

Article

Coal or Biomass? Case Study of Consumption Behaviour of Households in the Czech Republic

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Abstract: Renewable sources play a crucial role in the decarbonisation process of the current linear economy, aimed at reaching the 2030 climate objectives and fulfilling the EU's long-term strategy of achieving carbon neutrality by 2050. All economic subjects, including households, can contribute to the Green Deal goals. The main goal of this paper is to evaluate households' consumption of energy sources for heating purposes in the Czech Republic in the period 2003–2020 and depict possible drivers of switching to biomass. For this, various data were collected, such as data published by the Czech Statistical Office, ministries, and other national authorities, as well as data from Eurostat. Concerning methods, data analysis, correlation analysis, and regression analysis were used. Different models focus on the substitution effect, rebound effect, and behaviour of different kinds of households. The results show a substitution effect connected with the consumption of coal, electricity, and biomass for heating purposes. Many households substituted coal for biomass in the observed period. On the other hand, the environmental impact of such substitution is not significant, as carbon emissions and emissions of other pollutants are stable. The substitution of fuels should be accompanied by technological change, e.g., improvement of combustion boilers. Moreover, households of pensioners are the key economic subjects with the highest impact on biomass consumption for heating purposes. Against this background we recommend policies to support households in replacing their boilers for more environmentally friendly ones.

Keywords: biofuels; bioeconomy; fossil fuels; energy consumption behaviour; households; substitution; Czech Republic



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1. Introduction

The concentration of atmospheric carbon dioxide has steadily been increasing since the beginning of the pre-industrial era. It is unequivocal that atmospheric carbon dioxide concentrations and global surface temperature are strongly coupled [1]. Global warming has resulted in an increased frequency, intensity, and duration of extreme weather events, such as heat-related events and droughts [2]. Human activities have rapidly changed the climate system in recent decades. Human-induced climate change already causes modifications across an enormous number of climate system components [3]. Simultaneously, anthropogenic sources of greenhouse gases such as the current fossil-based economic regime and linear flows of materials and energy, contribute to accelerating and intensifying the ongoing climate change [4].

In an effort to reverse the above-mentioned trend, a number of initiatives have been set up to decarbonise economies around the world. Generally, to frame climate-neutral policies and agendas, the carbon budget [5], which is defined as the cumulative amount of carbon dioxide emissions allowed to keep within a temperature target, is adhered

to. In 2015 sustainable development goals [6] were developed to ensure prosperity for people and the planet. The Paris Agreement [7] was drawn up to reduce greenhouse gas emissions and limit the global temperature rise. Subsequently, the European Green Deal was created to meet the challenges of climate change. The European Union's vision is a climate-neutral European economy by 2050 [8]. The transformation process requires rethinking policies for clean energy, industry, production and consumption, large-scale infrastructure, transport, etc. Regarding [8], more than 75 per cent of European greenhouse-gas emissions originate from the production and use of energy across the economy. There is a need to prioritise energy efficiency and decarbonise the energy sector. The legal target of achieving climate neutrality by 2050 is further set out in the European Climate Law [9]. The Fit for 55 package [10] defines milestones with the ambition to reduce greenhouse gas emissions by 55 per cent by 2030. Regarding forestry and wood biomass, a recent legislation revision contains various directions, such as increasing the adaptability of forests and the natural restoration of forests, as well as financially supporting sustainable forest management across European economies. The New EU Forest Strategy for 2030 [11] can be considered as part of the package and calls for the principle of cascading use of biomass and financial support for forest owners and rural areas. The sustainable economy policy package is complemented by the EU Bioeconomy Strategy [12] and the New EU Circular Economy Action Plan [13]. Altogether, bioeconomy is a bridge between the above-mentioned concepts, and it seems to be an area with an enormous ability to resolve a set of global challenges. The synergistic effect of the different concepts then provides an opportunity to transform economies more effectively. For example, the most common links can be observed in fields such as innovations, the principle of cascading use of materials, and change in business practices [14].

Circular economy and bioeconomy hold a crucial position in the transformation towards a more sustainable economy that respects both the social and ecological aspects of society. Bioeconomy, as a renewable segment of circular economy, includes forestry as one of its priorities. Bioeconomy can generate significant carbon savings in the form of carbon sequestration in soil, forests, and wood products, and also by replacing fossil and non-renewable resources with biomass. Several definitions of bioeconomy can be found in the literature [15–17]. Bioeconomy consists of traditional sectors, such as agriculture, forestry, aquaculture, and the production of paper and wood-related goods. On the other hand, innovative sectors emerged, especially bioenergy, biofuels, biochemicals, etc. The updated EU Bioeconomy Strategy [12] tries to achieve sustainable management of natural resources; reduce dependence on non-renewable, unsustainable resources; mitigate and adapt to climate change; and create new jobs. Bioeconomy strategies and policies at the national level are available in Germany [18] (p. 60), Finland [19] (p. 24), Sweden [20] (p. 26), Italy, [21] or the Netherlands [22].

