THE IMPACT OF CLIMATE POLICY AND CLIMATE CHANGE ON $PM_{2.5}$ EMISSION FROM RESIDENTIAL WOOD COMBUSTION

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Abstract: *Residential wood combustion is the dominant source of particulate matter $PM_{2.5}$ in the Republic of Croatia. Although the wood biomass is considered a green, sustainable energy source, at the same time the inhalation of $PM_{2.5}$ particles from residential wood combustion, is associated with harmful effects on human health. The paper analyzes the variability of $PM_{2.5}$ emission regarding three factors, which are closely related to climate policy and climate change. The first factor is related to the introduction of new, more environmentally friendly wood biomass combustion technologies. The second factor relates to the consumption of wood biomass depending on climate variability. The third factor refers to the implementation of measures for energy renovation of family houses. The aim of this paper is to distinguish the contribution of individual factors, both on the historical $PM_{2.5}$ emissions from residential wood combustion, and on the emission projections up to the year 2050.*

Keywords: $PM_{2.5}$ emission variability, residential wood combustion, climate policy, climate change

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1. INTRODUCTION

Energy and climate policies and strategies increasing the use and boosted of renewable energy sources. The bioenergy from wood combustion considered a green and sustainable but has an impact on environment (UNFCCC, 2015; WBA, 2016; European Council, 2019). Particularly, the inhalation of $PM_{2.5}$ particles from residential wood combustion, is associated with harmful effects on human health (Air Quality Expert Group, 2017; WHO, 2015; WHO, 2021). In the Republic of Croatia, the residential wood combustion is the key source of many air pollutant emissions (Ministry of Economy and Sustainable Development, 2021; EMEP CEIP, 2022) with the impact on the local air quality considering $PM_{2.5}$, PM_{10} and benzo(a)pyrene (BaP) (Ministry of Economy and Sustainable Development, 2020; UN ECE, 2019). This paper starts with an overview on the policies concerning the use of the bioenergy from biomass, scope of the fuelwood combustion in households, resulting air pollution, specifically $PM_{2.5}$ emission and emission projection and impact of it on human health. The paper analyses the impact of selected three factors on $PM_{2.5}$ emission from household heating appliances on wood biomass as following: the introduction of new, more environmentally friendly wood biomass combustion technologies replacing the old, inefficient technologies with high particulates emission, the consumption of wood biomass depending on climate variability, and the implementation of measures for energy renovation of family houses. Finally, the conclusion discusses the results are presented.

2. POLICIES, WOOD BIOMASS AND $PM_{2.5}$ EMISSION

Energy and climate policies and strategies envisage increasing the use of renewable energy sources (RES), including wood biomass, as an important means for the energy sector to achieve environmental, economic, and social goals of sustainable development (Andersen, Allen and Domingo, 2021; UNFCCC, 2015; WBA, 2016). The application of RES is a key component of mitigating climate change and for achieving the international obligations of the European Union and member states under the Paris Agreement (UNFCCC, 2015). Biomass fuels were also included in the European Commission's strategy to achieve its climate and energy goals by 2020 (20% reduction in greenhouse gas emissions, 20% final energy consumption from RES and a 20% increase in energy efficiency) (WHO, 2015). For example, in the year 2018 the share of solid biomass in total Final Energy Consumption in the Residential sector was 16.3 % in the EU, and the Republic of Croatia achieved a share of 44.9 % (Eurostat a (n.d.)). By implementing RES, Europe has replaced part of its energy production from non-renewable sources (especially from fossil fuels) and managed to reduce greenhouse gas (GHG) emissions. The further goal of the EU's goal is to achieve climate neutrality by 2050 delivering on its commitments under the international Paris Agreement (European Council, 2019). The EU's strategy for reaching its 2050 climate goal is The European Green Deal. This requires current greenhouse gas emission levels to decrease substantially in the next decades. As

