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Decomposition analysis of district heating system based on complemented Kaya identity

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Abstract

The paper analyses possibilities for CO_2 emission reduction into the centralized district heating system by using the index decomposition analysis: Kaya identity equation. The classical Kaya equation is complemented with an energy efficiency indicator of a district heating system. The paper focuses on the impact of the Kaya equation components on the CO_2 emission reduction. The elaborated methodology is tested in order to analyze possibilities for CO_2 emission reduction at district heating systems in Latvia. 3 scenarios were formed for the forecast of the CO_2 emission reduction. In case the current model for the state development is continued (scenario1) CO_2 emissions will be reduced for 13%; however, in the scenario of orderly and balanced DH systems they will reduce for 29% by 2020 as compared to 2012.

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Keywords: district heating, decomposition analysis, Kaya identity, renewable energy, energy efficiency

1. Introduction

In many states of the European Union (EU), the district heating (DH) system plays an important role into solving of the problems caused by the climate change [1]. The DH system of the new generation (4th Generation District heating -4GDH) is based on the renewable sources of energy and energy efficient systems, thus reducing substantially the greenhouse gas (GHG) emissions [2]. This is one of the aims of the energy and climate package for all EU states [3]. It is of special importance for those states, into which the ratio of the DH systems into the heat supply is high; for instance, in Latvia it reaches 85% of the total fuel consumed by the transformation sector [4]. Over the last years, the ratio of renewable energy sources into the total fuel balance has raised (Fig.1). Back in 2002 the proportion of the renewable sources was only 9.8%, but in 2013 it was already 24.3%.

Nomenclature

C	amount of CO_2 emissions, tCO_2/year
HC	DH heat consumption, MWh/year
PF	consumption of primary energy by DH, MWh/year
Y	gross domestic product (GDP), EUR/year

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P	number of inhabitants connected to the DH system

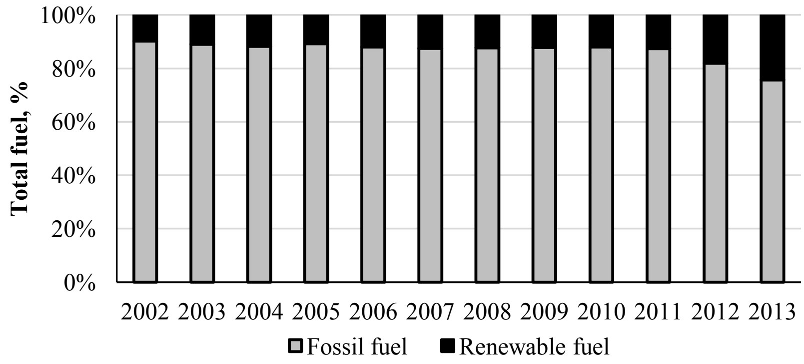

Fig. 1. Share of fuels in DH

Therefore in many Nordic countries the trends for development and possibilities of this sector will possess significant role into the GHG emission reduction.

The paper analyses the DH system development scenarios from the perspective of GHG emission reduction. Kaya Identity equation is used to analyze the different components and to determine the ones with the most significant impact on the GHG emissions. Each component is affected by different independent factors. This research determines the impact of the factors, which further could be integrated into DH enterprise and governmental policy aiming at GHG emission reduction.

2. Methodology

Index decomposition is a Kaya identity equation based method known in literature [5, 6] for analysis of the CO_2 emission dynamics [7]. Centralized heat supply differs from those other sectors of national economy, which produce GHG emissions, with the fact that important role is played not only by the type of fuel [8], but also by the energy efficiency of the system [9,10]. In order to analyze the efficiency of the primary energy consumption, the Kaya identity equation was complemented with the efficiency component (PF/HC):

$$C = (C/PF)(PF/HC)(HC/Y)(Y/P)P \quad (1)$$

In general, into formula (1) those GHG emissions are summed up, which is produced when firing different types of fossil fuel [7].