Forestry bioeconomy is a necessary element of climate-neutral transformation. Forests represent essential carbon sinks and provide the largest source of renewable biomass. However, human conduct related to biomass production and its subsequent use for bioenergy purposes can introduce additional benefits as well as conflicting side effects and risks in several areas, such as land degradation, food insecurity, or greenhouse gas emissions [23]. In this sense, cleaner energy sources and technologies can propel adaptation while mitigating the climate-change impact, and boost the range of energy supplies as well as socio-economic and health benefits. A study by [24] points out that climate change can lead to divergent climatic scenarios in the world's major forest areas. The authors of [25] examined the global supply and demand for biomass and biomass energy. For forestry bioeconomy, the most critical challenges lie in innovative forest-resource management which simultaneously escalates wood and non-wood production [26]. Scientific literature by [27] summarised types of innovations in forest-based bioeconomy, for example the development of production methods, innovations in goods and services, and innovations in later stages of development.

Enormous quantities of agricultural biomass can be transformed into biofuels [28]. Nonetheless, aspects such as damage to the environment, and competing applications for agricultural biomass require exploration regarding their effects on soil and biofuel conservation. Application of the principle of conversion of agricultural biomass waste into biochar can offer huge benefits to the environment and restore carbon deposits in soil [29].

Regarding energy from agricultural biomass, low-quality biomass coming from the production of food, feed and/or fibre, is the most promising area [30]. Simultaneously, organic agriculture seems to be a sustainable practice to avert negative consequences on the environment caused by the activities of conventional agriculture [31]. Energy production from biomass coupled with wind power and solar plants may represent a promising combination for moving away from fossil fuels. The authors of ref. [32] proposed how agriculture can assist in bioenergy production and identified the optimal land use solutions between farmers' income and biomass energy production. To achieve circular bioeconomy targets, there should be sufficient biomass of adequate quality to ensure food security of the growing population as well as the production of bioenergy [33].

Generally, there is pristine biomass waste originating from industry, agriculture and forestry, that represents an enormous possibility for the production of liquid biofuel, electric energy, and heat energy [34]. For example, ref. [35] provided results of potential for developing biomass heating systems based on agriculture and forestry biomass.

Generally, the Czech Republic is classified as a non-specialised bioeconomy [36]. In the Czech Republic, the first strategic framework for circular economy [37] (p. 160) has been approved with a necessary role of bioeconomy within the circular economy model. By 2040, the Czech Republic will rely primarily on the use of waste for energy purposes and the use of wood as a renewable raw material. Ultimately, there will be an attempt to ensure the sustainable production of biomass for materials, energy, and fuels. The Concept of State Forestry Policy until 2035 [38] (p. 32) deals with increasing biodiversity and ecological stability of forest ecosystems while maintaining industrial production in the face of ongoing climate change. The long-term goal is to develop sustainable forest management and financially support owners to manage forests sustainably. For example, ref. [39] analysed the present direction of bioeconomy in the Czech Republic. Regarding [40], opportunities for sustainable forest biomass and high-added-value products opened up in the forestry market in the Czech Republic. In addition, health conditions in traditional economic sectors such as forestry, agriculture, and food industries seem to be necessary for the development of a circular economy [39]. Currently, the bark beetle calamity [41] has affected forestry bioeconomy in the Czech Republic. Both ecological and economic impacts are noticeable. From an ecological perspective, Czech forests became a source of carbon dioxide emissions for the first time in 2018 [42]. According to the imports and exports of the Czech Republic [43] (p. 47), exports of raw timber have been on the rise and in 2019 reached a value of more than 19 billion CZK (800 million USD) with a total volume of around 16.4 million cubic meters. The main elements were spruce timber and pulpwood. Moreover, 81.5 per cent of total Czech exports flowed to the EU-28, with the highest shares going to Austria (38.8 per cent), Germany (21 per cent), Slovakia (7.1 per cent), and Poland (5.7 per cent). A report by [43] noted extreme timber harvesting, a drastic drop in the wood price, and hectares of recently planted mixed forests.

With the energy sector in the spotlight, renewable sources play a central role in the process of decarbonising the current linear economy. Energy efficiency and renewable energies have great potential for economic development in Europe's regions by boosting energy security, creating jobs, and increasing regional autonomy, as well as helping to fight climate change [44]. The European Union has contributed greatly to the growth of these sectors in Europe, with the Europe 20/20/20 targets setting the mid-term policy framework, and a variety of programmes and tools providing funding and support for regional development.

