THE IMPACT OF CLIMATE CHANGE AND BUILDING RENOVATION ON HEATING RELATED CO_2 EMISSIONS ON A NEIGHBOURHOOD LEVEL

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ABSTRACT

Building sector is currently one of the major sources of CO_2 emissions. Considering that the largest proportion of energy in buildings in Europe is used for heating services, significant potential for emissions decrease could be exploited through heat demand reductions.

The scope of this paper is to evaluate the impacts of changed climate and building renovation on heating related CO_2 emissions on a neighborhood level. A combination of existing tools (EnergyPLAN, ArcGIS, CCWorldWeatherGen) and a tool previously developed by the authors (resistance-capacitance analogy based heat demand model [1]) were used. Three weather scenarios for the future were considered (low, medium, high temperature increase), as well as four renovation paths (no renovation, shallow, intermediate, deep renovation path). Three heating system options were taken into the account: individual electric heaters in each dwelling, natural gas distribution network with individual boilers in each dwelling and district heating network with centralized heat production in natural gas fueled boiler. Generic neighborhood configuration for Portugal was created based on the district of Alvalade that is located in Lisbon. This particular district was chosen due to the fact that it possesses desirable urban morphology and it was built during several construction periods over the last century.

The results showed that the changed climate, by itself, could decrease annual CO_2 emissions from 8% up to 34% in 2050 compared to 2010 (depending on the weather scenario and heating system considered) due to the changed weather parameters. Furthermore, building envelope renovation could enable additional 80-260ktCO_2 savings in cumulative emissions for the regarded period (2010-2050).

Keywords: climate change, emissions, heating, urban environment

INTRODUCTION

In 2009, the European Council committed the member states of the European Union to reduce the carbon-dioxide emissions to a minimum of 80% (compared to the levels from 1990) by 2050. Due to the fact that the heat demand in Europe is the main energy end-use source of emissions [2], decarbonisation of this sector could improve the achievability of the goals set.

However, the CO_2 emissions from the building heating sector could decrease due to the reduced heat demand caused by the changed climate. Increased outdoor temperatures and changed levels of solar radiation could decrease the amount of heat required to reach the comfort temperature inside the buildings. Furthermore, improvements in the building envelope thermal performance due to the new energy efficiency policies could reduce the heat transfer between the building and the environment, further decreasing the heat demand.

Additionally, the penetration of renewable energy technologies (biomass boilers, solar thermal panels, geothermal heat pumps) for heating in urban environment had an increasing trend in the previous decade with efficiency improvements and decline in prices for such technologies. However, in high-density areas, limited amount of space available for placing the geothermal heat pump installation (heat exchangers and piping) and shading of the solar panels from the surrounding buildings could compromise the use of these systems. Considering the global population increase and dense urban environment expansion rates, the possible solution could be the production of heat outside the municipalities coupled with heat distribution through the networks.

District heating networks are commonly proposed in the literature as an environmentally friendly solution for providing heating services for the built environment due to their benefits, such as centralized heat production located outside the municipalities, utilization of renewable heat sources (biomass, solar, geothermal etc.) and comfort for the consumers. The subject has been widely researched in several scientific reports [2-5]. The conclusions were that the district heating should be considered as an essential cost effective technology for the EU energy system decarbonisation.

Another solution could be the natural gas distribution networks with high efficiency individual condensing boilers within each dwelling. Global demand for natural gas is projected to rise by 65 percent from 2010 to 2040, making it the largest volume growth of any energy source [6]. Additionally, due to the rise in new technologies for extracting natural gas from unconventional sources, it is considered that natural gas could have a major role in energy transition [7,8]. Additionally, natural gas networks could be used for distribution of other gaseous fuels such as hydrogen [9].

Furthermore, we have considered electric heaters in each dwelling for this study, due to the fact that significant proportion of heat demand in southern countries like Portugal is covered by these systems. Additionally, the change in emissions due to the heat demand reduction is not so obvious due to the energy mix used for electricity production, making it an interesting research topic.