an intermediate step towards climate neutrality, the EU has raised its 2030 climate ambition, committing to cutting emissions by at least 55% (compared to 1990) by 2030. The 'Fit for 55' legislative package will turn the EU's ambition into reality and strengthen the EU's position as a global climate leader. 'Fit for 55' package will additionally boost the development of renewable energy sources in the EU, especially through the implementation of the revised Renewable Energy Directive (RED). However, not all sources of renewable energy have the same environmental impacts. Energy from wood biomass combustion, in particular causes air pollution and impacts health (Air Quality Expert Group, 2017). Increased usage of energy from wood biomass can pose a challenge for EU Member States in meeting EU air quality standards, defined by current framework used to control ambient concentrations of air pollution in the EU - Ambient Air Quality Directive & daughter Directive 2004/107/EC, and their emission reduction commitments for air pollutants set out under the National Emission reduction Commitment Directive (NEC Directive) along with the parties of the United Nations Economic Commission for Europe (UNECE) Convention on Long Range Transboundary Air Pollution (Convention LRTAP) and belonging the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol) (Environmental Protection UK, n.d.). The Republic of Croatia, as EU Member State and the party of UNECE Convention LRTAP, is required to regularly compile and report official estimates of their emissions and projected (future) emissions for GHGs and air pollutants. The mandatory reporting of projections plays an important part in the policy process: it is designed to provide MS, the European Commission, and other stakeholders with a reliable early indication of the expected trend of future emissions, and thus with information on whether implementation of national and EU-wide policies and measures is helping countries meet their emission commitments. The set of projections scenarios that MS have been required to report fall into the two categories: 1) projections scenario 'with measures' (WM) - means projections of anthropogenic GHG or air pollutant emissions by sources that encompass the effects of currently implemented or adopted policies and measures, and 2) projections scenario 'with additional measures' (WAM) - means projections of anthropogenic GHG or air pollutant emissions by sources that encompass the effects of policies and measures which have been adopted and implemented, as well as planned policies that are judged to have a realistic chance to be adopted and implemented in the future. The officially reported emission estimations (EMEP CEIP, 2022) and project emission estimation for two scenarios (WM and WAM) (EMEP CEIP, 2021) for pollutant $PM_{2.5}$ are used in this paper for analysis and results presentation. The burning of wood biomass in household heating appliances is responsible for the majority of particulate matter emissions in Europe (EIONET, 2021; WHO, 2015; Environmental Action Germany, 2015; Carrington D, 2021). Ambient (outdoor) air pollution in cities and rural areas is estimated to cause 4.2 million premature deaths worldwide in 2016 and is the result of exposure to $PM_{2.5}$ particles, which cause cardiovascular and respiratory diseases and cancer (WHO, 2021). At EU27+UK level in 2016 as stated in ETC/ATNI Report 6/2020 (EIONET, 2021), it is estimated that the interrelationship between the increase in emissions due to biomass use and the reduction in emissions due to all other RES growth is responsible for around 9,200 premature deaths and 97,000 years of life lost. As such, the increase in solid biomass heating alone (particularly due to high particulate emissions from domestic stoves) is estimated to be responsible for an increase of around 10,700 premature deaths and 113,000 years of life lost in 2016. Official reported data (Ministry of Economy and Sustainable Development, 2021) show that in the Republic of Croatia, wood biomass burning in households is a key source of emissions of many pollutants, and $PM_{2.5}$ is one of them (**Figure 1**). In 2020, wood biomass in Croatia accounted for 63.3% of the total consumption of all energy sources in household heating appliances, and it dominates throughout the entire historical trend since 1990 (EMEP CEIP, 2022). The increase in the use of wood biomass in household heating appliances is associated with an increase in the concentration of $PM_{2.5}$, especially during the winter heating season (EIONET, 2021; Air Quality Expert Group, 2017; WHO, 2015).