Regarding scientific studies, we discovered mainly studies analysing and evaluating public policies and public support of renewable energy sources and their success in Europe as a whole [45,46] or in selected federal states of the USA [47,48]; however, most of those studies are based on national case studies evaluating domestic economic instruments and on state public policies supporting renewable energy sources, for example in Romania [49], Lithuania [50], Spain [51], or China [52].

In the coming years, energy production will require an increasing volume of biomass. According to [53], woody biomass residues, agricultural biomass, and purpose-grown biomass crops will be increasingly utilised for energy production. Other than that, biomass waste played a crucial role in emphasizing the importance of biorefinery processes within circular bioeconomy [54]. Moreover, charcoal is agreeably a sustainable biofuel and a substantial product of forestry bioeconomy [55]. A few national-level cases can be studied, e.g., [56] who carried out an analysis of regional charcoal production in Sub-Saharan Africa. In addition, a study by [57] offers an analysis of the utilisation of renewable energy sources, focusing on biomass. A paper by [58] offers the depiction of several transformation scenarios in Austria towards a low-carbon bioeconomy, integrating the energy sector, biomass flows, and land use.

The behaviour of households is central for powering the structural changes in the energy market, as this sector remains responsible for a considerable portion of the consumption of fuels for heating purposes. The behaviour of households in the area of making choices considering fuels used for heating, is the focus of the present research.

The motivation to undertake this effort stems from the following reasons:

- (1) Non-existent written knowledge of the problem: during our review of scientific research publications in the form of peer-reviewed journals, research studies, and research papers, it became apparent that, so far, no author confronted the problem. The four parameters of our research (fuel consumption issues, household segments, regional localisation, and behavioural aspects) are not analysed together in any research paper. At least two of the parameters are always missing;
- (2) Economic relevance and urgency of the issue addressed.

The main goal of this paper is to evaluate households' consumption of energy sources for heating purposes in the Czech Republic in the period 2003–2020 and depict possible drivers of switching from solid fossil fuels to biomass.

The following research questions underline the main goal:

RQ1 Focusing on households' consumption of fuels for heating purposes in the Czech Republic in 2003–2020, is there a substitution effect of coal for biomass?

RQ2 Can a rebound effect be observed in this period?

RQ3 Is the consumption behaviour of various households similar or different during the observed period?

2. Materials and Methods

2.1. Materials

For the period 2003–2020, we collected detailed data connected with the consumption of households (consumption of solid fuels, such as biomass, brown coal, black coal, coke, and brown coal briquettes); energy prices (price of coal, wood, electricity, and natural gas); general socio-economic indicators (GDP, wages, environmental investments); and data concerning consumption of different kinds of households (households of employees, self-employed and pensioners). Various data sources were used, mainly from the Eurostat database [59], the Ministry of Industry and Trade [60,61], the Czech Statistical Office [62], the Czech press monitoring agency [63] and the IEA [64].

Table 1 shows an overview of all data/variables used for correlation and/or regression analyses presented in this paper, including abbreviations, units, and the roles of the variables.

Table 1. List of variables.

Variable	Abbrev.	Units	Role
Consumption of households: biomass	BIO	GJ	Dependent
Biomass in press, media	BPRES	Number of yearly mentions in newspapers, TV, web	Independent
Coal price	PRCO	Current prices, CZK per tonne	Independent
Wood price	PRWO	Current prices, CZK per m ³	Independent
Electricity price	PREL	Current prices, CZK per MWh	Independent
Natural gas price	PRNG	Current prices, CZK per MWh	Independent
Consumption of households: black coal	COBL	Thousand tonnes	Independent
Consumption of households: brown coal	COBR	Thousand tonnes	Independent
Consumption of households: coke	COCO	Thousand tonnes	Independent
Consumption of households: brown coal briquettes	COBRI	Thousand tonnes	Independent
Gross domestic product	GDP	Current prices, million EUR	Independent
Wage	WAGE	Current prices, million EUR	Independent
Environmental investments	INV	Current prices, mil. CZK	Independent
Net money expenditure of households for solid fuels: households of employees	HEMP	Annual average per capita in CZK	Independent
Net money expenditure of households for solid fuels: households of self-employed	HSELF	Annual average per capita in CZK	Independent
Net money expenditure of households for solid fuels: households of pensioners	HPEN	Annual average per capita in CZK	Independent
Time	TIME	Years	Independent

Source: authors.