The main goal of this paper is to assess the possible heating-related CO_2 emission reductions on a neighborhood level, caused by the impacts of climate change and building renovation and taking into account several options for providing heating services to the urban environment.

METHOD

The methodology used in this paper is illustrated on Figure 1. Heat demand on a neighborhood scale was calculated by using the resistance-capacitance model (RC model) based on the thermo-electrical analogy that was developed for a previous study [1]. Heat demand is calculated on an hourly basis for each building within the studied area. The model was improved since the last case study, and its current version it capable to take into the account occupancy profiles, internal heat gains from the occupants and heat losses due to the air renewal (all on an hourly basis). Additionally, shading between the buildings was calculated depending on the season of the year considered (shading was estimated in ArcGIS). For the heat demand calculations, the model requires two main inputs: weather data and building data for the chosen case study location. Weather data consists of data for the reference year and weather scenarios for the future. Reference weather data can be obtained from the Energy Plus weather database [10] for multiple locations around the world. For the creation of the future weather scenarios (low, medium and high temperature increase) we have used the Climate Change World Weather File Generator tool [11] that uses reference weather data and outputs from the HadCM3 global circulation model as an input to forecast the weather conditions for the future.

Building data was obtained from calculations in ArcGIS (building geometry, shading between the buildings), the municipality database (construction period, typology, no. of inhabitants) and the Building Performance Institute Europe (thermal properties of the building elements – walls, roofs, floors, windows) database [12]. For the building renovation scenarios, we have assumed improvements in the thermal properties of the building elements, introducing four levels of renovations (low, medium, high and net zero energy buildings level) and four renovation depths that consider the number of buildings renovated with each level of renovation for each year (no renovation, shallow, intermediate, deep) as suggested by BPIE report [13]. Additional information about weather and renovation scenarios was provided in [14].