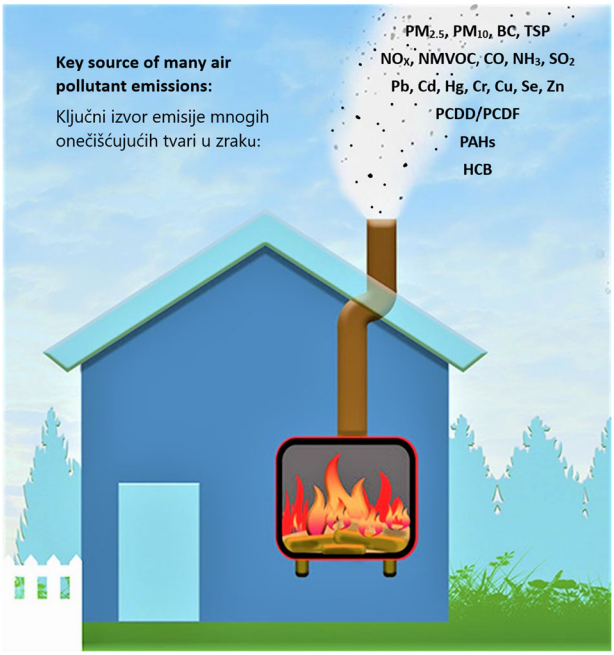

Figure 1. Residential wood combustion as a key source of many air pollutants emissions

According to Croatian strategic and planning documents (OG 25, 2020; OG 63, 2021; Ministry of Economy and Sustainable Development, 2020; OG 46, 2020; OG 140, 2020) it is expected that the consumption of wood biomass will increase until 2030, and then decrease due to boost of energy home renovation. Compared to 2018, the consumption of energy from biomass in households is expected to increase by 6% in WM and 4% in WAM scenario until 2030. Due to boost of energy home renovation, it is expected that consumption of wood biomass will decrease by 46% in WM and 53% in WAM scenarios until 2050. WM scenario assumes energy renovation rate of 0.75 % per year, and 20 % of total old wood heating appliances replacement by 2030. WAM scenario assumes energy renovation rate of 1.3 % per year, and 41.7 % of total old wood heating appliances replacement by 2030. There is no change in technology share after 2030 in both scenarios (Ministry of Economy and Sustainable Development, 2021; CEIP EMEP, 2021).

3. OBJECTIVE OF THE WORK AND METHODOLOGY

Objective of the work is distinguishing the impact of influencing factors on $PM_{2.5}$ emission and emission projections from household wood biomass burning. Factors that affect the amount of $PM_{2.5}$ emission from wood biomass combustion in residential heating appliances and, consequently, the level of $PM_{2.5}$ concentration in the air are following:

- amount (and type) of fuelwood - number of households that use it as an energy source
- climate conditions
- combustion technology
- operational settings maintenance of heating appliance and its age
- fuel quality (depending on storing practice, waste co-firing)
- implementation of energy efficiency measures

Among previously mentioned influencing factors, three of them, closely related to climate policy and climate change, were selected:

- Factor #1: Introduction of new, more environmentally friendly wood biomass combustion technologies,
- Factor #2: Wood biomass consumption variability depending on interannual climate variability, and
- Factor #3: Decreasing wood consumption due to improving the energy efficiency of family houses.

By analysing the variability of the emission of $PM_{2.5}$ regarding three selected influencing factors, it will be determined which of them has the greatest influence on $PM_{2.5}$ emission, that is, which of them contribute the most to its reduction.

The impact of each factor was analysed separately. The reference year for the analyses is 2018, the most recent year in the officially submitted emissions projections. The observed timeframe included the base year 2018 and regard this the historical period (1990 – 2020), and the projection period (after 2020 up to 2050). All results are

expressed as a difference from baseline year 2018. The input data were biomass energy consumption in households and share of biomass combustion technologies for two scenarios WM and WAM, all presented in **Figure 2**.

