PROFITABILITY OF CORN COB UTILIZATION AS A FUEL IN SMALL RESIDENTIAL HEATING APPLIANCES

Djordje M DJATKOV*[*1], Aleksandar Z NESTEROVIC[1], Miodrag I VISKOVIC[1], Milan L MARTINOV[1], Martin KALTSCHMITT[2]

[1]University of Novi Sad, Faculty of Technical Sciences, Department of Environmental Engineering, Trg Dositeja Obradovica 6, Novi Sad, Serbia

[2]Hamburg University of Technology, Institute of Environmental Technology and Energy Economics, Eissendorfer Strasse 40, Hamburg, Germany

[*]E-mail: djordjedjatkov@uns.ac.rs

The subject of this paper is utilization of corn cobs as a fuel in small residential heating appliances in Serbia. The objective was to investigate the profitability of the three cob forms: whole, crushed and pellets. Thereby, construction and reconstruction option of a heating system that uses corn cobs were compared with woody and fossil fuel forms. Net present values (NPV) of generated costs in the first option, as well as NPV of savings, payback period (PBP) and internal rate or return (IRR) in the second, were analyzed. Assessment was conducted using BiomasaPro calculator with integrated approach for energy facility investments. Only utilization of whole cobs were profitable, comparing with wood logs, coal and natural gas. In option construction, around 8,700, 7,000 and more than 4,100 € could be thus saved after the appliance lifespan, respectively. The savings could be 7,800, 5,500 and more than 3,600 € in option reconstruction, with PBP less than two years compared with wood logs and coal, and around 2,5 years with natural gas. Sensitivity analysis showed that utilization of whole cobs could be profitable with up to three times higher purchase price. With bank loan as a financing option for economically weaker biomass users, the scenarios though remain profitable. Subsidy of more than 40% for a heating appliance that uses crushed cobs would allow for profitable investment in comparison with wood chips. Future investigation should comprise assessment including social and environmental aspects, to conclude if corn cobs are a sustainable fuel in Serbia.

Key words: *corn cob, biomass, fuel, heating, small appliance, profitability, Serbia*

1. Introduction

Biomass is considered as an advantageous energy source concerning impact to climate change impact, since it has lower carbon footprint comparing with fossil fuels [1, 2]. Wood is the most common biomass type widely used [1-3]. However, there are regions where wood is scarce or with insufficient quantities to cover the existing market for solid biomass fuels [4]. This is typical for rural areas with intensive agriculture [5], where herbaceous biomass, *i.e.* crop residues, are used due to high availability and lower costs in comparison to wood and fossil fuels. However, crop residues have worse combustion properties comparing with woody fuels, due to the significantly higher content of ash and elements like N, K, S and Cl [6, 7].

The main consequences of the inappropriate combustion properties are higher potential for emissions of particulate matter (PM) in flue gases [8] and worse ash melting behaviour [9]. The success of combustion process regarding emissions of other pollutants and energy conversion efficiencies though depends on the quality of the heating appliance. For example, manual stoking causes incomplete combustion, due, first of all, to inability to control excess air ratio properly. Thereby, the automation of stoking process could significantly reduce emission of pollutants in flue gases and increase energy conversion efficiency [8].

Corn cobs are a fraction of the corn residues (corn stover), beside stalks, leaves (including tassels) and husks [10]. The common and new harvest technologies to collect separately corn cobs are thoroughly elaborated in several studies [10, 11]. Potentials of corn stover for energy generation are significant, since corn is one of the most widely grown field crops worldwide [12]. In Serbia, this is the case as well, where corn stover theoretical potentials rate up to 6 Mt [13]. The energy potential of corn cobs in Serbia is assessed to be about 1.2 Mt or about 430 ktoe [14]. This is the largest share of entire corn cobs potential, obtained on small & medium farms, where ears are solely harvested and after their natural drying in hovels and threshing, corn cobs remain available at farm premises. This significant potential is in Serbia almost completely used for household heating, but mostly in inefficient traditional stoves and boilers.