The key dependent variable was “BIO”, i.e., biomass-consumption of households, in total, in GJ. Regarding independent variables, they were chosen based on their expected influence on consumption of households. Keeping our research questions in mind, independent variables are represented by characteristics of substitutes of biomass, such as coal, coke, coal briquettes, electricity, and natural gas. For the analysis, price and consumption indicators were used. Regarding price, we expected a positive impact of an increase in price of substitutes on consumption of biomass (see Table 2). In case of consumption of substitutes (coal and related coal products), we expected a negative impact on consumption of biomass. These assumptions are based on economic theories, described for example in [65]. Concerning the impact of socio-economic indicators, the impact of an increase in GDP, wage, and environmental investments on consumption of biomass is not clear. This assumption is based on [66]. Focusing on behaviour of different kinds of households, including households of pensioners, net money expenditure for solid fuels is observed. The expected impact on consumption of biomass is not clear. Time represents the control variable, based on the statistics the expected impact is positive (consumption of biomass for heating purposes increased in the selected period).

The following Table 3 summarizes parameters of the variables described in Table 1. For each variable, minimum and maximum values, standard deviation, and median are indicated.

Table 2. Expected impact of variables.

Variable	Abbrev.	Expected Impact
Biomass in press, media	BPRES	Positive
Coal price	PRCO	Positive
Wood price	PRWO	Negative
Electricity price	PREL	Positive
Natural gas price	PRNG	Positive
Consumption of households: black coal	COBL	Negative
Consumption of households: brown coal	COBR	Negative
Consumption of households: coke	COCO	Negative
Consumption of households: brown coal briquettes	COBRI	Negative
Gross domestic product	GDP	Not clear
Wage	WAGE	Not clear
Environmental investments	INV	Not clear
Net money expenditure of households for solid fuels: households of employees	HEMP	Not clear
Net money expenditure of households for solid fuels: households of self-employed	HSELF	Not clear
Net money expenditure of households for solid fuels: households of pensioners	HPEN	Not clear
Time	TIME	Positive

Source: authors.

Table 3. Overview of the data statistics.

Variable	Minimum	Maximum	Standard Deviation	Median
BIO	35,214,844	64,636,619	9,243,844.28	49,852,116
BPRES	830	6474	1396.66	3739.5
PRCO	1695	3925	741.49	3331
PRWO	828	1687.61	313.67	1393.82
PREL	2380	4740	674.57	3728
PRNG	779	1712.1	314.93	1492.25
COBL	222	358	51.65	317
COBR	1123	1811	235.26	1488
COCO	19	37	5.25	32
COBRI	120	196	22.46	148
GDP	88,659.5	225,568.7	38,294.40	160,763
WAGE	16,905	36,180	5510.81	24,758.5
INV	3559	17,832	3901.50	5362
HEMP	294	1667	411.85	614
HSELF	302	1982	472.54	551
HPEN	515	2569	554.02	1009

Source: authors.

2.2. Methods

The main goal of this paper is to evaluate households' consumption of energy sources for heating purposes in the Czech Republic in the period 2003–2020 and depict possible drivers of switching to biomass. To achieve the main goal, the following research questions are discussed:

RQ1 Focusing on households' consumption of fuels for heating purposes in the Czech Republic in 2003–2020, is there a substitution effect of coal for biomass?

RQ2 Can a rebound effect be observed in this period?

RQ3 Is the consumption behaviour of various households similar or different during the observed period?

To achieve the goals of the research, the authors used the following methods: literature review, data analysis, correlation analysis, and regression analysis. Correlation analysis (Pearson's correlation coefficient) and regression analysis were carried out based on the

data described above (Tables 1 and 3). The authors used linear regression models which calculate the relation between dependent variable and all other variables.

The general regression equation of MOD is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots \dots \dots \beta_n X_n + u \quad (1)$$

where:

Y—BIO (biomass-consumption of households for heating purposes, in total, in GJ); β_0 to β_n —regression coefficients that reflect the impact of the independent variable on the dependent variable; u —random element of the model.

With respect to our research questions, we created and tested the following models:

- (1) Substitution model;
- (2) Price model;
- (3) Households model.

Substitution model (1) represents the relationship between biomass consumption for heating purposes (Y—BIO) and its substitutes: brown coal, black coal, coke, and brown coal briquettes. The regression equation of such model is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + u \quad (2)$$

where:

Y—BIO (biomass-consumption of households for heating purposes, in total, in GJ); X_1 —CBL (consumption of households, black coal); X_2 —CBR (consumption of households, brown coal); X_3 —COCO (consumption of households, coke); X_4 —COBRI (consumption of households, brown coal briquettes); u —random element of the model.

Price model (2) represents the relationship between biomass consumption for heating purposes (Y—BIO) and prices of energy sources, such as coal, wood, electricity, and natural gas. The regression equation of such model is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + u \quad (3)$$

where:

Y—BIO (biomass-consumption of households for heating purposes, in total, in GJ); X_1 —PRCO (price of coal for households); X_2 —PRWO (price of wood for households); X_3 —PREL (price of electricity for households); X_4 —PRNG (price of natural gas for households).

