Exploring the Drivers of Demand for Non-industrial Wood Pellets for Heating

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Abstract

The targets for renewable energy in the European Union (EU) have resulted in a surge in the use of wood pellets. The EU-28 consumption has outgrown domestic production, resulting in increasing net imports. This study analyses the drivers of the use of pellets for heating (non-industrial pellets). An enquiry directed to biomass and pellet organizations indicates that country specific subsidies could be a driver for the purchase of pellet stoves and boilers, resulting in a base level of consumption of non-industrial pellets. Further, light heating oil and natural gas are considered the main heating sources substituted by wood pellets. Econometric analysis indicates that GDP is less important, while the price of wood pellets as well as the price of alternative energy carriers seem to be significant drivers. Models using different combinations of these variables account for 63% to 76% of the variation in non-industrial pellet demand. The results indicate the importance of considering competing fossil-based fuels when modelling wood pellet demand. This aspect is also relevant when new policy measures for a low carbon economy are applied, such as the levying of carbon taxes on fossil fuels.

Keywords: renewable energy policy, wood pellets, heating, econometric analysis, elasticity of demand, carbon tax, natural gas, heating oil.

Introduction

Wood pellets are emerging as one of the most important contributors to the renewable energy goals of the European Union (EU). The current study analyses the non-industrial wood pellet market for heating purposes.

EU renewable energy policy

The European Union (EU) as a whole aims to utilize 20% renewable energy sources (RES) for its gross energy consumption by 2020 and 27% by 2030 (DG Climate Action 2014). The EU policy framework for climate and energy states that (woody) biomass can contribute to an increased use of woody and other biomass in the energy sector and also to other sectors of an emerging bioeconomy. The EU does not differentiate between the types of renewable energy source. EU's Renewable Energy Policy only prescribes the total share of all renewable energy sources to be attained by 2020 as a share of the total gross energy consumption. Additional efforts to increase renewable energy share in the EU include other renewable sources, like agricultural biomass, wind-energy, solar energy, and hydropower (Proskurina et al. 2016).

It is in the National Renewable Action Plans (NREAPs) wherein each EU member State lays out its plans for the current and future development of renewable energy sources. So far, woody biomass is playing an important role for the production of heat and electricity (DG Energy 2014). In addition to domestic supplies, a considerable share of the EU renewable energy is imported in the form of wood pellets, wood chips, other woody residues and lower quality roundwood like firewood and to some extent pulpwood. The expected additional contribution of firewood to EU's future targets is limited. Log boilers are regarded as low efficient, in comparison with pellet stoves and pellet boilers, and may be out of the scope for EU's transition plans to a resource efficient bio-economy (European Commission 2016). Forest chips and slash from forest operations (harvesting residues) are important for the EU's renewable energy target. They are increasingly used for district heating in the Nordic and Baltic countries (Ericsson and Werner 2016, LUKE 2016,2017, Rytter et al. 2014,2015). Simultaneously, forest chips and slash are important drying fuels ('hog fuel'), which are used in industrial boilers to dry the raw material (wet sawdust, wet chips) for the pellet production processes in North America and Europe. Wood pellets represent best the international and dynamic character of Europe's renewable energy market. Figure 1 highlights the largest producers and consumer countries of wood pellets, i.e. above a volume of 250,000 tonnes in 2016. Europe plays a large role, with several key markets, starting with the United Kingdom, followed by Germany, Denmark, Italy, Sweden, Latvia, Austria and France (FAOSTAT 2018).

The role of wood pellets in renewable energy

The consumption of wood pellets in the EU-28 has increased from 1.1 million tonnes in 2000 (Cocchi et al. 2011) to 20.5 million tonnes in 2015 (FAOSTAT 2018). The latter volume is equal to 360 PJ (Table 1), which expresses the primary energy value of pellets used for heat and electricity production, without taking the conversion losses during the production processes into account. For comparison the other woody biomass categories (mainly firewood, wood chips and pulpwood) for energy would have contributed about 130 million tonnes, based on a global estimation in the period 2009-2012 (Sikkema et al. 2013, Mantau 2015). The overall pellet market is made up of (i) industrial pellets for large-scale power production and (ii) non-industrial pellets for small-scale to medium-scale heating. About 7.5 million tonnes are used for electricity production, while the remaining 13 million tonnes are destined for heating (AEBIOM 2016). These volumes correspond to a small contribution of pellets to the EU renewable energy targets of about 130 PJ for electricity production and 230 PJ for heating in 2015 (Table 1).

The first category is associated with long distance trade and with national biomass support schemes accompanied by certificates to prove sustainable sourcing (Sikkema et al. 2011, 2013, Mai-Moulin et al. 2017). Major European exporters of industrial pellets are the Baltic States and Portugal, while Russia, Canada, and above all, the US are the major suppliers outside the EU for the EU market. Sweden, Denmark and Poland have a considerable market for industrial pellets, they are used for large scale electricity production or for a combination of electricity with heat production (CHP). The other important markets for industrial pellets in Europe are Belgium, the Netherlands, and the UK, where industrial pellets are used for power production only. Lately, South Korea, China and Japan have emerged as important consumer countries, importing industrial pellets from Canada, Vietnam, and some other countries in Southeast Asia (Gauthier 2017, Levinson 2017, Thrän et al. 2017). According to the latest statistics (FAOSTAT 2018), South Korea consumed about 1.7 million tonnes of pellets, whereas China and Japan consumed each about 0.5 million tonnes (Figure 1). To promote synergies of woody feedstock to the fullest for the production of wood-based panels, wood pulp or a range of new bio-economy products with high added value, only efficient conversion of biomass to energy should receive public support (European Commission 2016). Very likely, the existing biomass support schemes, shall be phased out after 2024 for co-firing of wood pellets for power production only, due to the relative low energy conversion in comparison with more efficient options like CHP's.