Corn cobs have more advantageous combustion properties comparing to other crop residues [15, 16]. Therewith, this fuel could better compete with woody fuels, aiming to reduce undesired effects after combustion. Moisture content of corn cobs, after drying and threshing of grains, reaches a value of about 12%, *i.e.* about 2% lower than that of grain [17]. The ash content rates, in average, 1.4% [15], which is lower than for other agricultural biomass, *e.g.* corn stover has an ash content of 6.7% and wheat straw of 5.7%, but higher than for woody biomass with average ash content between 0.9 and 1.2 [7]. The gross calorific value (GCV) of corn cobs is from 18.3 to 18.8 MJ kg^{-1} [15], while the net calorific value (NCV) with a moisture content of 11.5% rates around 15.7 MJ kg^{-1} [18].

Corn cobs and its combustion properties have not been investigated as a fuel so often as other crop residues. Several studies were though conducted to determine its potentials and quantities. The dry mass distribution in corn stover rates 50.9% stalk, 21.0% leaf, 15.2% cob and 12.9% husk [19]. Martinov *et al.* [17] stated that the average corn cobs yield, relative to grain, rates 18%, for the same moisture content. Djatkov *et al.* [20, 21] concluded that corn cob pellets have better mechanical properties than corn stover pellets. The bulk density of corn cob pellets was in range 550 to 720 kg m^{-3}, mechanical durability 88 to 99%, and pellet yield 98 to 100.0%. Martinov *et al.* [17] developed and tested a corn cob crusher, which application increased the bulk density from 104 to 227 kg m^{-3} and enabling its use as a fuel in boilers with automated stoking. Kaliyan and Morey [16] concluded that feedstock preheating to 85 °C activates the natural binders in corn cobs, suitable for pelleting or briquetting. Miranda *et al.* [18] produced corn cob pellets with bulk density higher than 600 kg m^{-3}, mechanical durability lower than 95% and a NCV of 15.68 MJ kg^{-1}, requesting the total specific energy of 0.1 kWh kg^{-1} for milling and pelleting. The ash melting behavior for corn cobs showed that the ash deformation temperature starts already above 1,030 °C [22], whereby comparing by woody biomass with deformation temperatures higher than 1,215 °C could restrict the utilization of corn cobs as a fuel for combustion.

Energy, economic and environmental assessment for utilization of other types of biomass have been investigated in numerous studies. Las-Heras-Casas *et al.* [23] investigated the replacement of fossil fuels by biomass pellets for heating and sanitary water heating in multi-family buildings in Spain. The savings of non-renewable primary energy consumption and CO_2 emissions were assessed to be over 90%. However, other emissions like CO, NMVOC and PM_{10} emissions increased significantly. Biomass boilers have made significant accumulated savings over the lifetime of the facility, in comparison with heating oil between 26.34 €/m^2 and 100.99 €/m^2, with LPG between 20.60 €/m^2 and 83.16 €/m^2, and natural gas between 0.27 €/m^2 and 16.73 €/m^2. The average heating energy cost was 5.23 € kWh^{-1} by using biomass, while for fossil fuels around 40%, 63% and 76% higher than for natural gas, LPG and heating oil, respectively. Wang *et al.* [24] conducted an economic and environmental assessment for a 25 kW wood pellet boiler with heat accumulator in northern New York State. The sensitive analysis showed that the investment cost, the pellets purchase price and the annual energy conversion efficiency were the three most important influencing factors on the heating energy cost. Thereby, 5.12 to 8.26 t a^{-1} of CO_2 emission could be saved by replacement of natural gas, heating oil and propane by wood pellets. Profitability assessment was performed for four types of boilers, to compare the utilization of olive husks with liquid petrol gas, diesel and electricity in Lebanon [25]. Regarding the average energy cost and net present value (NPV), heating by electricity is the most polluting and least cost effective. Heating energy costs during the appliance lifespan were approximately the same for other three fuels. In order to allow for profitable utilization of olive husks, import tax reduction on the import for olive husks should be introduced.