Households model (3) represents the relationship between biomass consumption for heating purposes (Y—BIO) and expenditures of various kinds of households, such as households of employees, self-employed, and pensioners. The regression equation of such model is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + u \quad (4)$$

where:

Y—BIO (biomass-consumption of households for heating purposes, in total, in GJ); X_1 —HEMP (expenditures of households of employees); X_2 —HSELF (expenditures of households of self-employed); X_3 —HPEN (expenditures of households of pensioners).

3. Results

3.1. Correlation Analysis

For correlation analysis, all selected variables which can influence the consumption of biomass by households for heating purposes were used. These variables are described in the above chapter, Tables 1–3, in more detail. The following Table 4 shows the results of the correlation analysis.

Table 4. Correlation analysis.

	BIO	BPRES	COBL	COBR	COCO	COBRI	PRCO	PRWO	PREL	PRNG	HEMP	HSELF	HPEN	GDP	WAGE	INV	TIME
BIO	1																
BPRES	0.504	1															
COBL	−0.297	−0.678	1														
COBR	−0.925	−0.423	0.249	1													
COCO	−0.889	−0.598	0.610	0.798	1												
COBRI	−0.075	0.481	−0.163	0.072	0.070	1											
PRCO	0.923	0.685	−0.536	−0.823	−0.910	0.187	1										
PRWO	−0.202	−0.862	0.687	0.532	0.662	−0.629	−0.49	1									
PREL	0.946	0.622	−0.513	−0.613	−0.913	0.038	0.959	−0.412	1								
PRNG	0.884	0.510	0.318	−0.205	−0.326	−0.601	0.926	0.526	0.918	1							
HEMP	0.821	0.416	−0.430	−0.716	−0.779	0.347	0.686	−0.529	0.738	0.518	1						
HSELF	0.587	0.369	−0.151	−0.430	−0.398	0.413	0.488	−0.324	0.462	0.352	0.842	1					
HPEN	0.867	0.441	−0.540	−0.746	−0.904	0.268	0.744	−0.594	0.842	0.593	0.953	0.664	1				
GDP	0.944	0.676	−0.396	−0.839	−0.819	0.211	0.932	−0.451	0.911	0.822	0.862	0.692	0.868	1			
WAGE	0.974	0.569	−0.413	−0.905	−0.896	0.112	0.893	−0.453	0.918	0.790	0.904	0.652	0.937	0.969	1		
INV	0.664	0.101	0.294	−0.455	−0.165	−0.278	0.502	0.309	0.465	0.522	0.557	0.550	0.467	0.582	0.615	1	
TIME	0.995	0.496	−0.187	−0.919	−0.809	−0.100	0.911	−0.146	0.922	0.870	0.822	0.603	0.851	0.949	0.973	0.709	1

Source: authors.

Based on the results of the correlation analysis, we can observe statistically significant negative correlations between BIO (consumption of biomass for heating purposes), COBR (consumption of households: brown coal) and COCO (consumption of households: coke). There are also negative correlations in the cases of COBL (consumption of households: black coal), COBRI (consumption of households: brown coal briquettes), and PRWO (wood price). However, their statistical significance is lower.

Concerning statistically significant positive correlations, these are visible in the case of PRCO (coal price), PREL (electricity price), PRNG (natural gas price), HEMP (expenditure of households of employees), HPEN (expenditure of households of pensioners), and the control variables GDP, WAGE, and TIME. In addition to these relationships, there are other positive correlations with lower statistical significance, such as BPRES (biomass in press), HSELF (expenditure of households of self-employed), and INV (environmental investments).

3.2. Substitution Effect

For analysis of the substitution effect, the following models consider consumption of various kinds of fuels and price of fuels (substitutes).

First, consumption of fossil solid fuels in relation to consumption of biomass is observed, using regression model 1, the substitution model. First, we tested the model containing consumption of all possible substitutes (solid fuels), such as black coal, brown coal, coke, and briquettes. Following that, we tested various models in order to find the most statistically significant model with a high index of determination.

The results are presented in the following Table 5.

Table 5. Regression analysis—substitution model.

	MOD1: All Solid Fuels		MOD2: Brown Coal, Coke	
	Sig.	Coef.	Sig.	Coef.
COBL	0.484	5342.464	X	
COBR	0.641	−1151.827	0.007	−13,837.273
COCO	0.029	−346,580.756	0.037	−432,222.380
COBRI	0.512	6865.428	X	
TIME	0.002	1,122,662.741	X	
Constant	0.003	−2,197,297,191	0.000	89,031,063.08
Observ.	11		11	
R2	0.996		0.959	
Signif. F	0.000		0.000	
Durbin–Watson test	x		1.595	

Source: authors.