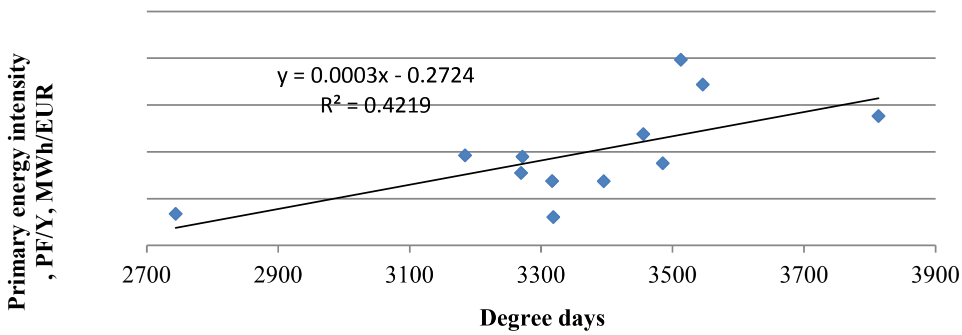

Fig.2. Dependency of primary energy consumption on the number of degree-days

The degree-days form an important index of primary energy intensity, which increase the intensity, when raising, and decrease it, when falling. Regression analysis performed on the historic data shows that the established connection has a low value of R^2 (Fig.2).

It means that it is impossible to form a statistically significant connection between the primary energy consumption and number of the degree-days. Wide data dispersion was also confirmed by the attempt to find with the help of the regression analysis the connections among other independent variables (CO_2 emissions versus GDP, primary energy consumption versus number of inhabitants, etc.). This especially highlights the significant role of the index decomposition method: analysis of CO_2 emissions by using the Kaya equation.

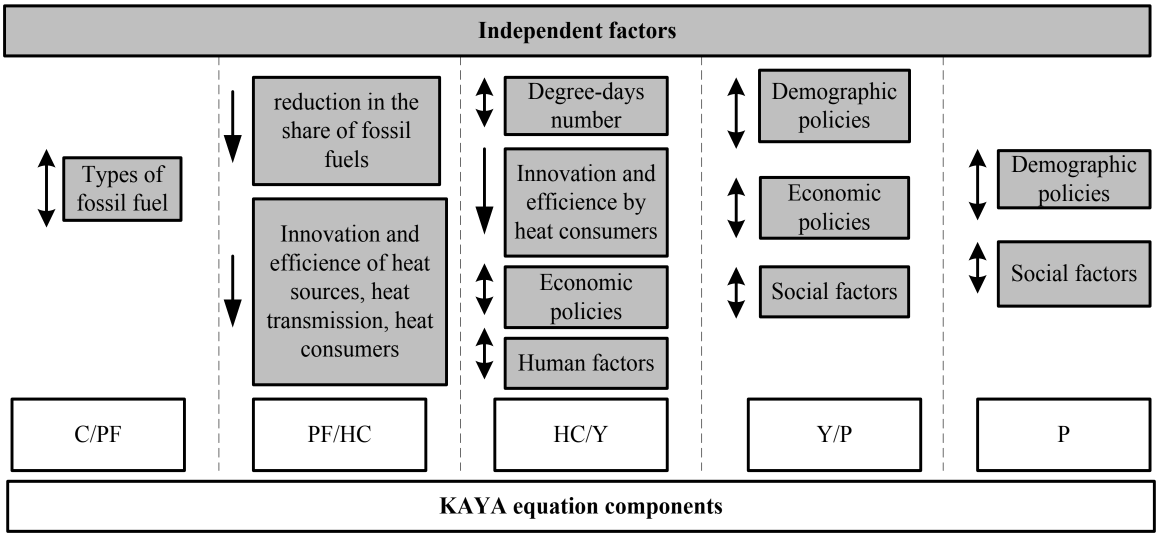

Fig.3. KAYA equations component analysis

The suggested methodology provide for identification of independent variables, alterations of which have impact on the changes of each Kaya equation component. Figure 3 shows, how factors can impact changes of Kaya equation components: they can both further the growth of CO_2 emissions, or reduction thereof. Everything depends on the dynamics of independent factors (increase or decrease).

Implementation of innovative technologies increase heat production efficiency, thereby decreasing amount of CO_2 emissions.

Economic policies have substantial effect on fossil fuel consumption. In case of increased price for fossil fuels DH enterprises are trying to reduce fossil fuel consumption or replace it with alternative energy sources. If price of fossil fuel decreases, in best case scenario fossil fuel consumption would stay at the same level, but most likely it would increase, thereby increasing amount of GHG emissions.