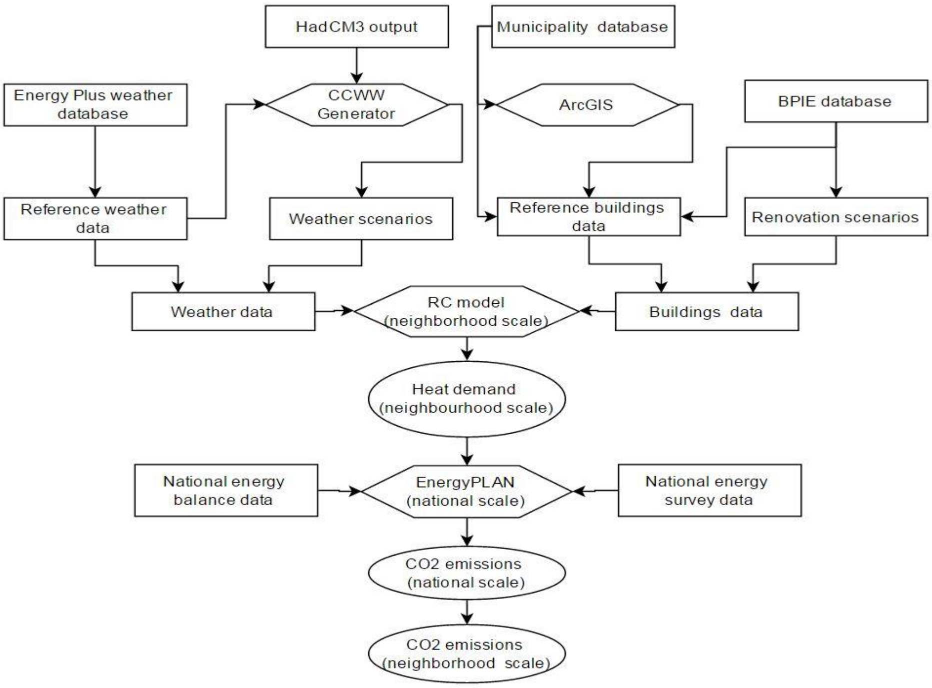

Figure 1 Methodology outline

CO_2 emissions are calculated in the EnergyPLAN software. EnergyPLAN is a deterministic model for evaluating the operation of an energy system. It has been applied for the evaluation of energy systems and strategies for increasing the penetration of renewable energy sources on a national scale for different countries, such as Norway [15], Denmark [5], China [16], USA [17] and Serbia [18]. The model is capable of taking into the account several sectors within the energy system, including the electricity sector, heating and cooling sector, and industry and traffic sectors. Primarily, the model for the whole country (Portugal) was created and verified based on the data from the national energy balance [19]. Since the energy balance does not contain data about the energy consumed for heating and cooling in Portugal, a national survey [20] was used as a source. This caused a misbalance in the results (compared to the energy balance) of only 1.2%, which we found acceptable. After the reference case calculations and model calibration, the estimated heat demands for each scenario of the studied neighborhood were introduced in the model and the emissions were calculated. The level of emissions on a neighborhood scale for each scenario was obtained through the comparison with reference case results. Fuel emission factors were obtained from the SenterNovem [21] report. Low heating values of the fuels were considered constant.

For this paper, a generic neighborhood for Portugal was created based on the Alvalade district in Lisbon. We have used this district due to the fact that it has as desirable morphology (ratio of private, public and service areas) and that it is consisted of 665 buildings constructed during various periods in the last century. In this study, we have neglected the cooling demand in the district, due to the fact that only a small number of buildings within this district have cooling systems. This is also true on the national level, since the energy survey for Portugal indicates that the amount of energy for cooling on a national level was significantly smaller than the amount of energy used for heating (13,107Mtoe compared to 533,892Mtoe in 2010, respectively [20]), despite the warm climate.

For heating systems, we have considered three scenarios: individual electric heaters, two-pipe district heating network with central boiler fueled by natural gas (network losses $\zeta_{dhn} = 0.2$, boiler efficiency $\eta_{ngn} = 0.8$) and natural gas distribution network with individual gas boilers in each dwelling (network losses $\zeta_{ngn} = 0.15$, boiler efficiency $\eta_{ngn} = 0.9$).

RESULTS AND DISCUSSION

The impact of climate change on annual heating related CO_2 emissions is represented on Figure 1 for all considered heating system scenarios (EH – electric heaters, NGDHN – district heating network with natural gas boiler, INGN – natural gas distribution network with individual gas boilers). It can be noted that the neighborhood with electric heaters has the highest emissions for all weather scenarios (36% higher than NGDHN and 43% higher than INGN). Due to the changed weather conditions, annual CO_2 emissions could decrease from 8-33% in 2050 (compared to 2010 and depending on the weather scenario) for natural gas fueled systems and 9-34% for the electric heaters scenario.

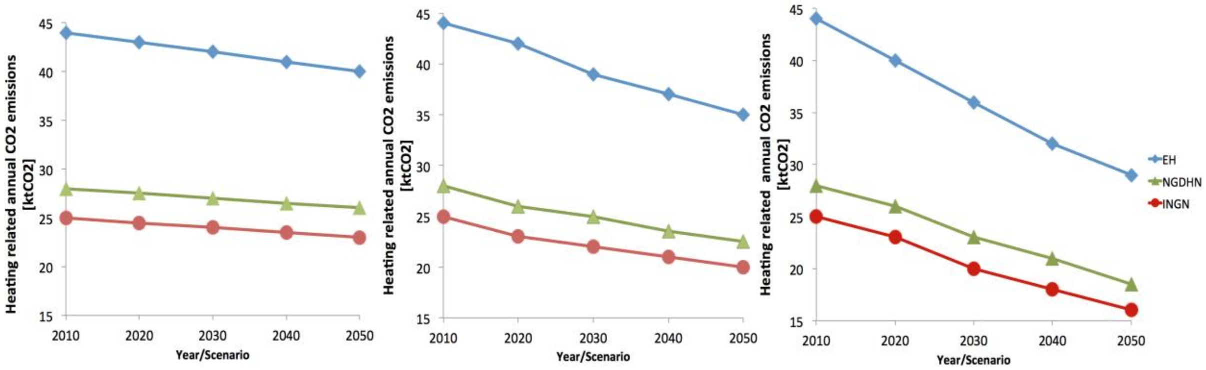

Figure 2 The impact of climate change on heating related annual CO_2 emissions on a neighborhood level (low (a), medium (b) and high temperature scenario (c))

Combined effects of climate change and building renovation (NR - no renovation, SR – shallow renovation path, MR- medium renovation path and DR – deep renovation path) on cumulative CO_2 emissions for the period 2010-2050 are illustrated on Figure 2. Building renovation could enable additional 107-260ktCO_2 emission savings for low temperature scenario, 94-245ktCO_2 for medium temperature scenario and 80-214ktCO_2 for high temperature scenario (depending on the heating system observed).

