ENERGY CONSUMPTION AND EQUIVALENT EMISSION OF CO_2 AT WOOD PELLETS PRODUCTION IN SERBIA

by

Mladen A. FURTULA*, Gradimir J. DANON, Vojislav V. BAJIĆ, and Dragan N. LUKAČEV

Faculty of Forestry, University of Belgrade, Belgrade, Serbia

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The paper is analyzing wood pellets production from forest to end user, respectively, from breeding, protection, management, maintenance, and regeneration of forests to gate of end user in case of Serbia. Analysis includes all kind of input materials, energies, and equivalent emissions of CO_2 in wood pellets production. The results obtained are: specific energy consumption (heat and electricity) was 2,419 kWh/t_{pellet}, equivalent emission of CO_2 was 293 kgCO_2/t_{pellet} and the relationship between the net calorific value of wood pellets and the total input energy for their production and transport (EROI) was 1.9. The results were compared with those in world factories and based on that certain conclusions and recommendations are given.

Key words: *forest, harvesting, wood fuel production, energy used, energy returned on energy invested, CO_2 equivalent emission*

Introduction

Total firewood consumption in Serbia in 2010 was 7.4 million m^3. Nearly million households in Serbia depend fully or partially on wood fuels for cooking and/or heating (6.4 million m^3) [1]. Wood energy accounts for about 13% of Serbians total final energy consumption, and use of wood fuel prevented emissions of about 7 million tones of CO_2 from fossil fuels [2].

Fuel wood is the main type of wood fuel in Serbia. Modern wood fuels, such as wood pellets, only in recent years gain popularity [3]. Future growth of production and use of wood fuels in Serbia will be possible only with respect to some basic principles, such as: sustainability, conversion efficiency, and competitiveness on the market.

In order to produce wood fuels, it is also necessary to spend a different kind of energies whose amount depends on the complexity and efficiency of a transformation process. Net calorific value (NCV) of wood fuel and the total input energy for their production and transport (EROI) is a (one of) measure of net energy effect of transforming raw wood into wood fuel [4]:

$$EROI = \frac{\text{Energy returned}}{\text{Energy invested}} \tag{1}$$

The EROI is an important but not the only parameter that should be taken into account when selecting technologies for wood fuels production. In production process, energy from renewable sources can be used as well as the energy from non-renewable sources (fossil fuels).

*Corresponding author, e-mail: mladen.furtula@sfb.bg.ac.rs

Too large participation of fossil fuels (in acquired energy) can *ruin* the image of CO_2 neutrality of wood fuels. Impact of fossil fuels use on global warming is estimated by global warming potential (GWP) of CO_2 and certain other gasses such as CH_4 and NO_2 [4]. The GWP of a gas is the warming caused over a 100-year period by the emission of one tone of the gas relative to the warming caused over the same period by the emission of one tone of CO_2 [5].

The paper deals with energy and environmental aspects of wood pellets in Serbia. The main objective was to observe the current situation and determine the carbon footprints and the GWP of wood pellets production on example from Serbia. Based on this, total consumed energy in production process is calculated as well as adequate values of EROI and equivalent CO_2 emission. Analysis of the obtained results and proposals for future research are presented in the conclusions.

Production of wood pellets

Production of wood pellets started with production of wood biomass necessary for pelletizing. Raw material can be wood chips from diverse wood processing steps, short rotation crops, forest residues, fuel wood, round wood, and sawdust. Generally, pellet production process consists of the following phases (fig. 1).

- Forest management (breeding, protection, management of protected natural goods, maintenance, and regeneration of forests, *etc*.).
- Producing and collecting wood residues and fuel wood; the collected biomass is usually of different size and hence it was to be prepared for further
- Transportation of raw material for pellet production.
- Chipping of fuel wood and wood residues by stabile chippers.
- Drying, depending on wood biomass moisture; green wood chips arriving at the mill typically contain about 40-65% of moisture, which is reduced to about 9% by drying.
- Grinding – dried wood chips are additionally fragmented.
- Compression/pelletizing – grinded wood biomass is pressed in a ring molds.
- Cooling – temperature of pellets after compression is relatively high, so that cooling is important part of pellet production.
- Transportation to the end user.