The second category, at times referred to as premium pellets, generally has a higher quality standard, i.e. extra requirements for fines, size, moisture and mineral content. EU is to a considerable extent self-sufficient as regards non-industrial pellets. Major EU consumers of non-industrial pellets for heating are Austria, Denmark, France, Germany, Italy and Sweden. This type of pellets is distributed to households or district heating plants in bulk by trucks, or through the purchase of small bags (varying from 15 to 25 kg per

Table 1. Overview of the EU energy mix in 2004-2015 and the pellet contribution to Gross Energy Consumption (GEC) – in PJ*) Sources: (JRC 2017, AEBIOM 2016)

	Total amount gross energy consumption (GEC)		Contribution of renewable energy sources (RES) in progress reports			Apparent consumption of wood pellets*)		
	2004	2015	2004	===2015===		2004	===2015===	
	PJ	PJ	PJ	PJ	Share GEC **)	PJ	PJ	Share GEC
Electricity production	11,760	11,586	1,682	3,157	28.8%	22	130	1.1%
Heat production	24,404	20,720	2,513	3,947	18.6%	26	230	1.1%
Transportation fuels	12,952	12,571	146	665	6.7%	0	0	-
TOTAL	**51,082**	**46,846**	**4,290**	**7,764**	**16.7%**	**48**	**360**	**0.8%**

*) 1 PJ = 57.000 tonnes of pellets. Industrial pellets mostly destined for electricity production; non-industrial pellets for heat production.
**) Due to inclusion of RES-electricity for transport and double counting for residues used as feedstock, the share is upgraded.

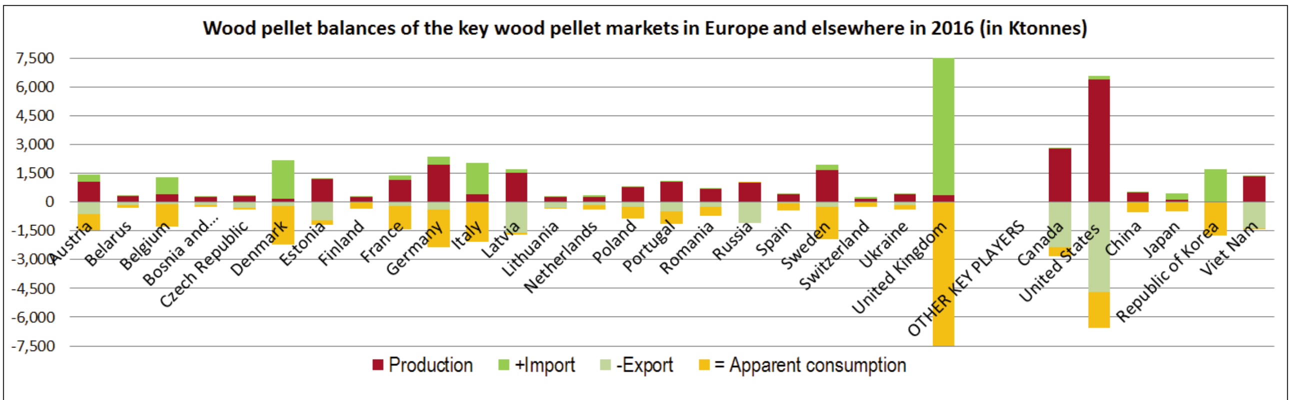

Figure 1. Major wood pellet markets via national wood pellet balances*) – 2015. Source: FAOSTAT 2017

bag) at shops, petrol stations or other type of retailers. United States is also a large user, about 2 million tonnes of pellets (AEBIOM 2016, FAOSTAT 2018), mainly pellets in small bags for residential heating (Spelter and Toth 2009). Bagged pellets are generally used for stand-alone stoves, whereas bulk pellets are used for boilers at households, district heating systems and other medium scale heating systems (including CHP's) in Europe. However, a new survey in Austria indicated that boiler owners do use both bagged pellets and bulk pellets (Schlagitweit 2016).

Wood pellets have been reported as a separate commodity in international trade statistics since 2009 in Europe and since 2012 outside Europe. As a consequence, wood pellet market studies are increasingly published. Some studies focus on the evolving pellet markets (demand) and its feedstock availability (supply) in Europe and North America (Olsson 2009, Magelli et al. 2009, Spelter and Toth 2009, Olsson et al. 2011, Sikkema et al. 2011, Proskurina et al. 2015, Lamers et al 2016, Nunes and Freitas 2016, Duden et al. 2017, Thrän et al. 2017, Roni et al. 2018). Some others have included the cross-sectoral market impacts, like the competing needs of wood supply by the pellet production sector and the traditional forest sector in North America or Europe (Trømborg et al. 2013, Abt et al. 2014, Dymond and Kamp 2014, Wang et al. 2015, Johnston and van Kooten 2016, Dale et al. 2017, Jonsson and Rinaldi 2017). We zoom in on the sensitivity of the pellet demand to changes in economic variables such as pellet prices, income and other parameters (*elasticity of demand*).

Factors influencing wood pellet demand

So far, two studies have derived estimates of the elasticity of demand for wood pellets in Europe. One refers to non-industrial pellets for heating in Austria and the other to industrial pellets for power production in the EU-28.

Kristöfel et al. (2016) account for the first econometric analysis as to household demand for non-industrial wood pellets in the period 2000-2014. They analysed the demand for wood pellets in residential heating in Austria, using pellet price, the number of pellet boilers, and heating days or winter days as explanatory variables. Apparently, several countries, among them Austria, use the active wood pellet boiler stock and weather conditions to calibrate the national consumption of pellets for residential heating, along with the total apparent consumption of (non-industrial and industrial) wood pellets (Bau 2016, Schlagitweit 2016, Sievers et al. 2016, Vial 2016). The apparent consumption is compiled by means of national pellet production and Eurostat trade data, similar to our compilation of apparent consumption in Figure 1 with FAOSTAT data. The Austrian analysis entails a serious drawback, in that the data on non-industrial pellets consumption are partly derived from the number of boilers, and as such the explanatory power of the wood pellet boiler stock is inflated, in what resembles circular logic. Actually, the 'stock' (or boiler capacity) is used as an independent variable to estimate consumption, but as an endogenous variable it is biasing the estimation results. In another Austrian study (Karner et al. 2017), the actual price of heating oil and the price of pellets in the previous year were used to estimate the actual changing boiler capacity in Austria. The estimated capacity was used to predict pellet demand, similar to the approach by Kristöffel et al. (2016). The Austrian studies seem incomplete as they did not consider the number of stoves for domestic heating, which have a 25% market share in Austria, in terms of numbers (AEBIOM 2015, 2016, Schlagitweit 2016).