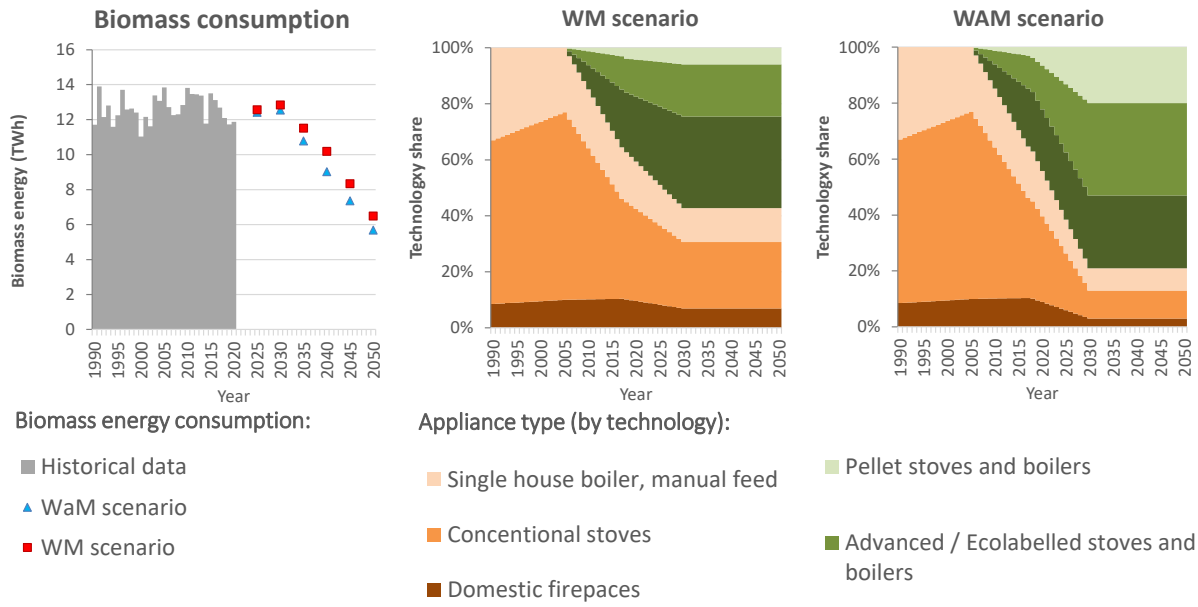

Figure 2. Biomass energy consumption in households and share of biomass combustion technologies for historic period (1990 - 2020) and projection period (after 2020) for the WM and WAM scenarios

Emission factors showed in *Figure 3* present the range of $PM_{2.5}$ emission from various type of biomass burning appliances used in households. It can be seen that pellet stoves and boilers have approximately ten times lower $PM_{2.5}$ emission than conventional alliances (conventional stoves and single house boilers).

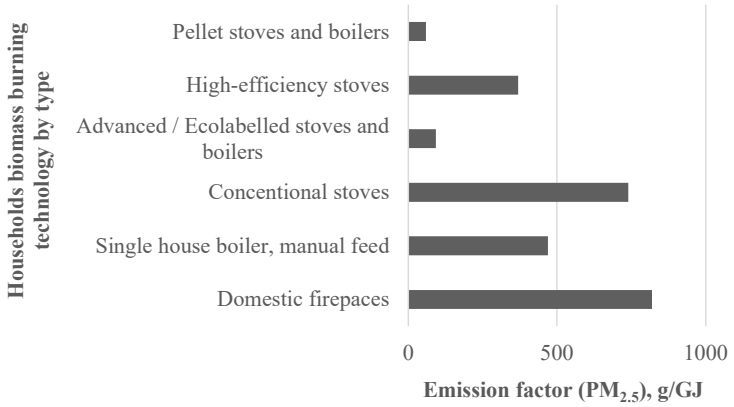

Figure 3. $PM_{2.5}$ emission factors for different wood biomass appliances used in households

4. RESULTS AND DISCUSSION

The impact of wood biomass combustion technology (Factor #1) and climate variability (Factor #2) on $PM_{2.5}$ emission and emission projections from household biomass heating appliances are presented on **Figure 4**.