3. Testing of methodology

Within the paper, the complemented Kaya equation method is tested on the operational data of DH systems of Latvia.

The main focus is on the aforementioned factors – reduction of fossil fuel proportion, introduction of innovations, and performance of efficiency measures. Therefore, 3 development scenarios were selected in order to determine the amount of CO_2 emissions in 2020. Considering the impact of independent variables on the Kaya equation, two factors were used to select the development scenarios (Fig. 4.).

Based on tendency reflected into the Figure 1, three hypotheses were set forth, that by 2020, as compared to 2012: consumption of renewable sources and alteration dynamics of heating system energy efficiency remains at the current level (scenario 1); their proportion is raised by 5% and, owing to the tendency to increase the energy efficiency of the DH systems, the total fuel consumption is reduced by 10% (scenario 2); and optimistically the proportion of renewable sources is raised by 10%, and total fuel consumption would be reduced by 15% (scenario 3).

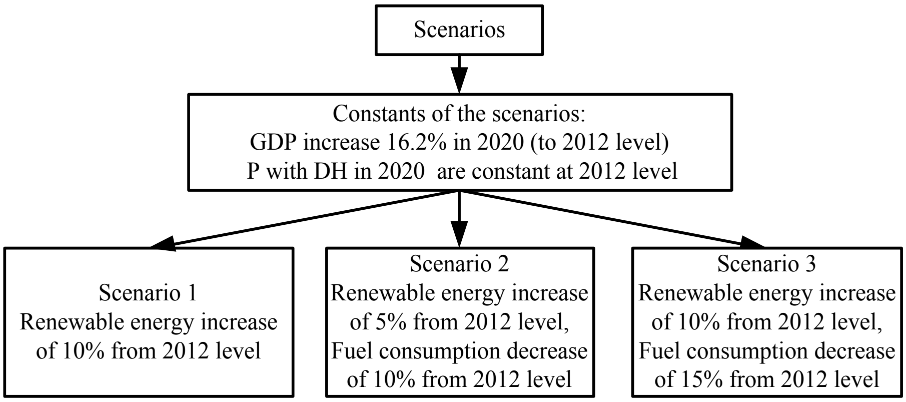

Fig. 4. Scenarios of CO_2 emissions of Latvian DH

The historic input data (2002-2012) required for the scenarios were obtained from the Central Statistical Bureau of Latvia [4]. Also the necessary data on forecasts until 2020 were obtained there [4]. The number of inhabitants in Latvia has a negative tendency, but considering the fact that multi-apartment buildings constitute the main part of DH system clients, in all scenarios it was assumed, that number of inhabitant using the centralized heat supply remains unchanged.

4. Results

In the article the dynamics of alterations in Kaya equation components were compared. All data were applied to the beginning of the research period – the year 2002, which does in fact illustrate the intensity of the changes into these components. Results are summarized into Figure 5.

One of the Kaya equation components is the emission factor (C/PF). During the last years, the total emission factor of fossil fuel has reduced minimally in the DH systems of Latvia: for 6% (see Figure 5). Substantial changes are experienced by the energy intensity factor (HC/Y) which decreased by 40% till 2013. It is very important that over the last years the intensity of primary energy consumption (PF/HC) falls. It represents an increased energy efficiency (HC/PF).