Sun and Niquidet (2017) derived the elasticity of import demand for industrial wood pellets by the European Union from the EUROSTAT's database on pellet trade statistics. Import demand was found to be relatively price inelastic. A significant portion of the international industrial wood pellet trade occurs on the basis of long term contracts (Gauthier 2017, Levinson 2017), which may be influencing the lack of statistical significance for the own price elasticities (Sun and Niquidet 2017).

Competing fossil fuels and carbon taxation

There was one large econometric study on the elasticity demand for fuelwood in the United States (Song et al. 2012ab), in which fossil fuel prices, income and the house area (square meters) were the explanatory variables. Rising prices of non-wood energy sources (natural gas, heating oil, liquid propane, kerosene or electricity) had the largest impacts on the US' residential wood energy consumption in the period 2000-2009 (Song et al. 2012ab). The use of wood for heating houses is stated to be elastic to changes in non-wood energy prices in the long-run, less so from one year to the other. A possible explanation for this finding is that homeowners are reluctant to change heating system in the short term. Public policies and market forces that reduce wood energy cost or increase costs of alternative fuels for households may promote the use of residential wood energy in the US, especially in rural areas. The estimated inelastic effect of income on the use of wood for residential heating varied with income level: for low-income households the marginal effect of income was positive, but for high-incomes in rural areas it turned to be negative. Finally, the house area was found to be the most marginal impact factor. Following the outcome of the econometric study in the United States, it was stated that taxation of fossil fuels or tax credits for fuelwood resources may be effective policy tools to induce greater household wood energy consumption (Song et al. 2012a).

Assumptions, aim and approach

Building on the above, it seems as if the demand for wood pellets has been positively affected by subsidies for the purchase of wood pellet boilers, induced by EU renewable policy and applied at country level (European Commission 2015, Proskurina et al. 2016). In addition, weather conditions and the prices of competing fossil-based fuels are expected to play an important role (Vial 2016). The influence of income seems less clear. It could even have a negative effect on wood pellets demand: this is something that is also noted for some other wood-based commodities, i.e. in newsprint and fuelwood demand (Hetemäki and Obersteiner 2001, Caurla et al. 2009). Further, less surprising, wood pellet price seems to have a negative effect on woody biomass used for residential heating, while the price of competing fossil-based fuel alternatives should have a positive effect on wood pellets demand, ceteris paribus.

In conclusion: (national) income, pellet own prices and prices of competing fossil-based energy carriers are expected to be the main factors (independent, explanatory variables) affecting wood pellets demand for heating (dependent variable) in Europe (hypothesis). Introduction of wood pellet boilers (both households and district heating) and wood pellet stoves (households) through temporary subsidies around and soon after the millennium change, has established and lifted the pellet consumption for heating, inherent to a higher base load (capacity) level in Europe. Through its bias with pellet demand, the capacity is left outside our inventory. Simultaneously a technological shift should be considered, i.e. more efficient heating technologies for pellet boiler systems. In the long run temporary subsidies should have less impact on the base load level when established, except for considerable efficiency improvements. The latter holds true when new, improved heating technologies are constantly introduced on the heating market, while replacing inefficient older ones.

The objective of the current study is to explore the wood pellets markets for heating. In particular, we focused on the influence of fossil-based fuel prices and other possible parameters for the household and medium scale district heating demand for wood pellets (non-industrial pellets). In addition to taking stock of the implications of literature, we sent an enquiry to national biomass expert organisations to derive the key drivers of non-industrial wood pellets consumption. The drivers thus derived are then used as key parameters in our econometric analysis. The paper proceeds as follows: analysis of the current state of wood pellet for heating markets and of competing fuels for wood pellets derived from an enquiry and a literature review. Those are followed by an overview of data availability for wood pellets and fossil fuels. Thereafter, pellet demand equations are specified and tested. The study concludes with results and discussion, and conclusion sections.

Materials and Methods

Enquiry and literature review

The European biomass association (AEBIOM, 2014-2016) publishes consumption data for wood pellets heating markets, divided over three sub-markets: small residential heating, medium scale heating and larger combined heat and power (CHP). Appendix A (Table A1) shows the 2014 overview, complete with literature review on market divisions in that period. Small scale residential heating in stoves and boilers consists of bagged pellets and pellets in bulk deliveries. Medium scale heating is dominated by bulk pellets for district heating boilers. The large scale CHP market consists of large users of industrial pellets, producing power and heat. Those CHP's are assigned to industrial use and excluded from our non-industrial pellet investigation.

After reviewing country price data for non-industrial pellets, including VAT, we selected the following seven non-industrial pellet markets for an analysis: Italy (number 1 in the market of non-industrial pellets), Germany, France, Sweden, Austria, Finland, and Switzerland. Those countries were selected as these markets have relative high market shares of non-industrial wood pellets and the availability of pellet price and consumption data was sufficient for our purpose. The remaining pellet using countries in Appendix 1 (Table A1) are left out for further analysis, due to lack of or incomplete price data. Total consumption of non-industrial pellets in the seven selected countries was about 7.9 million tonnes (Table 2) in 2015, that is about 60% of EU wood pellet consumption for heating (AEBIOM 2016).

Through an email enquiry directed at wood pellet organizations in European countries selected for their role as important users of non-industrial wood pellets, the relevance of different heating fuels as substitutes for wood pellet was investigated (question 1) and possible other factors that could influence the pellet consumption (question 2). The biomass and pellet organizations have been contacted again by skype or by phone, to discuss registered pellet prices and volumes, as well as the inventoried potential explanatory variables, before starting the econometric analysis.

Econometric analysis

In brief, we have put the weighted average prices for bulk and bagged pellets per country together to one set of cross-cut data series. Therefore, we have panel data (56 observations) for seven European countries over a time frame of 8 consecutive years (2008-2015) to increase the efficiency of the estimation.

The selected countries are all major European consumers of non-industrial wood pellets. In this way the annual demand fluctuations in Europe for non-industrial pellets (small scale residential heating, medium scale district heating) can be analysed for changing prices of non-industrial pellets, together with the effects from changing incomes, and changing light heating oil and natural gas prices.