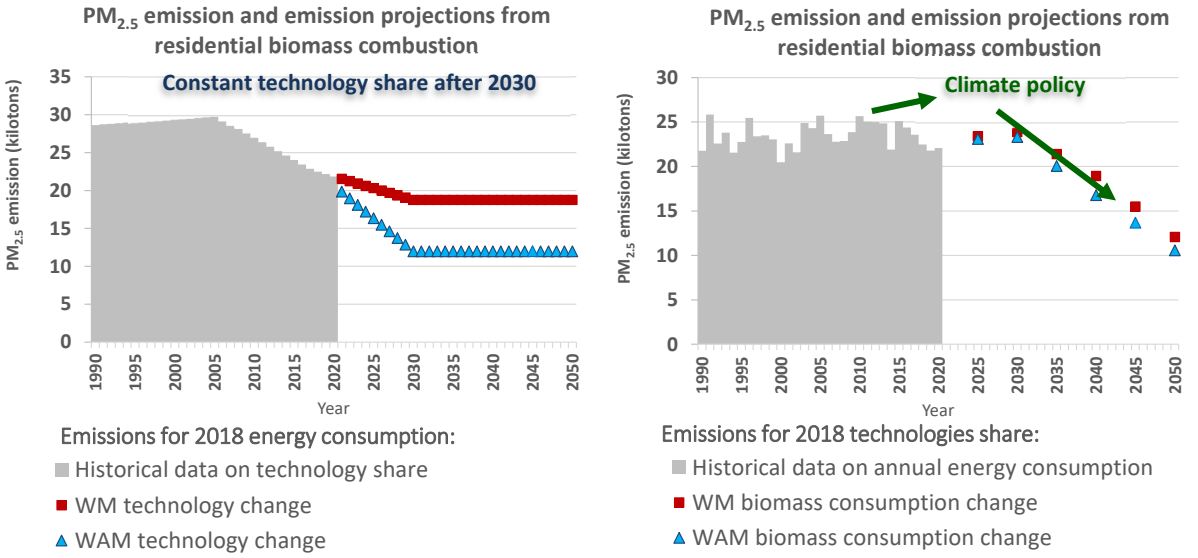

Figure 4. Impact of wood biomass combustion technology (left) and climate variability (right) on $PM_{2.5}$ emission and emission projections from household fireplaces on wood biomass for the historical period and scenarios WM and WAM

The implementation of the climate polices, which is expected increased use of firewood in households by 2030, will consequently result in higher $PM_{2.5}$ emission. The results of the sensitivity analysis regarding Factor #1, show that within the historical period, due to a greater share of old combustion technologies, $PM_{2.5}$ emission could be up to 25% higher than in 2018 (**Figure 4 (left)**). Regarding Factor #2, the sensitivity analyse shows that $PM_{2.5}$ emission difference may go between -10 % to +13 % due to variability of the biomass energy consumption (**Figure 4 (right)**). **Figure 5 (left)** compares the historic trends variability of heating-degree days (HDD) (EUROSTAT b, n.d.) and biomass energy consumption in households. HDD variability goes between -12 % and +35 %, while the biomass consumption variability goes between -9 % and +15 %. The discrepancy between variability of HDD and biomass consumption indicates an increase in biomass consumption in households, which is in line with climate policies. According to climate projections for 2030 and 2040, HDD is expected to decrease by 2.3% and 4.7%, respectively, compared to 2018 (Ministry of Economy and Sustainable Development, 2021).

