old appliances would represent in the theoretical scenario only 13% of energy consumption and 28% of emissions. On the other hand, advanced appliances would represent 14% of energy consumption and 3% of the emissions.

The Figure 8 illustrates the emissions computed for the years 2020 and 2030 with the different sources of emission factors. RWB emissions over France computed with using EF for the solid fraction from the Real-Life Protocol (solid emissions factors from CITEPA for appliances before 2022) would be equal to 44 kT in 2020 and 31 kT in 2030. Much higher emissions (by almost a factor 3) are estimated when using the EF including condensables (118 kT in 2020 and 84 kT in 2030).

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[5] ADEME (2024). Situation du chauffage domestique au bois en 2022-2023. https://librairie.ademe.fr/energies/7443-situation-du-chauffage-domestique-au-bois-en-2022-2023.html

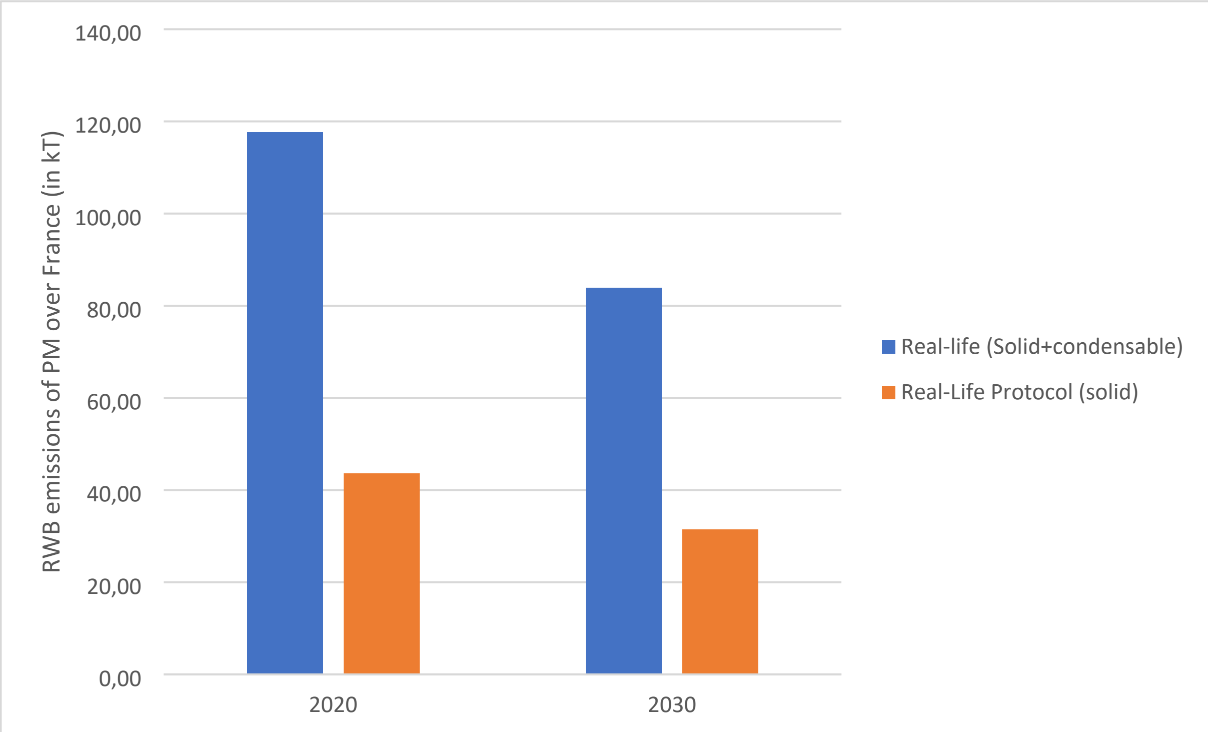

Figure 8: RWB PM emissions over France for years 2020 computed with the different types of EF.

France has the objective to reduce PM2.5 RWB emissions by 30% between 2020 and 2030 (Plan air bois). This objective increases to 50% for the highly polluted areas covered by an Atmosphere Protection Plan. Based on our scenario, reaching the objective of a 30% reduction is possible as we estimated a decrease of emissions of 28.7% with EF including condensables and 27.7% for the EFs without condensables from the Real-Life protocol. Reaching this objective would mean a renewal rate above 3.2%. A much higher renewable rate would be needed to reach the 50% objectives for areas covered by an Atmosphere Protection Plan.

3. Conclusion

Additional initial investment costs ranged from 2000 € for scenario 1 to 34588 € for scenario 3. Total added cost (€/stove tested) was 510 €, 743 € and 884 € for the scenarios 1, 2 and 3, respectively, when labour costs were estimated to 100 €/h. With increased labour costs to 200 €/h the total added cost was 960 €, 1303 €, and 1564 € for the scenarios 1, 2, and 3, respectively. Scenarios 2 and 3 require more labour than scenario 1 so this emphasises that the labour costs have the highest contribution to the total added cost and investment cost would be acceptable.

To study the benefits of using realistic emission factors for air quality assessment based on atmospheric modelling, a theoretical scenario was analysed for France as an example. This scenario describes the impact of replacing old appliances with more modern ones by 2030 as part of a plan to reduce emissions by 30% on average in France and by 50% in the most polluted area between 2020 and 2030. The scenario indicates that emissions will fall significantly by 2030 and that the 30% reduction could be achieved. However, a much higher replacement rate would be required to achieve the 50% target in the most polluted areas.

In conclusion, using realistic EFs, including condensables, is essential for accurate air quality modelling and achieving emission reduction targets. This approach not only improves model accuracy but also supports effective environmental policy and planning

UNIVERSITY OF EASTERN FINLAND

Harmonizing reliable test procedures representing real-LIFE air pollution from solid fuel heating appliances - **Real-LIFE Emissions** project.

Project Partners

- University of Eastern Finland (UEF)
- Technical University in Ostrava (VSB)
- The French National Institute for Industrial Environment and Risks (INERIS)
- Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ)

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