Theoretical frame

The applicable framework for econometric analysis of wood pellets demand is derived demand. Thus, non-industrial wood pellet is assumed to be similar to any other semi-

Table 2. Key factors impacting the consumption of non-industrial pellets used for heating

Country	Volume of non-industrial pellets in 2015 - in 1,000 tonnes	1. Which of the following fossil fuels are relevant for competing with wood pellets?			2. Which other factors do impact the pellet consumption volumes		Organisations to whom the enquiry about key factors was sent
	As monitored by organisations in the last column	Natural gas	Heating oil	Other	Financial support purchase equipment	Carbon taxes or other incentives?	
Italy (IT)	2,883*)	Yes	Yes	LPG	Feed-in-tariffs for new heating equipment. Plus tax deduction for energy efficiency of house constructions.		AIEL
Germany (DE)	1,850*)	Yes	Yes	-	Subsidies boilers; from 2000	Efficiency measures; energy tax.	Carmen, DEPV
Sweden (SE)	925	No	Yes, but taxes bridge the gap	Low electricity prices provides advantages for other options e.g. heat pumps and central heating	-	Carbon and energy tax Total 4.07 SEK per litre (2015)	ÄFAB, Pellets-Förbundet (PFB) and Svebio
France (FR)	900*)	Yes	Yes	-	Plus low VAT tariff for pellets.	Tax credits for energy efficient equipment (CITE) both for fossil and renewable fuels	Propellet France
Austria (AT)	850*)	In urban areas, where use of pellets is low	Yes, in rural areas where pellet use is high	Relative high electricity prices; LPG in the past	Regional boiler subsidies	No carbon tax	Propellets Austria
Finland (FI)	301	No	Yes		Boiler subsidies	No	Bioenergia, Finland
Switzer-land (CH)	200 (BfS 2016b)	No	Yes	-	Central heating, per region	84 CHF per tonne CO_2 (2015)	Propellets Switzer-land

*) Along with the apparent consumption data (national pellet production + import - export), the residential heating volumes are further calibrated via the active pellet boiler stock and the weather conditions in the winter season.

finished forest product, such as, e.g., sawnwood and wood-based panels. The analysis relies here on combined factor and consumer demand theory (see, e.g., Andersson and Brännlund 1987):

$$Q_{st} = Q_{st} (V_{st}, Z_{st} T) \qquad (1)$$

where Q_{st} is production volume in firm/sector/country s at time period t, V_{st} is the input volume of a product in firm/sector/country s at time period t *(in this case pellets)*, Z_{st} is a vector of other inputs (e.g. price of other commodities used) in country s at time period t, T is time index and indicator for technological change t = 1,…,T, and s = 1,…,S is the number of firms/sector/countries. We have assumed negligible technological changes in the time frame 2008-2015. The production volume Q_{st} is derived from the consumer demand through maximizing the utility function of a single consumer, restricted by available income and prices. The total consumer demand will be identical to the production volume of Q_{st} in equation (1). Accordingly, the combined factor and consumer demand equation can be expressed as:

$$V_{st} = H_s (P_{vst}, P_{zst}, Y_t, t) \qquad (2)$$

where H_s indicates the functional formula with variables: P_{vst} is the price of pellets, P_{zst} is the price vector of other inputs (i.e. supplementary or complementary fuels light heating oil and natural gas, respectively) and Y_t is a proxy for income; i.e. Gross Domestic Product (GDP) in a certain year (t). All monetary values are expressed in constant prices in euros (€), with GDP deflator 2010 = 100, and further in natural logarithms for the interpretation of estimated coefficients as elasticities.

Apart from GDP and the own price of pellets, the costs of alternative energy carriers for heating houses, and offices; i.e. LHO, natural gas, or any others applicable in near future, are the primary test parameters. The estimation covers the whole sample for the period 2008-2015, n_s = 1,…,7, t_t = 1,…,8.

When dealing with pooled cross-sectional time-series data with short time-series, our approach is applied for both a fixed effects model and a random effects model (Kmenta 1987, Hamilton 2013) for the estimation of price elasticities. The approach makes use of the panel data characteristics, the basic regression model being $y_{it} = X_{it}\beta + u_{it}$ where u_{it} consists of individual, and time effects. The fixed effect model deals with the systematic character of u_{it} (error term) to be higher for some individuals than other (individual effects) or higher for some time periods than others (time effect). As to random effect models u_{it} is further decomposed: $u_{it} = \varepsilon_i + \lambda_t + \eta_{it}$. The ε is representing individual effect, λ time effect and η the random effect. Generalised least squares (GLS) is used in estimating β applying the structure imposed on u_{it} by this assumption.

Data for pellet volumes and prices

Total apparent consumption of wood pellets is derived from annual production, net trade flows and stock changes at the end of the year. We assumed no stock changes over the end of the year because data on national pellet storage were not available. At the EU-level, the trade of wood pellets is dealt with as separate category only from 2009 onwards (Eurostat 2017), and at the global level the production and trade has been registered since 2012 (FAOSTAT 2018). Thus, for having longer time series, there was a need for supplementary pellet volume data for bagged pellets on the one hand, and bulk pellets on the other hand. The national biomass or pellet association provided the supplementary volume data, which consist of time-series on residential and district heating (Table 3). These data are somewhat unbalanced; the earliest data series starting even before 2000 and the latest only since 2008.

Volume and price information of the seven countries are provided by national biomass or wood pellet associations (see Acknowledgements), except for Switzerland. Swiss price information is independently provided by a public organization (BfS 2016a). The prices of bulk pellets in delivery packages have been retrieved from deliveries in between 3 and 6 tonnes, as delivered to households or district heating plants. Also, the delivery distance for bulk

Table 3. Descriptive pellet statistics for countries included in the pellet demand analysis 2000-2015 (BfS 2016ab, AIEL 2016, Bioenergia 2016, Carmen 2016, DEPI/DEPV 2016, LUKE 2016, 2017, PelletsFörbundet 2016, Propellets Austria 2016, Propellets France 2016)