In this case study, the natural gas distribution network had the lowest emissions for all weather and renovation scenarios considered, due to the efficiency of the small individual condensing natural gas boilers and lower losses in the system (compared to traditional two-pipe district heating network). On the other hand, new low-temperature district heating networks designs have lower losses and can integrate the heat production from renewable sources such as solar thermal panels and biomass. However, there are only few such systems operating today (mostly in Nordic countries).

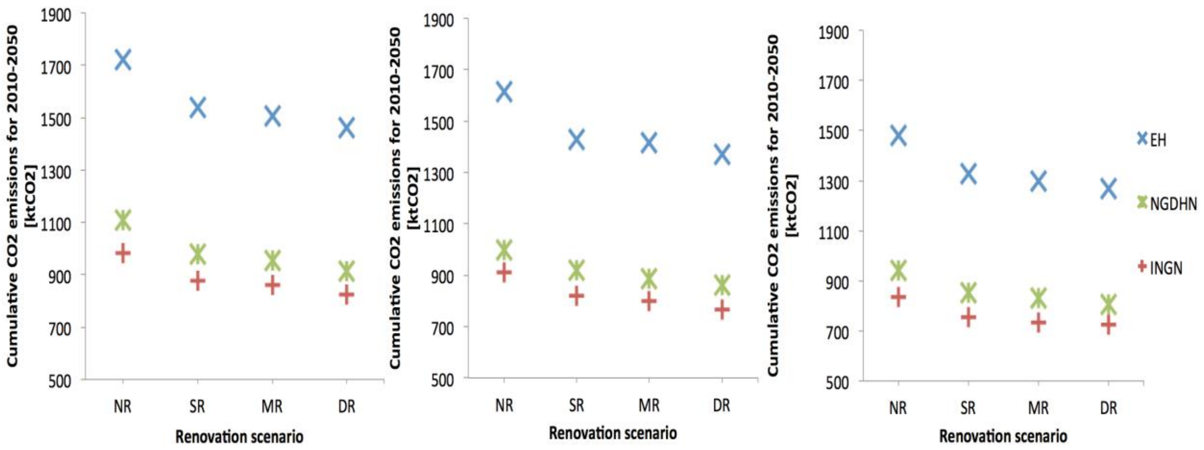

Figure 3 The impact of climate change and building renovation on heating related cumulative CO_2 emissions on a neighborhood level (low (a), medium b) and high(c)) for the period 2030-2050

CONCLUSIONS

The main goal of this paper was to evaluate the potential decrease in heating related CO_2 emissions on a neighborhood scale due to the impacts of climate change and building renovation. Additionally, different options for providing the heating services for urban environment were considered. A generic neighborhood for Portugal was created based on the Alvalade district located in Lisbon.

The results showed that just due to the changed weather variables, annual CO_2 emissions could decrease from 8% up to 34% in 2050 (compared to 2010, depending on the weather scenario and heating system considered). Additionally, building envelope renovation could enable additional 80-260ktCO_2 savings in cumulative emissions for the regarded period (2010-2050).

Furthermore, natural gas distribution network with individual boiler in each dwelling caused the lowest emissions for all weather and renovation scenarios studied (compared to electric heaters and two-pipe district heating network considered). However, new low-temperature designs for district heating networks are currently emerging, enabling the utilization of renewable sources such as solar thermal panels. Additionally, we note that for fully evaluating the emissions from the building sector, cooling demand should also be taken into the account, since the increased outdoor temperature could result in increased cooling demand, which we will address in our next case study.

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