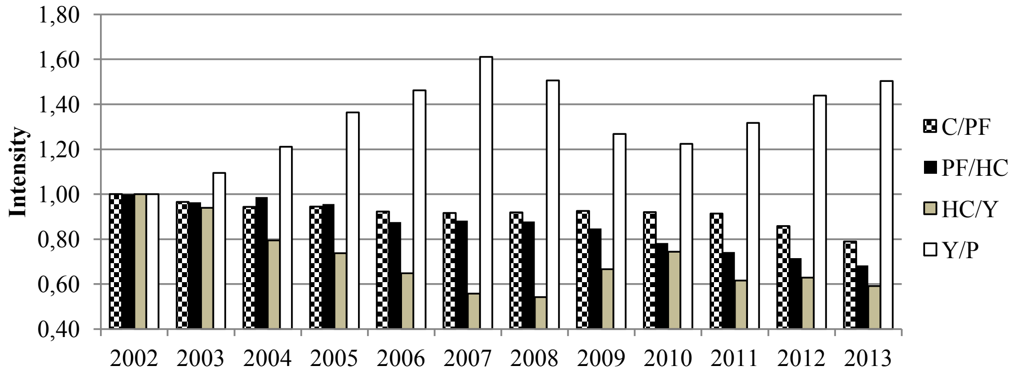

Fig. 5. Intensity of alterations into Kaya equation components

Owing to the fact that Kaya equation was complemented with the formula (1), to which the energy efficiency component (PF/HC) is added, it is possible to analyze the impact on CO_2 emissions by the renewable sources of energy and efficiency of heat production, transmission, and consumption. Over the last years, production of heat from renewable sources of energy has increased, and therefore the consumption of primary fossil fuel has. The intensity of affluence (Y/P) has a growing tendency in Latvia (Fig. 5.), because the GDP level grows.

Based on the said assumptions (Fig. 4.), CO2 emission modeling for the year 2020 was performed (Fig. 6). According to the forecasts of the Central Statistical Bureau of Latvia [4] until 2020 the GDP will raise for 16.2%. At the unchanged conditions and volumes of DH production, until 2020 the total amount of CO2 emissions will reduce by 13% (scenario 1).

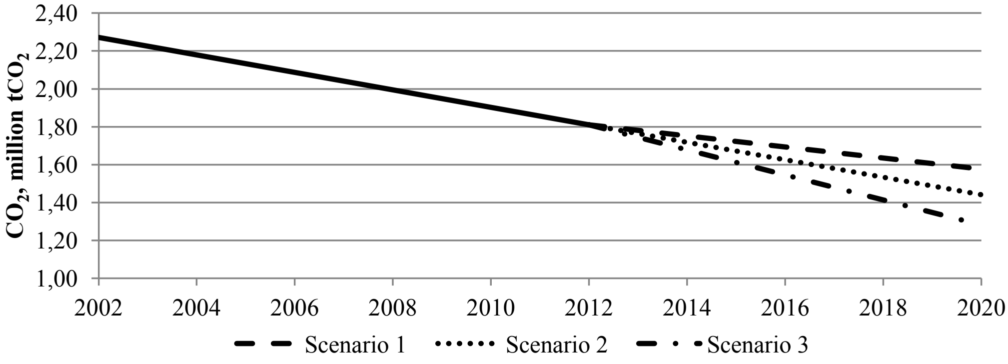

Fig. 6. Scenarios of CO_2 emissions

Increase of renewable sources by 5%, and reduction of fuel consumption for 10% permits to reduce CO_2 emissions for 20% until 2020, as compared to 2012.

Under the optimistic scenario, the increase of renewable sources will constitute 10%, but reduction of fuel consumption – 15% (scenario 3). In total, this will allow to decrease the CO_2 emissions by 29% until 2020, as compared to 2012.

5. Conclusions

In the paper, CO_2 emissions were analyzes with the index decomposition analysis: Kaya equation, which was complemented with the efficiency component of the primary energy consumption (PF/HC), which is the specific consumption of primary energy sources on the unit of the consumed heat power, and is inversely proportional to the usefulness ratio of the system. Methodology is tested on the heat supply system of Latvia: several factors affecting CO_2 emission changes, are determined and analyzed. Analysis of separate factors of Kaya equation show that two of Kaya equation factors (energy efficiency and reduction of fossil fuel proportion into the total consumption of primary energy sources) may change only to the direction of GHG emission reduction, but alterations of other analyzed factors may both increase and decrease the total amount of CO_2 emissions. The sharp increase into the fossil fuel prices over the last years has furthered the shift of the DH system to the renewable sources.

3 possible scenarios for GHG emission reduction are formed into the paper. The largest CO_2 emission reduction may be obtained under scenario 3. In case this optimistic scenario is implemented, CO_2 emissions will decrease by 29% until 2020, as compared to 2012. Smaller decrease, which would not exceed 13%, may be achieved, in case DH system operators will continue at the current pace to substitute fossil fuel with the renewable sources of energy, and will perform energy efficiency measures at all stages of the heat supply – heat source, heat lines, storage, and at the consumer.

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Biography

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