Country	Market type of pellets	Mean annual Volume (tonne)	Min. annual Volume (tonne)	Max. annual Volume (tonne)	Standard deviation of volume	Mean Unit price (€/per ton)	Min. Unit price (€/ton)	Max. Unit price (€/ton)	Standard deviation of price	Number of observations (years)
Austria	Bulk	409,774	43,300	774,400	247,952	219	163	253	27	16
	Bagged	83,956	40,800	120,000	23,089	255	228	274	16	9
Finland	Bulk/ bags together	201,625	151,000	301,000	47,450	260	223	284	18	8
France	Bulk	141,059	8,450	325,000	102,188	260	190	282	27	11
	Bagged	311,850	17,550	675,000	234,931	282	245	302	14	11
	Bulk	776,707	51,350	1,600,000	534,839	234	176	273	31	14
Germany	Bagged	274,056	13,650	400,000	71,486	305	268	328	15	8
Italy	Bulk	348,833	186,000	424,000	77,450	230	196	267	27	6
	Bagged	2,205,167	1,761,000	2,697,000	294,074	245	217	279	24	6
Sweden (prices SEK)	Bulk small	198,809	186,193	218,750	9,865	2,540	2,278	2,755	144	10
	Bulk medium	528,674	389,980	716,502	107,726	1,791	1,693	1,814	40	7
	Bagged	370,708	345,787	406,250	20,107	2,633	2,500	2,779	96	7
Sweden (in €)	Bulk small		See above			273	219	307	26	See above
	Bulk medium					196	177	211	11	
	Bagged					288	260	310	16	
Switzer-land (CHF)	Bulk/ bags together	102,534	3,606	204,860	70,356	379	302	404	38	16
Switzer-land (in €)	Bulk/ bags together		See above			289	196	352	54	See above

pellets may vary, e.g., from 50 km in Germany to 100 km in Finland, although this is not indicated for each country. In case of bagged pellets (15 kg bags), the prices relate to purchase at retail shops. The bulk and bag prices are monthly recorded by the national inventories, except for Finland with quarterly records.

The available price data cover bagged and bulk pellets, where the bagged pellets are used for residential heating, bulk pellets for residential heating and bulk pellets for medium scale district heating. The prices for non-industrial wood pellets are compiled in two steps. First, the average annual prices for bags and bulk can be extracted from available monthly or quarterly statistics, depending on the country. Each month (or quarter) is assumed to have the same weight, thus we ignore any potential seasonal influences (Schipfer et al 2016). In the same way, the national associations compute their annual price statistics, by summing all months (or quarters) and dividing the total by 12 (or 4). Second, we have compiled one average weighted annual price for non-industrial pellets for heating, for each country involved in both bagged and bulk prices. For example, the Austria market consists of 12% bagged pellets and 88% bulk pellets in 2014; the annual average of the price for bagged pellets gets a weight of 12% and that for bulk pellets 88% (see Appendix 1). The final result is one average price for non-industrial pellets heating for Austria. In case of Switzerland and Finland, the average price calculation is applicable for bulk pellets only, due to lacking price figures and relatively small markets for bagged pellets.

Exchange rates

Furthermore, the non-industrial pellet market for heating is assumed not to be vulnerable to exchange rates, as most of the contracts for non-industrial pellets are stated in euros and trading occurs within Europe. Italy is an exception, as it has temporarily imported considerable pellet volumes from the United States in dollar contracts. Italy reported to have imported considerable US pellet volumes only over the year 2015. After 2015, this overseas import reduced again (Eurostat 2017). In case of Switzerland and Sweden, we have to deal with the import of pellets in euros, and domestic pellet prices in respective Swiss francs (CHF) and Swedish crowns (SEK) (Table 2). Switzerland is importing a relatively large amount from the Eurozone via Germany and Italy, whereas Sweden does the same via the Baltic States, Latvia and Estonia. The relatively large Swedish import from Russia is mostly payed in euro's and seldom transferred *via* Ruble contracts due to the relatively large exchange risks. Concluding: the effects of fluctuating exchange rates for the domestic pellet prices in Switzerland (CHF) and Sweden (SEK) have been accounted for through the conversion into euro's.

Data for competing fossil fuels

For the competing fuels heating oil and natural gas (Table 4), we used the categories light fuel oil and natural gas for households. First, heating oil (indicated per 1000 litres) is based on the retail purchase price for households in the period 2008-2015 (IEA 2010, 2015). In case of preliminary heating oil figures (2015), we made an average annual estimate based on the quarterly prices available. Second, we used the natural gas prices (per MWh gross caloric value) as published by Eurostat (Eurostat 2016). The Eurostat data series apply for the same consumption pattern of households in 2008-2010: a natural gas consumption between 20 and 200 GJ per annum.

The effects of existing additional taxes on carbon emissions from fossil fuels are reflected in the total price of heating oil and natural gas in our inventory, in which carbon and energy taxes are included. Sweden and Swit-

Table 4. Prices of competing fuels for heating oil and natural gas households – 2000 through 2015 (IEA 2010, 2015)

Light heating oil (LHO) for households (1,000 litres)									
	Austria	Finland	France	Germany	Italy	Sweden		Switzerland	
Period	2000-2015	2000-2015	2000-20015	2000-2015	2000-2015	2000-2013		2000-2015	
	In €	In €	In €	In €	In €	In SEK	In €	In CHF	In €
Average	675	710	651	588	1,113	9,678	1,048	752	545
minimum	383	366	364	351	820	5,425	614	409	279
maximum	1,000	1,133	969	888	1,455	13,757	1,603	1,096	862
Standard deviation	204	261	197	178	212	2,714	308	226	204
Natural gas for households (per MWh gross caloric value)									
	Austria	Finland	France	Germany	Italy	Sweden		Switzerland	
Period	2000-2015	2000-2014	2000-20015	2002-2015	2004-2015	2007-2015		2000-2015	
	In €	In €	In €	In €	In €	In SEK	In €	In CHF	In €
Average	56	30	51	63	72	1,005	108	85	61
minimum	32	15	32	35	54	844	86	60	38
maximum	70	49	68	71	89	1,078	124	104	91
Standard deviation	13	12	12	9	11	75	14	15	17

zerland are examples of countries with carbon taxes for heat producers, whereas Germany has a tax on the annual heat consumption produced from fossil fuels (Table 2).

Results

The inquiry to national wood pellet organizations indicates the importance of price developments of competing fossil-based fuels and carbon taxes for the demand for wood pellets. To wrap up non-industrial wood pellet prices, GDP, natural gas (or heating oil) are sufficient and adequate estimators for the annual fluctuations of the non-industrial pellet demand. Overall, all elasticities in Tables 5 and 6 are significant, except when LHO and natural gas are used together as explanatory parameters together with pellet price and income.

Outcome enquiry: pellet market characteristics

The results of the inquiry (Table 2) suggest that light heating oil (LHO) is the most relevant competing fuel in all countries, with natural gas being important in France, Germany, and Italy, where pellet stoves are common. Natural gas is also used in Switzerland and Austria, but only in urban areas, where wood pellet consumption is quite low.