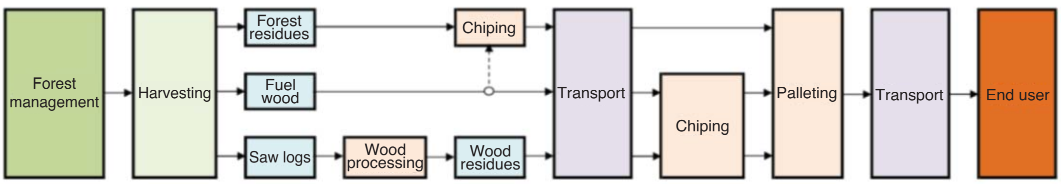

Figure 1. Scheme of the steps of assessment in wood pellets production

Based on this, total consumed energy in pellet production process and values of EROI and equivalent CO_2 emission can be calculated.

Material and methods

The data from different sources are used for necessary calculations.

- For section *Forest Management* the averaged data from three forest estates (FE) from Eastern Serbia, which are part of SE Srbija sume (Juzni Kucaj from Despotovac, Severni Kucaj from Kucevo and Timocke sume from Boljevac) are used. Material in this research is beech fuel wood as most used wood for pellet production in Serbia. Average density of the beech solid wood in Eastern Serbia is 690 kg/m^3 (bone dry). Database contains harvest volumes, structure of produced forest assortments, as well as consumed motor fuels, lubricants, fuel wood, and electricity for year 2012 (more details can be found in [6]).

- Required data regarding energy necessary for harvesting and transportation are taken from the norms of the SE Srbija sume [7] and available literature [8-12]. Data about forest harvesting practices are adopted from our earlier research [8]. Focus is on the issues of technique and technology used in beech forests in Serbia.
- Data for equivalent emission of (CO_{2e}) in forestry sector for fuel wood production and forest residues are adopted for calculations and comparison from *Ecoinvent* database [13].
- Energy consumption in pellet mill is made from data from largest pellet mill in 2012 in Serbia [6] and compared with other sources [14-17].
- Transportation of pellets to end user is calculated by using EXCEL program [18].

Inventory

Forest management

Core scope of activities of FE in SE Srbijasume are breeding, protection, management of protected natural goods, maintenance, and regeneration of forests. Production of forest seeds, and planting material and growing of new forests and forest. Plantation, forest utilization, production of forest products and other products of forestland areas, utilization of forests for recreational purposes, sawn-wood production and other ways of forest utilization, and other activities in accordance with the Forest Law of Serbia [19]. The FE performs the largest part of these operations by their own. However, some of these, such as harvesting which involves felling, production of forest assortments, and their skidding from the forest to the Lorry road or forest depot, are subcontracted to other specialized companies.

In observed FE, with mostly coppice beech forests, structure of forest assortments was in 2012 as it is shown in fig. 2.

Amounts of fuels, which FE consumed in 2012 for perfoming operations (excluding harvesting), are given in tab. 1.

Motor fuels, – diesel, liquefied petroleum gas (LPG) and petrol – are used for vehicles, electricity for lighting, office equipment, *etc.* and wood biomass is used for heating.