MOD 1 consists of all independent variables (COBL, COBR, COCO, COBRI, and TIME). The whole model is statistically significant (see significance F), but not all selected variables are statistically significant.

MOD2 represents selected variables with statistical significances of $p < 0.05$. This model is the statistically significant model—all variables are statistically significant and the whole model is also statistically significant. The results from Table 5 illustrate that both presented models have a high coefficient of determination, which means that in the case of MOD2, the general formula that is specified explains almost 96% of the variance with less than 5% of random deviations. Variables with a p -value of below 5% are COBR, COCO, and the constant. According to the outcomes of the overall F-test, the estimated regression model of substitution is statistically significant at 1% level of significance. The result of

Durbin–Watson test (DW) is also acceptable (1.595). This value expresses that MOD2 shows no autocorrelation.

Based on the results presented in Table 5, there is a statistically significant negative relationship between consumption of biomass and consumption of both brown coal and coke. We can write the following regression equation:

$$Y = 89031063.08 - 13837.273 \text{ COBR} - 432222.380 \text{ COCO} + u$$

Secondly, the relationship between prices of substitutes and consumption of biomass is observed. For this, we used regression model 2, the price model. Analogous to the substitution model, we tested the more general model and then the specific ones. First, we tested the model containing prices of all possible substitutes, such as coal, electricity, and natural gas. Following that, we tested various models in order to find the most statistically significant model with a high coefficient of determination.

The results are presented in Table 6.

Table 6. Regression analysis—price model.

	MOD3: All Substitutes		MOD4: Electricity	
	Sig.	Coef.	Sig.	Coef.
PRCO	0.243	−1057.727	x	
PREL	0.002	3603.989	0.001	2661.194
PRNG	0.983	−30.929	x	
TIME	0.000	143,795.764	0.000	1,412,435.463
Constant	0.000	−2,852,741,070	0.000	−2,801,304,477
Observ.	18		18	
R2	0.998		0.997	
Signif. F	0.000		0.000	
Durbin–Watson test	x		1.214	

Source: authors.

MOD3 consists of all independent variables (PRCO, PREL, PRNG, and TIME). The whole model is statistically significant (see significance F), but not all selected variables are statistically significant.

MOD4 represents selected variables with statistical significances of $p < 0.01$. This model is the statistically significant model—all variables are statistically significant and the whole model is also statistically significant. The result of the F-test leads to the conclusion that the estimated regression model is statistically significant at the 1% level of significance. Variables with a p -value of below 5% are PREL, TIME and the constant. The values of the F-test are normal with a high coefficient of determination. The result of the Durbin–Watson test (DW) is also acceptable (1.214). Such value expresses that MOD4 shows no autocorrelation.

Based on the results presented in Table 6, there is a statistically significant positive relationship between consumption of biomass and price of electricity, and the influence of the time is also positive. We can write the following regression equation:

$$Y = -2801304477 + 2661.194 \text{ PREL} + 1412435.463 \text{ TIME} + u$$

3.3. Rebound Effect

As Czech households substituted fossil solid fuels with biomass during the time period of 2010–2020 where disaggregated data is available, the level of total energetic throughput remained stable (with two peaks due to temperature lows), while total CO₂ emission production stemming from heating increased slightly, as woody biomass has been

reported to emit higher emission levels per unit of energy when compared to coal-related fuels during stationary combustion [67]. A slight rebound effect in a sense of increased emissions due to switching consumption patterns for biomass can hence be observed in Figure 1 which is further elaborated on in the discussion of the present research.