One could assume that both heating oil and natural gas are substitutable by pellets, depending on the phase when people take their investment decision on new equipment. The competitive element is valid before the purchase of equipment, when all kinds of investment expenses (including operating and maintenance) of gas and oi-fired boilers or stoves are compared with those for wood pellets. The phase before purchase, however, is out of scope in our inventory. The competitive element is also partly valid after the purchase step, both for small scale and medium scale consumers of wood pellets. Small scale users, i.e. households, can still switch between fuels, when the older fossil fuel equipment is retained with the pellet stoves. For example, in Germany and Austria, some old heating oil boilers are maintained as a back-up to remain flexible for peak loads (Schlagitweit 2016, Sievers et al. 2016). As for Italy, the wood pellet stove is mostly a heating system integrating the central natural gas boiler of Italian houses (Francescato 2016). In case of medium scale heating, e.g., district heating plants, operators can occasionally switch to heating oil or natural gas, once the equipment is bought. An example is Sweden, where domestic fuel oil is a substitute for some pellet fuelled heating plants (Harrysson 2016). Natural gas is again the substitute in Italy; larger residential buildings share a common back up natural gas fired boiler, in case the pellet boiler is out of service. Another possibility in Italy is that the single house connected with the district heating has kept the natural gas boiler beside the heat exchanger (Bau 2016, Francescato 2016). In the case of France, pellet and natural gas fuelled boilers can be operated together (Vial 2016). Furthermore a certain influence of heating oil can be stated for medium scale heating in Germany; many pellet boilers in bigger buildings are combined with back-up-systems that can use other fuels such as fuel oil, depending on the price (Sievers et al. 2016).

Only a few countries reported Liquefied Petroleum Gas (LPG) and electricity as alternative options. LPG was used in the past in Austria and is nowadays still being substituted in Italy, but to a limited extent. Electricity is a special case. It plays an important role in Austria and Sweden before the purchase of equipment. It is reported that the growth of purchased pellet boilers has decreased, because it is more attractive to invest in heat pumps and central heating (Löfgren 2016, Schlagitweit 2016). After the purchase of equipment, the competing factor for electricity is not valid anymore. Swedish households sparsely use the electricity option of the boilers, i.e. in summer to heat up the house a little (Löfgren 2016). It saves time as they do not have to clean the boilers afterwards. At the end, we left out LPG and electricity as being substitutable competitors in our wood pellet analysis.

Outcome modelling: demand elasticities

The outcome of the basic model formulation, starting with GDP and pellet price as explanatory variables, is presented in Table 5. The sign of pellet price and national income elasticities are in accordance with our hypothesis. European pellet demand is elastic with respect to the price of pellets (-2.38), but inelastic (0.14) to income (GDP). The share of pellets purchased by total household expenditures is relatively low, that partly may explain an inelastic effect of income on the pellet demand. The significance levels of both variables are satisfactory, and the explanatory power of the model is satisfactory. When we consider pellet price as the only explanatory variable, the elasticity increases, but the contribution to the variation (adjusted R^2) is considerably lower.

As extracted from Table 2, the universal competitive heating fuel in our sample is light heating oil (LHO). Indeed, adding light heating oil as an independent variable increases the explanatory power (Table 6). First, it is striking how the own-

Table 5. Model estimations for the whole sample: Austria, Finland, France, Germany, Italy, Sweden, and Switzerland - for demand of wood pellets (in bulk and bags)

Fixed effect model – contribution to variation	**Elasticity for GDP**	**Elasticity for own (real) prices of pellets Weighted annual average bulk and bagged pellets**	Durbin Watson (DW) values
Adjusted R^2 =0.46	Excluding GDP	-3.14***	0.498
Adjusted R^2 = 0.60	0.14***	-2.38***	0.482
Random effects test	**Elasticity for GDP**	**Elasticity for own (real) prices of pellets. Weighted annual average bulk and bagged pellets**	-
*Hausman =12.43 Intercept = - 27.29****	Excl. GDP	- 2.87***	-
*Hausman = 14.08 Intercept = 21.33****	0.15***	- 2.17***	-

Based on *t*-tests, estimations have three significance levels: *=10 %; ** =5 %; *** =1 %.

price elasticity of pellet demand increases. Second, the pellet demand is also rather cross-price elastic, considering LHO or natural gas separately. Thus, pellet demand is quite sensitive to price changes of fossil fuel alternatives. Obviously, when the consumer has more alternatives to choose, he or she will most likely switch to the most affordable one. Cross-price elasticity of LHO is elastic (1.20) and highly significant as an explanatory variable, and the same applies to natural gas (1.86).

Table 6. Model estimations for the whole sample: Austria, Finland, France, Germany, Italy, Sweden, and Switzerland - cross price elasticities for demand of wood pellets with GDP and competing fuels

Type of modelling – contribution to variation	Elasticity for GDP	Elasticity for own pellet price	Elasticity for competing fuels		Durbin Watson (DW) values	References (IEA 2010, 2015, Eurostat 2016)
			LHO	*Natural gas*		*Specifications for competing fuels*
Fixed effects Adjusted R^2 = *0.63*	*0.11****	*-2.60****	*1.20****	-	*0.485*	
Random effects *Hausman = 12.99; Intercept = 13.73****	*0.11****	*- 2.43****	*1.45****	-	-	*Households – end price incl. VAT and taxes*
Fixed effects Adjusted R^2 = 0.76	0.11***	-3.50***	-	1.86***	*0.464*	
Random effects Hausman = 13.95; Intercept = 20.83***	0.11***	- 3.38***	-	1.91***	-	*Households – annual use from 20 to 200 GJ, price incl. VAT and taxes*
Fixed effects Adjusted R^2 = 0.76	0.11***	-3.50***	-0.10	1.88***	*0.532*	*LHO not a significant estimator in this combined equation*
Random effects Hausman = 13.65; Intercept = 20.40***	0.11***	- 3.38***	+ 0.09	1.88***	-	

Based on *t*-tests, estimations have three significance levels: *=10 %; **=5 %; *** =1 %.

