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Feasibility of energy reduction targets under climate change: The case of the residential heating energy sector of the Netherlands

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A B S T R A C T

In order to achieve meaningful climate protection targets at the global scale, each country is called to set national energy policies aimed at reducing energy consumption and carbon emissions. By calculating the monthly heating energy demand of dwellings in the Netherlands, our case study country, we contrast the results with the corresponding aspired national targets. Considering different future population scenarios, renovation measures and temperature variations, we show that a near zero energy demand in 2050 could only be reached with very ambitious renovation measures. While the goal of reducing the energy demand of the building sector by 50% until 2030 compared to 1990 seems feasible for most provinces and months in the minimum scenario, it is impossible in our scenario with more pessimistic yet still realistic assumptions regarding future developments. Compared to the current value, the annual renovation rate per province would need to be at least doubled in order to reach the 2030 target independent of reasonable climatic and population changes in the future. Our findings also underline the importance of policy measures as the annual renovation rate is a key influencing factor regarding the reduction of the heating energy demand in dwellings.

1. Introduction

In order to meet global climate targets, the building sector needs to reduce energy consumption by 60% worldwide by 2050 [1]. However, to increase the chances of successful and far-reaching measures on a national level, reliable estimates regarding the future energy demand are required. We take the Netherlands as a case study and assess the nation's ability to achieve given national heating energy saving targets. The Netherlands are a small country with 17 mio. inhabitants but belong to the 25 countries worldwide with the largest CO_2 emissions. Thus, the country can make a considerable contribution to climate mitigation. Furthermore, the Netherlands could be representative for regions such as Belgium, Great-Britain, Luxembourg and huge parts of France that have the same maritime temperate climate [2] and similar population projections for the future [3].

To avoid adding one more example to the large number of published assessments in this field, we went through the literature, categorized existing studies and chose on this basis an appropriate approach for our case study. Publications considering the impact of climate change and other future changes on the energy demand of buildings are shown in Table 1 which is partly based on Li et al. [4] and Yang et al. [5] who reviewed existing papers regarding the impacts of climate change on energy use in the housing sector.

Concerning the modeling approach, we find statistical models (S) which relate heat energy consumption with driving forces like temperature on the basis of observed, historical data. Here the difficulty lies in the correct statistical distinction between the weather influence and the other independent variables (insulation etc.) due to the restriction to historical data which may not contain all relevant combinations of these variables. This can cause problems for the application of the statistical model in the scenario calculations. In contrast, mechanistic approaches rely on the representation of the physical processes of heat transfer which are all well known. The achievable level of detail in these models depends on the availability of detailed building properties. Therefore, these detailed models (MD) are applied mainly in small scale studies (see Table 1). The application on more aggregated mechanistic models of intermediate complexity (MI) might be advantageous in data sparse situations compared to MD-models where unknown parameters are simply fixed to a roughly estimated value. The spatial

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Table 1
List of papers that deal with the impact of climate change on the future energy demand or consumption of buildings. We give an overview over the modeling approach they use, which scale they analyse and which future influencing variables they consider. S = Statistical models, MD = Data demanding models, MI = Intermediate complexity models, R = Residential, C = Commercial, a = Annual, m = Monthly, G = Global, N = National, L = Regional/Local, Compreh. = Comprehensive.

Paper	Modeling approach	Sector	Temporal scale	Spatial scale	Climatic changes	Renovation measures	Population changes	Compreh. Stock
Aguiar et al [6]	MD	R + C	m	N + L	x	–	–	–
Jenkins et al [7]	MD	C	a	L	x	–	–	–
Zmeureanu and Renaud [8]	S	R	a	L	x	–	–	–
Lam et al [9]	MD	C	a	L	x	–	–	–
Dolinar et al [10]	MD	R	a	L	x	–	–	–
Wan et al [11]	MD	C	a	L	x	–	–	–
Wang et al [12]	MD	R	a	L	x	x	–	–
Scott et al [13]	MD	C	a	L	x	x	–	–
Gaterell and McEvoy [14]	MD	R	a	L	x	x	–	–
Wan et al [15]	MD	C	a	L	x	x	–	–
Chow and Levermore [16]	MI	C	a	L	x	–	–	x
Collins et al [17]	MD	R	a	L	x	–	–	x
Isaac and vanVurren [18]	MI	R	a	G + N	x	–	x	–
Frank [19]	MD	R + C	a	L	x	x	–	–
Zhou et al [20]	MI	R + C	a	N	x	–	x	x
Belzer et al [21]	S	C	a	N + L	x	x	x	x
Olonscheck et al [22]	MI	R	a	N	x	x	x	x
Yu et al [23]	MI	R + C	a	N + L	x	x	x	x
This study	MI	R	m	N + L	x	x	x	x