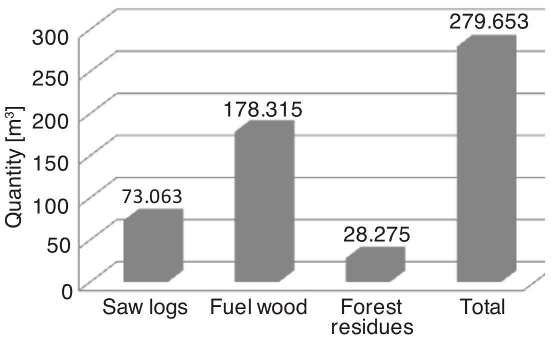

Figure 2. Volume and structure of beech wood harvests in observed FE for 2012 [6]

For the purpose of further analysis, it was necessary to express the consumed fuel in a joint measurement unit, namely, consumed energy (kWh). Use of fossil fuels results in the emission of CO_2 and other GHG which have an impact on global warming. This impact is estimated based on GWP. The GWP of a gas is the warming caused over a 100-year period by the emission of one tone of the gas relative to the warming caused over the same period by the emission of one tone of CO_2. Apart from CO_2, the paper takes into consideration the impacts of CH_4 and NO_2, which are significantly more dangerous for the atmosphere (CH_4 25×CO_2 and NO_2 298×CO_2 for time horizon of 100 years) [4].

Table 2 gives NCV and the taken over and calculated values for equivalent emission of CO_2e for used fuels [13].

Table 1. Consumption of various fuel types in 2012 in observed FE – forest management [6]

Assortment	Unit of measure	Three FE from eastern Serbia
Diesel	L	157590
LPG	L	86273
Petrol	L	77757
Fuel wood	m^3	915
Electricity	kWh	579347

Table 2. The NCV of selected fuels [13]

Type of fuel	NCV		Equivalent emission [kgCO_2e/kWh]
	[kWh/L]	[kWh/kg]	
Diesel	9.98	11.92	0.3418
LPG	6.85	12.86	0.2532
Petrol	9.08	12.26	0.2532
Lignite		2.41	0.4109
Fuel wood/Forest residues*		3.01	0.0502
Electric mix – low voltage			1.0312
Electric mix – high voltage			0.8942

* Wood from forest in furnace up to 50kW;

Based on the data from tabs. 1-3, annual energy consumption is calculated at the FE for the operations of forest management. Calculations are made in kWh/m^3 and emission of CO_2e/m^3 at the FE as the consequence of forest management can be calculated by multiplying data on energy value (given in tab. 2) with the data on equivalent emission of CO_2 for certain fuel types. Calculation results are given in tab. 3.

Table 3. Specific energy consumption and emission of CO_2e – forest management

Fuels	Unit of measure	Quantity per m^3	Energy consumption	Equivalent emission
			[kWh/m^3]	[kgCO_2e/m^3]
Diesel	L	0.63	6.26	1.67
LPG	L	0.34	2.35	5.41
Petrol	L	0.31	2.81	7.16
Fuel wood/Forest residues	m^3	0.0032	9.21	0.58
Electricity	kWh	2.30	2.30	2.48
Total			22.93	6.50
Total fossil fuels			13.72	5.93

Calculated amounts (6.5 kg CO_2e/m^3) are higher than the figures that can be found in the available literature [10]. In [10] calculated equivalent emission of CO_2 amounts only 1.32 kg CO_2e/m^3 of harvested wood and refers to the operations of seeding, soil preparation, afforestation, and tending. The difference can be explained by different natural conditions, different productivity in Serbia and New Zealand as well as by the fact that the data in [10] include only a part of the activities performed by FE in Serbia.

Harvesting

There are a lot of different methods for forests utilization in the world. Selection of the method depends on stand and habitat situation and the level of technical equipment of the companies which perform harvesting [20]. Short wood system is applied in observed FE.

This system implies the following operations [8]: felling, delimbing, bucking, fuel wood production from branches, production of chopped logs, transportation of assortments (skidding) to the depot, and arranging of fuel wood. Felling is done manually with chain saws. Bucking is manual. Skidding is done with animals or tractors. Assortments are loaded onto a Lorry mechanically with self-powered grapple loaders or grapple loaders mounted onto the vehicle connected to its power.

Harvesting operations are done by specialized companies, while the FE performs only supervision and control. Since the FE contracted a lot of various companies, it was not possible to collect reliable data on fuel consumption for harvesting operations. Therefore, consumption of fuel, required for harvesting, production and transportation of assortments to the depot are calculated based on technical norms of the SE Srbijasume [7].