Besides the fixed effect approach, estimations applying random effect models were performed. The estimations applying random effect models, as displayed in Tables 5 and 6, have resulted in rather similar estimates and test statistics relative to fixed effect estimations. Both approaches have their pros and cons regarding the treatment of individual effects. On the one hand, in a fixed effect model the individual intercepts have the possibility to take any "individual" value. On the other hand, an individual effect in a random effect model is a part of the error term, which may entail possible bias depending on eventual correlation between it and the regressors (independent variables). Overall, our model specifications tend to generate appropriate estimates for the pellet demand elasticities in this study context, regardless of minor problems of correlation. The applied methodologies (both fixed and random effect approach) are able to master this correlation to some degree.

Time series data usually have trends, thus always with the potential risk of non-causal correlation, even if transformed to logarithms. When this occurs for the explanatory variables, problems of non-stationarity may arise. The use of cross-sectional time-series data will, however, decrease the non-stationarity problems, of which the relatively high R^2 values and significant estimators provides satisfactory evidence.

Methodological constraints for demand elasticities

Remarkably, all estimated elasticities remained more or less the same when we include both the price of natural gas and of LHO as explanatory parameters. However, LHO became a non-significant estimator (no stars) when we included this explanatory parameter together with natural gas. The changed significance of LHO is clearly an effect of correlation between LHO and natural gas markets: 48.1%. It is known that some European countries, e.g. the Netherlands, connect their domestic natural gas sales with the international market price for a barrel of oil. Therefore, the explanatory parameters natural gas and LHO should not be put together in the model specifications. Table 7 shows also cross-correlations (two stars) between GDP and own price on the one hand, and GDP and LHO prices on the other hand. But these correlations occur to some moderate degree: respectively -28.8% and 27.7%. However, the correlations detected, for example between GDP and pellet own price, can be a sign of autocorrelation between these variables. Typically, economic time series such as GDP and price are suffering of inertia. Therefore, in such regressions, successive observations over a time period are likely to be interdependent to some degree, as also turns out to be the case here for the regression with GPD and pellet own price as independent variables. In this connection the Durbin-Watson value (Simangunsong and Buongiorno 2001) in our inventory results (see displayed DW values in tables 5 and 6) indicates the presence of some positive autocorrelation. However, due to the moderate degree of autocorrelation, this should not violate the model results seriously for the purposes of this study. In a next, near future inventory, when more data series of pellet prices and volumes become available, it is recommended to additionally test one-year lagged variables or to work with differentials instead of absolute values.

Table 7. Overview of correlations among the variables affecting the non-industrial pellets demand

	GDP	Pellet own price	LHO	Natural gas
GDP	1	-28.8%**	27.7%**	15.6%
Significance*	-	0.004	0.006	0.128
Pellet own price	-28.8%**	1	1.7%	4.2%
Significance*	0.004	-	0.868	0.682
Light heating oil (LHO)	27.7%**	1.7%	1	48.1%**
Significance*	0.006	0.868	-	0,000
Natural gas	15.6%	4.2%	48.1%**	1
Significance*	0.128	0.682	0.000	-

*) Significance is two tailed
**) Correlation is significant at the 0.01 level

Furthermore, our analysis has detected a low degree relationship of the explanatory variable 'pellets own price' with the competing prices of natural gas (4.2%) and of light heating oil (1.7%). The reasons for those latter correlations, although not significant, can be found in current practices within the international pellet supply chains. Some large-scale pellet mills (notably in Russia, and a few in Canada) use natural gas for drying the wet wood pellets feedstock. However, these mills produce mostly industrial pellets, which are exported to Europe for large scale power production (Magelli et al. 2009, Ehrigh and Behrendt 2013). Instead, the non-industrial pellets are largely produced in European wood pellet mills, using wood residues such as bark and slash (forest residues or hog fuel) to dry the wet feedstock. Therefore, the influence of natural gas on the price of non-industrial wood pellets can be considered negligible. As for the price of heating oil, the effect on the price of wood pellets concerns the transport of non-industrial pellets by diesel trucks or, in some cases, vessels throughout Europe (Sjølie and Solberg 2011, Thrän et al 2017). We also assume the diesel price to have a negligible effect on the total cost and pellet price, as the share of transport is relatively small in comparison with other cost supply aspects.

Critical policy implications

TThe results of the current study suggest the need to consider price developments of competing energy carriers – natural gas and heating oil – when assessing the demand for wood pellets. Further, the impact of (national) income on wood pellet demand seems to be rather small. This insight has implications for the assessment of the impacts and effectiveness of different policy instruments.

One of the major proposals for further harmonized measures on the EU level is the levying of carbon taxes for the heating and cooling sector (excluded from the EU emission trading system or EU-ETS), and removing the subsidies from fossil fuels (European Commission 2013, 2014b). Those measures are equivalent to higher fossil fuel prices, with expected positive impacts on the renewable energy market. As an example, levying of carbon taxes and resulting price increases for fossil fuels could, according to our results, lead to increased demand for wood pellets, ceteris paribus. This positive effect on wood pellets demand is of the same magnitude as the effect of a corresponding decrease in non-industrial wood pellet price, triggered via an own and cross-price elastic demand for wood pellets. Currently the European framework for energy taxation does not provide for a full harmonization, so member states may choose their taxes individually (European Commission 2014a). The remaining but still significant public support for oil, coal and other carbon-intensive fuels continues to distort the energy market, creating economic inefficiency and inhibiting investment in the clean energy transition and innovation (European Commission 2016).

Hence, an important aspect to consider in a policy context is the impact of potentially increased demand for non-industrial wood pellets resulting from levying of carbon taxes, on wood-based product markets. Similar impacts could perhaps also occur for industrial pellets, depending on the role of the coal price and other factors like dedicated support programs, when pellets substitute coal in coal-fired power plants (Sikkema et al. 2016). Industrial residues — chips and sawdust— as well as roundwood can be used directly for energy, indirectly for energy as feedstock for wood pellets, and for material purposes such as the production of pulp for paper and wood-based panels. In particular, wood-based panels factories, pulp and paper industries and wood pellets manufacturers make use of the same feedstocks (low quality roundwood, wood chips, wood particles and to some extent sawdust) reflecting a clear competition in the uses of primary as well as secondary sources of woody biomass (Jiang et al. 2017, Parish et al. 2018). Further, as sawdust, particles and wood chips are co-products derived from sawnwood production, the production and demand for wood pellets, wood-based panels and woodpulp are synergic to the production and demand for sawnwood (see for example Jonsson and Rinaldi 2017). The latest economic modelling results indicate that increased wood pellets demand in EU could result in increasing sawnwood consumption in all (Johnston and van Kooten 2016) or most (Jonsson and Rinaldi 2017) of the countries or regions modelled, while production increases in most regions and on the global level. On the contrary, production and consumption of particle board, fibreboard, and wood pulp reduces in all (Johnston and van Kooten 2016) or most (Jonsson and Rinaldi 2017) regions.