scale of the considered studies is typically either global (G), national (N), or regional/local (L) and related to the model type as mentioned above. Most studies calculate the energy demand annually (a) which may induce complications in case of the presence of non-linear relationships between weather variables and heat flows – here a monthly temporal scale (m) would be more appropriate. The studies vary widely in the consideration of relevant influencing factors and their trends, including climatic changes, thermal renovation measures, and population changes. Table 1 shows that only a few studies consider all factors simultaneously. Regarding the building sector, most studies deal with the residential (R) or the commercial (C) sector, few with both. Some studies consider a comprehensive stock of buildings, while others only use a limited number of prototype buildings and their respective distribution over the whole housing stock leading to a more coarse grained representation of the relevant parameters.

For our case study country, a statistical model is not possible as sufficiently long-term historical time series are not available to determine and discriminate the influence of the different driving factors. Therefore, a mechanistic approach is needed. The available Dutch housing typology covers the whole country and comprises 18 dwelling types by year of construction, size, and insulation standard of the main dwelling components. It does not allow for an application of a data demanding model (MD) that normally requires parameters like the exact location of windows and doors to model the energy demand of a specific building. However, using the heat flux components as defined in the national building standards for the modeling of the monthly heating energy demand of dwellings together with regional population and climate data, the available housing typology allows for the establishment of an intermediate complexity model (MI) with a monthly (m) and local/regional (L) resolution for the residential sector. By using the monthly resolution, we consider possible non-linear effects which would be masked by an annual time resolution. The data situation enables us to consider temperature projections, population trends, and future renovation measures on a regional level. Our study simulates for the first time the combined effect of these factors on the monthly space heating energy demand of the housing stock of each Dutch province.

Belzer et al. [21] and Yu et al. [23] who did similarly comprehensive studies (Table 1), only analyze the heating energy demand on an annual level. There are some studies for the Netherlands that deal with energy use in the building stock which are discussed in Section 4. Only one of these Dutch studies took future changes in climate and the housing stock into consideration. We limit the analysis to the calculation of the useful heating energy demand which is defined as the energy that a heating system must theoretically supply to a building. This useful heating energy demand does not say anything about how efficient this demand is supplied. Moreover, as cooling has only a share of 6% in the energy consumption of the Netherlands at the moment, we focus on the calculation of the future heating energy demand.

National targets of the Dutch government aim to achieve an energy neutral building stock in 2050 [24] which is somewhat more ambitious than the EU target of 80% reduction in energy consumption of buildings by that same year [25]. By 2030, the energy consumption of the Dutch building sector should be reduced by half when compared to 1990 [26]. For two reasonable future scenarios, we calculate whether it is possible to decrease the heating energy demand of the Dutch housing stock to these two aspired levels and give recommendations regarding the required annual renovation rate per province in order to achieve these goals. Furthermore, we are able to determine which influencing factor – population development, temperature changes or annual renovation rate – has the strongest effect on the future heating energy demand which might be policy relevant.

In Section 2, we introduce the used housing stock data and the method to determine its quantitative (number of dwellings) and qualitative (renovation measures) change over time. Moreover, we present the equations used to calculate the heating energy demand of dwellings. The results are described in Section 3. The discussion in Section 4 is followed by a conclusion and an outlook in Section 5.

2. Data and methods

The Netherlands are characterized by some differences regarding the share of different dwelling types per province, the future population development on a regional level and the projected change of the outdoor temperature (Table 2, Table A & B in the appendix). While this future temperature is varied per province and per month, the mean amount of energy of incoming sun rays [in W/m^2] was assumed to be constant over time. There are about 7.2 million dwellings in the Netherlands of which roughly 26% are situated in freestanding and semi-detached houses and about 40% in row houses [27].