According to the norms [7], petrol and oil consumption for chain saws used for felling and forest assortment production depend on the type of assortment produced (saw logs or fuel wood) and tree species which is processed (in this paper beech wood). The largest part of the consumed oil is used for lubricating chain saws and only a small portion (about 2%) is combusted in the mixture with fuel and has a direct impact on CO_2e emission. Norms for chain saw consumption mostly match with the data that can be found in [20].

Skidding of saw log assortments to the forest road is done by horses or tractors with winches. Assumption is that 70% of assortments are skidded with tractor winch and 30% with animals. According to [11], consumption of energy for skidding per m^3 of wood with winch is 14.7 kWh.

Forest assortments are loaded onto Lorries with grapple loader mounted onto the Lorry, which uses power from the Lorry engine. Energy consumption depends on the loader capacity and type of material which is being loaded. Iwaoka *et al.* [11] gives average consumptions of energy for loading various assortments.

Workers are transported by off-road vehicles from the gathering location (usually in front of the forest administration building) to the workplace. For the calculation of the energy required to transport workers to the site, certain assumptions certain assumptions have been made.

– Average distance from the gathering location to the workplace was 5 km.
– Average consumption of the vehicle was 25 L per 100 km.
– Daily norm of the team for felling and skidding is 40 m^3 (all values are adopted in accordance with the obtained data).

Table 4 gives calculated values of fuel consumption for all previously mentioned individual operations of wood harvesting.

Based on the calculated values, it is possible to calculate energy consumption for producing certain assortments obtained in harvesting process (tab. 5).

Table 4. Fuel consumption for individual operations of wood harvesting

Harvesting operation	Petrol consumption*		Diesel consumption*	
	[Lm^{-3}]	[$kWhm^{-3}$]	[Lm^{-3}]	[$kWhm^{-3}$]
Chain saw – saw logs	0.20	1.85		
Chain saw – fuel wood	0.31	2.78		
Skidding**			1.12	11.22
Loading logs on a Lorry with a grapple loader			0.42	4.19
Loading fuel wood and forest waste on a Lorry with a grapple loader			1.8	17.96
Transportation of workers to the workplace			0.13	1.30

* Including oil consumption;
** Logs are skidded by winches and fuel wood and wood waste are skidded by animals.

Table 5. Energy consumption and equivalent emission of CO_2 for 1 m^3 of produced assortments

Assortment	Unit	Chain saw	Skidding	Loading	Transportation of workers	Total
Saw logs	kWh/m^3	1.85	11.22	4.19	1.30	18.56
	$kgC0_2e/m^3$	0.47	3.00	1.21	0.35	4.94
Fuel wood	kWh/m^3	2.78	0	17.96	1,30	22.04
	$kgC0_2e/m^3$	0.71	0	4.80	0.35	5.86
Forest residues	kWh/m^3	0	0	17.96	1.30	19.26
	$kgC0_2e/m^3$	0	0	4.80	0.35	5.15

Calculated values are lower than the value (8.2 kg CO_2e for 1 m^3) found in [10]. By comparing the structures of operations, it can be concluded that the difference occurs primarily because our calculation does not include the construction of infrastructure (these matters are the responsibility of FE) as well as because of the fact that a part of harvesting operations is done manually or by using animals, not by machinery.

Transportation from forest to pellet factory

Produced forest assortments are arranged on temporary roadside depots and loaded onto Lorry and delivered to buyers according to specifications. Data from the norms regarding fuel consumption for Lorries from [7] are given in tab. 6.

Table 6. Consumption of fuel and lubricants for the transportation by Lorries [7]

Type of transportation	Fuel consumption [L/kW/100 km]	Lubricant consumption [L/kW/100 km]	Correction coefficient – Road quality				
			Earth road	Macadam	Local asphalt	Regional road	Main road
Lorry	0.24	0.006	2.5	1.5	1.3	1	0.9
Lorry with trailer	0.30	0.007					

The tab. 6 shows that the consumption, according to the norms, differs for Lorries with and without trailers as well as for different types of pavement.