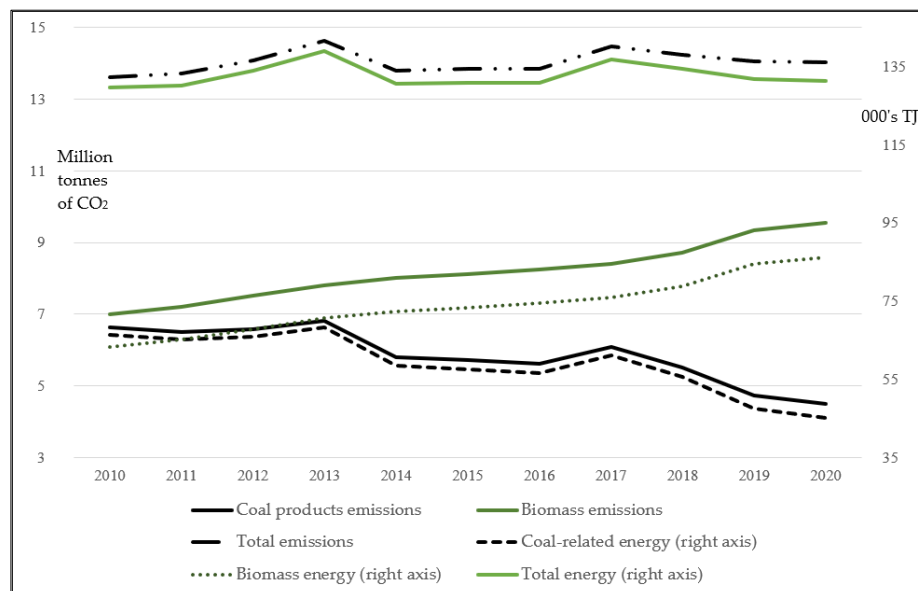


Figure 1. Emissions and energy obtained (various fuels, 2010–2020, Czech households). Source: authors' calculations based on the data reported in [60,61,67].

3.4. Households of Pensioners

Based on the correlation analysis, increase in biomass consumption should be connected with an increase in net expenditures of all kinds of households, specifically households of employed, self-employed, and pensioners. For this, we used regression model 3, the households model. Analogous to the models presented above, we first tested the general model containing expenditures of households of employees, households of self-employed, and households of pensioners. Following that, we tested various specific models for finding the most statistically significant model with a high determination index.

The results are presented in Table 7.

Table 7. Regression analysis—households model.

	MOD5: All Households		MOD6: Employees, Pensioners	
	Sig.	Coef.	Sig.	Coef.
HEMP	0.015	−11,055.544	0.040	−3753.124
HSELF	0.066	2785.798	x	
HPEN	0.005	7490.882	0.014	3790.121
TIME	0.000	1,620,956.064	0.000	1,634,380.265
Constant	0.000	−3,213,552,291	0.000	−3,239,872,214
Observ.	17		17	
R2	0.997		0.997	
Signif. F	0.000		0.000	
Durbin–Watson test	1.293		1.285	

Source: authors.

MOD5 consists of all independent variables (HEMP, HSELF, HPEN, and TIME). The whole model is statistically significant, but not all selected variables are statistically significant.

MOD6 represents selected variables with statistical significances of $p < 0.05$. This model is the statistically significant model—all variables are statistically significant and the whole model is also statistically significant. The results from Table 7 illustrate that both presented models have a high determination index, which means that in the case of MOD6, the general formula that is specified explains more than 99% of the variance with less than 1% of random deviations. Variables with a p -value of below 5% are HEMP, HPEN, TIME and the constant. According to the outcome of the overall F-test, the estimated regression model of substitution is statistically significant at the 1% level of significance. The result of the Durbin–Watson test (DW) is also acceptable (1.285). This value expresses that MOD6 shows no autocorrelation.

Based on the results presented in Table 7, there is a statistically significant positive relationship between consumption of biomass and both net expenditures of households of pensioners and time. We can observe simultaneous negative influence of net expenditures of employees on the consumption of biomass. The following regression equation can be written:

$$Y = -3239872214 - 3753.124 \text{ HEMP} + 3790.121 \text{ HPEN} + 1634380.265 \text{ TIME} + u$$

4. Discussion

Although the total energetic throughput of Czech households for heating purposes remained stable during the timeline studied herein, the composition of its sources changed considerably and such trend bears noteworthy implications.

Firstly, and perhaps most importantly, when households substituted solid fossil fuels for renewable sources of heating (biomass) in this scenario, they were making a choice oftentimes perceived as environmentally conscious. While a move in a sustainable direction certainly seems eco-friendly, as trees can be grown while coal is finite, the assumption does not hold when considering CO₂ emission levels. As depicted in Figure 1, the level of CO₂ emissions rose due to households behaving in this manner as the stationary combustion of woody biomass tends to be “dirtier” than that of any coal-related fossil fuel [59]. Hence, the forces which allured households into switching their consumption patterns in favour of biomass did not produce a Jevons paradox, as the motivation for substitution was not mainly powered by price advantageousness and the total throughput remained stable over time. A by-product of this transition, however, is a rebound effect of a type where “green” behaviour tends to have unforeseen negative consequences in the form of increased emissions. This situation provides opportunity for policy intervention in the form of support for more emission-effective boilers.