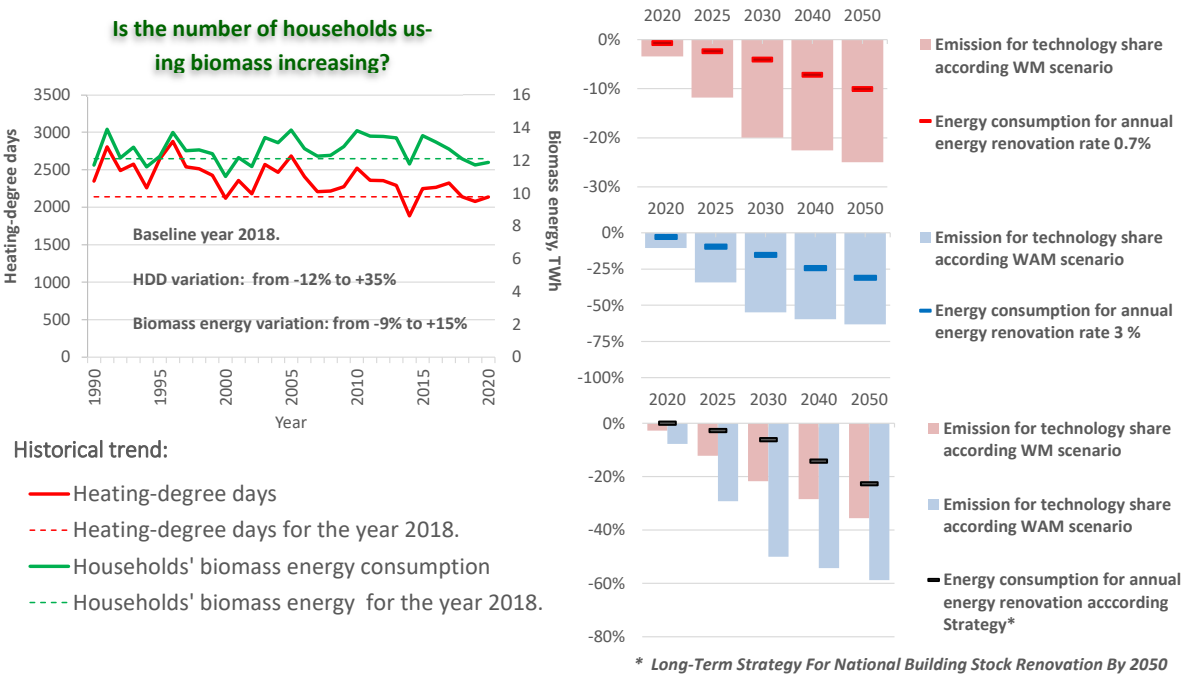

Figure 5. Heating-degree days and biomass energy consumption for the historic period (left) and the impact of energy renovation and technology improvement on $PM_{2.5}$ emission decrease (4 scenarios) (right)

The impact of improving the energy efficiency of family houses (Factor #3) is analysed for three different renovation rates: 1) constant energy renovation rate of 0.7 % per year, 2) constant energy renovation rate of 3 % per year, and 3) linear change of energy renovation rate from 1 % in 2020 to 3 % in 2030). For the sensitivity analysis of Factor #3 following scenarios were used: conservative, optimistic, moderate conservative and moderate optimistic one and results are presented in *Figure 5 (right)*. The conservative scenario (**Figure 5** *(right), upper graph*), which includes WM biomass technology change scenario and energy renovation rate of 0.7 % per year, may result with -22 % reduction of $PM_{2.5}$ emission in 2030 when comparing to base year 2018. The optimistic scenario (**Figure 5** *(right), middle graph*), which includes WAM biomass technology change scenario and energy renovation rate of 3 % per year, may result with -56 % reduction of $PM_{2.5}$ emission in 2030 when comparing to 2018. The moderate conservative scenario (**Figure 5** *(right), lower graph, red*), which includes WM biomass technology change scenario and linear change energy renovation rate from 1 % to 3 % per year, may result with -24 % reduction of $PM_{2.5}$ emission in 2030 when comparing to 2018, while conservative optimistic scenario (**Figure 5** *(right), lower graph, blue*) with the same linear change energy renovation rate, and with WAM biomass technology change may bring -51 % reduction. The year 2030 is chosen to indicate how energy and climate policies may have impacted $PM_{2.5}$ emission in this decade.

5. CONCLUSIONS

This paper analyses the impact of three influencing factors on $PM_{2.5}$ emission from household heating appliances using wood biomass which are closely related to climate policy and climate change. The first factor refers to introduction of new, more environmentally friendly wood biomass combustion technologies replacing the old. The second factor is related to the climate variability which effects consumption of wood biomass. The third factor refers to the implementation of energy renovation of family houses.

With energy renovation rates of family houses according to the Long-term strategy [22], and widespread use of eco-friendly biomass appliances, a reduction in $PM_{2.5}$ emissions between 24 % (WM scenario) and 51% (WAM scenario) could be expected up to 2030.

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