The tab. 7 presents the calculated average energy required to transport 1 m^3 of solid wood assortments to the pellet mill and the corresponding GHG emissions.

Table 7. Energy consumption and equivalent emission of CO_2 for transportation 1 m^3 of solid wood assortments to pellet mill

Operation	Diesel fuel consumption		Equivalent emission of CO_2
	[L/m^3]	[kWh/m^3]	[kgC02e/m^3]
Transportation	2.88	28.74	9.82

The calculation is done for the following input data: specific consumption was 0.24 L/kW per 100 km [9], engine power of a Lorry is 180 kW [15], average distance to pellet mill was 80 km [6], (Lorry mainly returns empty), and average volume carried by a Lorry was 30 m^3 [12].

Densification

Wood pellet is generally made by compressing chopped wood and therefore originates as a by-product of the *pulp & paper* industry, sawmill industry, and other wood processing activities. The densification process consume a significant amount of heat and electricity. Heat is primarily used for drying input raw material and electricity is used in all phases of the process. Motor fuels are consumed as well, however, to a significantly smaller degree. A densification process consists, in the narrow sense, of five main unit operations: chipping, drying of wood chips, grinding of dried wood chips, densification/pelleting, and cooling.

For research purposes, data, about raw material and energy consumption were collected from the largest pellet plants in that moment in Serbia. In 2012, analysed pellet plant produced 35309 tones of wood pellets [6]. Raw materials used in production were beech fuel wood (64717 m^3), beech sawdust (54 tones) and coniferous (spruce) fuel wood (1240 m^3). Average moisture content of the raw material was 44% (wet basis) [6]. The total energy consumption of the whole factory, rather than consumption by individual operations is used. It was presumed that all the activities and related energy consumptions in company are directly or indirectly related to the production of pellets. We analysed the consumption of wood necessary to obtain heat for drying, electricity required for the process and the administration building, and fuels for various types of vehicles and equipment (diesel, petrol, and LPG). The total consumption of all types of energy is shown in tab. 8.

Table 8. The consumption of different types of energy in the analysed pellet plant in 2012 [6, 21]

Energy source	Annual consumption [kWh/a]	Specific consumption [kWh/t_{pellet}]	Energy [%]	Annual emission of CO_{2e} [kgCO_{2e}/a]	Equivalent emission of CO_{2e} [kgCO_{2e}/t_{pellet}]	Equivalent emission of CO_{2e} [%]
Electrical energy	7191346	204	10	6430433*	182	90
Diesel	1235758	35	2	382869	11	5.5
Petrol	39369	1	0	10593	0.3	0
LPG	187002	5	0	84625	2	1
Wood (for drying)	66427667	1881	88	239140	7	3.5
Total	75081142	2126	100	7147660	203	100

* Electric mix – high voltage

Total consumption of energy for one tone of produced pellets depends on numerous factors. The most important factors are type of raw material, moisture content of raw material and type of dryer used. Other factors are less significant from the aspect of energy consumption.

The data in tab. 8 indicates that the most of necessary energy was obtained from wood (88%) used for drying of raw material. For this purpose bark and rest of wood chips are used. Calculation shows that specific consumption of energy for heat per tone of evaporated water (from 44% to 9.1% w.b.) was 2,130 kWh NCV of wood.

The tab. 9 shows data on specific consumption of heat and electricity in all phases of pellet production process given by other sources.