Conclusions

For the inclusion of the European bioenergy market in a larger framework, wood pellets are of relevance when assessing developments and changes within Europe's energy sector. Hence, wood pellets are almost entirely destined for energy production, whereas other wood commodities like wood chips can have both energy and non-energy related destinations. A caveat is in order: due to short time series for some countries and variables, the non-industrial pellet data for the remaining years had to be estimated. Our results should therefore be considered as merely indicative, in the sense of identifying relevant drivers of non-industrial wood pellets demand for heating. More near future research is especially recommended for the possible co-existence of autocorrelation and possible bias to our pellet demand elasticity values.

Time-series cross sectional analysis was performed for seven European countries. We have focused on and estimated the cross-cut influence of income (via the GDP), wood pellet own price, and the price of different competing energy sources for small and medium scale heating on the demand for non-industrial pellet (elasticity of demand). The explanatory variables give an indicative explanation: the different model specifications explain from 63 to 76 percent of the variation in the non-industrial pellet demand for heating (Table 6). An enquiry sent to different wood pellet organizations indicates that light heating oil and natural gas are the main energy sources being substituted by wood pellets. The demand was found to be income (GDP) inelastic, while the pellet own price and cross-price elasticity for competing energy carriers are more elastic. Natural gas price was found to be the most significant explanatory variable for wood pellet demand, while the heating oil price was the second most important factor. In the end, the substitution of pellets by heating oil or natural gas depends on the local situation. The switch from pellets to heating oil is only likely for residential heating when the old oil equipment is still maintained. The switch to natural gas is more common sense; natural gas boilers are used as a backup for medium scale heating to comply with peak loads and energy security. So overall, the natural gas substitution effects are more resembling current practice than the heating oil effects.

Up to now, each country involved in the analysis has different renewable energy policies, which in the current study are expected to affect the pellet demand mainly through the selected explanatory variables. Germany, Finland, and Austria promote bio-energy, and support the purchase of pellet boilers or stoves. France specifically promotes the efficiency of heating equipment in general, with no distinction for pellet or fossil fuel boilers. Italy promotes energy efficient buildings and has feed-in-tariffs for new pellet heating equipment. Finally, Sweden and Switzerland have introduced taxes for fossil-based fuels (Table 2). The apparent importance of competing fossil fuel prices as determinant factor for non-industrial wood pellets demand has implications for possible more harmonised policy measures on the EU level. As such, levying of carbon taxes on or removing subsidies from fossil fuels could seemingly result in an increased demand for wood pellets, assuming any random income effects to be less substantial.

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Appendix 1. Additional information pellet market division in 2014

The European biomass association (AEBIOM 2014-2016) publishes consumption data for wood pellets heating markets, divided over three sub-markets: small residential heating, medium scale heating and larger combined heat and power (CHP). Table A1 shows the 2014 overview, which was completed with an additional literature review on sub market divisions and tracking lacking data for large scale power consumption. Small scale residential heating in stoves and boilers consists of bagged pellets and pellets in bulk deliveries. Medium scale heating is dominated by bulk pellets for district heating boilers, sometimes including power production. The large scale CHP market consists of large users of industrial pellets, producing power and heat. Those CHP's are assigned to industrial use and excluded from our non-industrial pellet investigation.

Table A1. Subdivision of main pellet markets for heating and power production in 2014. The highlighted countries are selected for our market assessment (AEBIOM 2014-2016, Dell 2015, FAOSTAT 2018, Granath 2015ab, McDermott 2015, Swedish Energy Agency 2016, Zhange 2016)

Country	Consumed volume in Ktonne in 2014	National market division for pellets				Prices for non-industrial pellets		References for price data non-industrial pellets
	source: (FAOSTAT 2018)	Residential heating (<50kW); bulk boilers; bags mostly stoves		Medium scale heating (e.g. district heating)	Large scale power (incl CHP)	Bulk pellets	Bagged pellets	n.a. = price data are not available
Top 20*)		non industrial bagged pellets	non industrial bulk pellets	non industrial bulk pellets	Industrial pellets	delivery at home	Purchase at retailers	
1. United Kingdom	5,013	4%			96%	-	-	n.a
2. Italy	2,375	85%	15%	0%	0%	Monthly prices	Monthly prices	AIEL
3. Denmark	2,199	29%		6%	65%	-	-	n.a
4. USA	2,162	98%	0%	2%	0%	-	-	n.a
5. Republic of Korea	1,865	5%		0%	95%	-	-	n.a
6. Sweden	1,846	21%	11%	24%	43%	Monthly prices (3 tonnes)	M-prices (bags up to 16 kg)	Pellets-förbundet (PFB)
7. Germany	1,815	21%	79%		0%	M-prices (5 or 6 tonnes)	M-prices (per pallet)	Carmen; DEPV
8. France	1,097	67%	33%		0%	M-prices (5 tonnes)	M-prices (per pallet)	Propellets France
9. Belgium	951	34%			66%	-	-	n.a
10. Austria	806	12%	88%		0%	M-prices (6 tonnes)	M-prices (15 kg)	Propellets Austria
11. Poland	570	33%		18%	49%	-	-	n.a
12. the Netherlands	490	42%			58%	-	-	n.a
13. Portugal	348	100%			0%	-	-	n.a
14. Spain	348	75%	25%		0%	Limited time series available for prices and volumes (2012-2015)		Avebio
15. Finland	314	6%	20%	72%	2%	Q-prices (5 tonnes)	-	Bioenergia
16. Canada	293	75%			25%	-	-	n.a
17. Japan	219	46%		0%	54%	-	-	n.a
18. Switzerland	216	5%	71%	24%	0%	M-prices (6 tonnes)	-	(BfS 2016a)
19. China	211	0%	0%	0%	100%	-	-	n.a
20. Estonia	189	41%		59%	0%	-	-	n.a