Secondly, this transition engenders another negative impact in the form of deforestation. According to [68], the Czech Republic experienced a net loss of 75 kilohectares of tree cover from 2000 to 2020 whereby over 98% of this change occurred due to forestry (the remainder was caused by urbanization and agriculture). The country is a major exporter of both cut and rough wood [43,69] and was a subject to a severe bark beetle calamity recently, but the switching patterns of (not only domestic) household consumption doubtlessly contribute to the forest loss. Every hectare of forest not planted back after being harvested produces the following missed opportunity concerning carbon capture: with trees planted approximately 2.5 m apart in order to allow thinning approximately 15 years thereafter, 1600 trees can be planted. According to the measures provided by [70], if trees are replanted and left to grow for 15 years, every hectare of conifer forest (the type of tree mostly harvested in the Czech Republic [62]) has a potential to capture 127 tonnes of CO₂ under a moderate scenario for sequestration. With proper care, bringing the survival rate to 85% from the initial 52%, the figure grows to 210 tonnes. Every kilohectare not replanted therefore creates a carbon-capture-deadweight loss of 210 300 tonnes of CO₂ not captured

in a 15-year horizon—an amount of yearly output of 22 100 Czech dwellers who had, according to the study by [71], a yearly output of 9.5 tonnes of CO₂ per capita on average during the last decade. Excessive logging proves to be a concern on a larger scale as well, given, e.g., that research by the European Commission shows a growing cleavage between being able to trace the origin of wood and the volume actually being put to use. An unenviable 118 million m³ of woody biomass were reported by [72] (p. 47) to be of unknown origin. Again, this situation serves as firm ground for targeting unintended (and likely negative) outcomes of the currently ongoing rush for renewables. Here again, a tighter control of loggers balancing the carbon cycle by replanting forest populations and harvesting in a way which actually enables effective replanting could be an area of concern for policymakers aiming to minimize societally negative impacts of the green transition. This recommendation applies to every country with an abundance of forest area.

Thirdly, one of the sub-objectives was to investigate possible motivations why households switch from solid fossil fuels to biomass. Based on the finding that retired households play a key role in this transition, it can be deduced that convenience and environmental perspective are the main reasons. In fact, in general, the behavioural change of pensioners can be seen as a manifestation of a desire to simplify operations or awareness [73–75].

In general, the following basic assumptions (motivations) for switching from solid fossil fuels to biomass can be identified:

- Price of substitutes—as shown in Table 6;
- Environmental awareness—since the rebound effect was not confirmed and pensioner households played a key role in the switch to biomass, the motivation to switch to biomass in the form of environmental awareness is crucial. Based on [73–77], it can be inferred that there is a very significant causality between environmental awareness and old age. This connection is highly underestimated and could play a significant role particularly in estimating potential motivations to switch to biomass (but at the same time this motivation is often accompanied by nescience of the context, see below);
- Convenience (handling biomass is physically lighter than handling fossil solid fuels)—as pensioner households have played a pivotal role in biomass switching, this is one possible motivation [78–81].

It is worth reflecting on whether nescience (in the sense of ignorance, lack of information, lack of awareness, or lack of promotion) is a concomitant of biomass switching. This fact is not directly apparent from our results but can be inferred. Given the desire to grasp the issue at hand comprehensively, it is appropriate to have a discussion on this ignorance. Although people switched to environmental fuels in good faith, the environmental effect did not occur due to the use of inappropriate (outdated) technology. The households should be aware that up-to-date technology is important to achieve the environmental goals.

A deeper reflection on the reasons why people switch to biomass; why some groups of households switch to a greater extent (pensioners); how to motivate society to switch even more, with a special focus on those groups of households that have not yet switched to eco-friendly combustion; and how to combine the environmental effort with the knowledge of the necessary technologies (so that the environmental effect actually occurs), creates a demand for further scientific research activity in this problematic area the current research addressed. Moreover, it would be worthy to extend the analysis to other states of Central and Eastern Europe, or at least other members of the Visegrád Group, such as Slovakia, Poland, and Hungary. Behavioural economics and behavioural management methods, such as sunk cost aversion, crowd behaviour effect in decision making, anchoring effect, or hidden costs, could be very useful in exploring these issues.

5. Conclusions

The main goal of this paper was to evaluate households' consumption of energy sources for heating purposes in the Czech Republic in the period 2003–2020 and depict

possible drivers of switching to biomass. For this, various models were created and tested, i.e., the substitution model, the price model, and the households model.

The methodological approach used in this paper is suitable; however, there are limits connected with the structure and availability of underlining data. We used various data sources providing a varying time range, therefore, the time series used in the particular models do not cover the same period (time series for 11, 17 and 18 years). On the other hand, the research questions can be answered using such data sources. Based on the results, and answering the research questions, households in the Czech Republic substituted coal for biomass in the period 2003–2020 (RQ1). On the other hand, the environmental impact of such substitution is not significant, as carbon emissions and emissions of other pollutants are stable (RQ2).

To achieve environmental goals, the substitution of fuels should also be accompanied by technological change, e.g., improvement of combustion boilers. In this place, the socio-economic aspects are important, because households of pensioners are the ones with the highest impact on biomass consumption for heating purposes (RQ3). Therefore, it would be worthy to support households in replacing their boilers for more environmentally friendly ones. This recommendation for policymakers in their effort to achieve the Green Deal targets stems from the present research.

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