Table 9. Specific consumption of heat and electricity per tonne of pellets in pellet production

Operation	Risović *et al.* [14]		Obeenberger and Thek [15]		MacLean *et al.* [16]		An Pa [17]	
	Heat [kWh/t]	Power [kWh/t]	Heat [kWh/t]	Power [kWh/t]	Heat [kWh/t]	Power [kWh/t]	Heat [kWh/t]	Power [kWh/t]
Drying			1200**	24	889		294***	
Grinding		13		19				
Pelleting		139		51				
Cooling				2				
Other		74		18				
Total		217*	1200	114	889	131	294	136

*Without the consumption of electricity in the chips dryer; **Heat per tonne of evaporated water;
*** Pellets are made of almost dry sawdust

The tab. 9 shows that there are mostly no significant differences regarding the average consumption of electricity. The only source which differs is [14] where consumed power (217 kWh/t) is almost double without power consumption for drying. This difference is coming from different type of raw materials (beech wood instead fir/spruce). Electricity consumption in this study (tab. 8) is similar to [14] probably because it is same raw material.

Regarding heat, there are differences mostly because of the differences in moisture content of the starting raw material. Specific consumption of energy for heat per tone of evaporated water is high regarding the results for [15] and reason could be low efficiency of dryers in study case (efficiency of boiler would be 0.56 if it is 2,130 kWh of wood fuels NCV for power consumption 1200 kWh per tone of evaporated water [14]).

Transport to end users

Produced pellets were delivered to end user by Lorries (tab. 10). Average distance from pellet mill to end user was 600 km, mainly because it was exported to the neighbouring countries [6].

Table 10. Transport of pellets to end user [18]

	Annual consumption [kWh/a]	Specific consumption [kWh/t_{pellet}]	Annual emission of CO_2e [$kgCO_2e/a$]	Equivalent emission of CO_2e [$kgCO_2e/t_{pellet}$]
Lorry transport	5532529	156	1745535	49

The calculation is done for the following input data: semi-trailer Lorry with maximum load of 25 tones, energy consumption was 0.261 kWh/t per km, and equivalent emission 0.082 $kgCO_2e$/t per km (round trip considered) [18].

Results and disscusion

Pellet production is calculated by adding energy consumptions for operations regarding forest management, harvesting, chipping, transportation, drying, grinding, pelleting, cooling, and transportation to the end user. To produce one tone of pellets it was necessary to use 1.855 m^3 of wood which includes 2% of production losses. This is about 65500 m^3 of chopped wood. It is assumed that all of the rest of dried raw material is used for heat production. The largest part of this heat is consumed for drying of a feedstock, and the rest is used for other parts of the process and space heating during the winter.

Table 11. Energy consumption and equivalent emission of CO_2e of pellet production

Process phase	Energy consumption		Equivalent emission of CO_2	
	[kWh/t_{pellet}]	[%]	[kg$C0_{2e}$/t_{pellet}]	[%]
Forest management	43	2	12	4
Harvesting	41	2	11	4
Transportation of raw material	53	2	18	6
Pelleting (chipping, drying, grinding, densification, cooling, other)	2126	88	203	69
Transportation to end user	156	6	49	17
In total	2419	100	293	100

Results from tab. 11 shows that pelleting process used most of energy (88%) and also emitted most of CO_2e (69%). Transportation (of raw material and pellets) spent 8% of consumed energy but it has more influence on emission of CO_2e (23%). Forest management and harvesting has lowest influence (energy 4% and emission of CO_2e 8%), fig. 3.

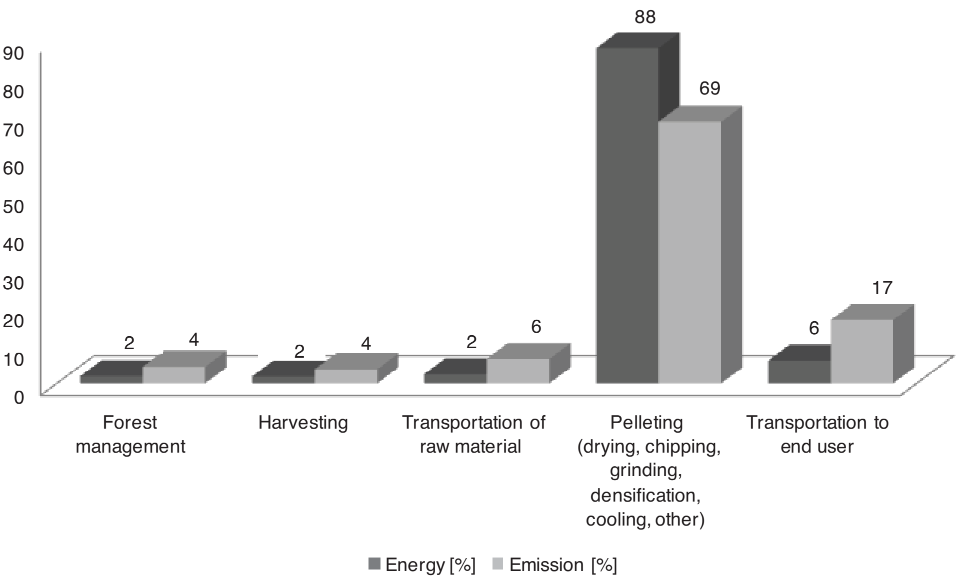

Figure 3. Percentage of energy consumption and equivalent emission of CO_2e of pellet production

Pelleting as a process has biggest influence in the whole chain from the forest to the end user according to both criteria (energy and emission).

The EROI value for fuel wood is calculated:

$$EROI_{\text{Pellet}} = \frac{\text{LHV}_{\text{Pellet}}}{\text{Energy used}_{\text{Pellet}}}[-] = \frac{4611}{2,419} = 1.9 \tag{2}$$

where NCV_{pellet} = 4,611 kWh/t_{pellet} [18] and Energy used = 2,419 kWh/ t_{pellet}.

From results presented in tab. 8 it can be concluded that significant savings can be gained by making more energy efficient drying of raw wood material. Assuming to increase the efficiency of the heat production for drying (boiler efficiency) from 0.56 to 0.81 then the total energy consumption would be 1,846 kWh per ton of pellets (reduced to 24%), EROI would be 2.5 (32% difference), while emissions fell by 2 kg $C0_2e/t_{pellet}$ (difference 0.7%, which is understandable if you take into account the production of thermal energy needed for drying wood chips was used wood fuel). Natural drying of biomass raw material could be one of way to reduced used thermal energy and improve energy balance of pellet production from fresh wood fuel.

Equivalent CO_2 emission can be reduced mostly using more renewable electricity (*e. g.* biomass CHP coupling with drying).

Conclusions

Wood energy accounts for about 13% of Serbians total final energy consumption. This justifies the efforts of Serbia to work on improving of the production of wood fuels, primarily for domestic consumption.

Research has provided an approximate picture of the energies consumed, share of fossil fuels and emissions of CO_2e to the atmosphere in a pellet production in Serbia.

The main sources of raw wood biomass for energy are state and private forests. Public companies that take care of the forests are spending significant amounts of different types of energy to manage the entrusted forests. Other authors do not include or only partially include this consumption in the emission calculations, which is unjustified. The main activity of the forest companies is related to forest, so energy consumptions (and all costs) should be included in the cost of the products which are largely wood assortments.

A large amount of the GHG emissions associated with wood fuel productions (especially pellets) can be attributed to the production of electricity from lignite burning power plants. Cogeneration of heat and electricity in pellet factories and increasing on-site pellet consumption would reduce fossil GHG emissions. The situation differs if a part or entire amount of wood pellets is exported. In such cases, GHG emissions burden the balance of fuel producer's country and environmental benefits from using renewable fuels go to the credit of the country where the fuel is consumed.

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Nomenclature

CHP	– combined heat and power production	GWP	– global warming potential
CO_2e	– equivalent emission of CO_2	NCV	– net calorific values, [kWh/kg]
EROI	– available energy on energy invested	SE	– (forest) state enterprise
FE	– forest estate		

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