The objective of this research was to investigate whether and under which conditions the utilization of corn cobs as a fuel for heat energy generation in small residential heating appliances could be profitable in Serbia. Thereby, the three corn cob fuel forms, *i.e.* whole, crushed and pellets were considered in the three utilization scenarios and assessed for profitability in comparison with selected fuels. The most significant energy sources for residential heating, in Serbia, are firewood, electricity, coal, district heating systems and natural gas [26]. In this study, electricity was not selected as comparative energy source due to its unacceptable energy balance and environmental impact. Also, it was supposed that users in urban areas with access to district heating systems would not invest in a biomass heating appliance and therefore district heating was not selected as comparative energy source as well.

2. Materials and methods

2.1 Materials

2.1.1 Corn cob fuel forms and utilization cases

The three cases of the corn cob utilization as a fuel for residential heating are graphically presented in Fig. 1. These comprise the three different fuel forms, with appropriate storage, processing and transportation, whereby each form requires adequate heating appliance. The first case subsumes no fuel processing and the simplest heating appliances with manual stoking. The following cases imply utilization of the improved fuel forms in more sophisticated combustion appliances with automated stoking, higher efficiencies and lower emissions of pollutants.

In the first case, whole corn cobs are stored in hovels within the farm premises prior to utilization for own residential rooms heating (no transport needed). The heating appliance with manual stoking has simple control of the combustion process. The second case is an advanced approach with fuel processing by size reduction (crushing) to enable automated stoking. Crushed corn cobs are utilized either for own heating needs or traded within the same rural community, optionally delivered to biomass user with additional packaging, transport (up to 30 km) and storage. The third case is similar to the second one, but the fuel processing includes, besides grinding, the pelletizing. Therewith, fuel bulk density is significantly increased, enabling its shipping to longer distances (up to 300 km).

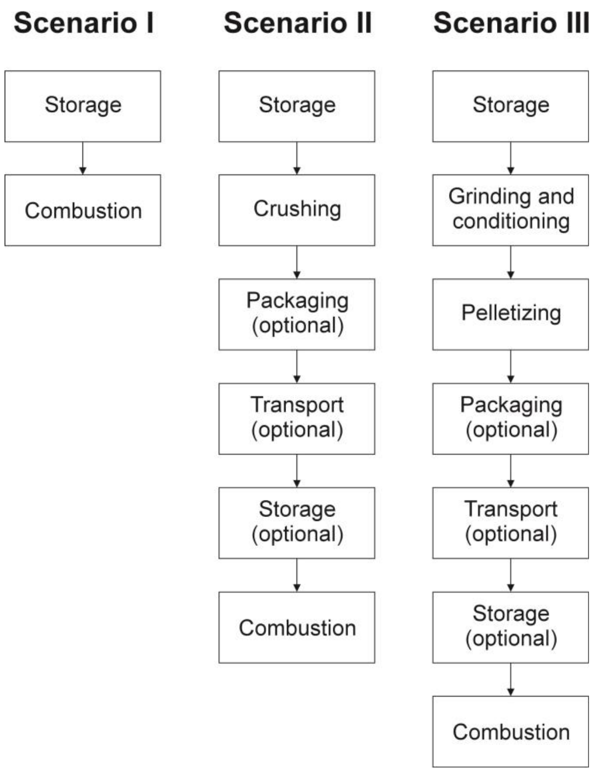

Fig. 1 Three investigated cases of corn cob fuel processing and utilization

2.1.2 Properties, prices and costs of fuels and heating appliances

Fuel properties and their purchase prices are given in the Tab. 1. Moisture contents and net calorific values for the three corn cob fuel forms available on the Serbian market were determined in line with the standard procedures [27, 28], and for natural gas and woody biomass (beech) literature data were used [6]. Purchase prices that users should pay for corn cobs were collected from biomass producers and traders [29, 30] and for other fuels the actual market prices were used [31, 32].

Tab. 1 Properties and purchase prices of assessed fuels

Fuel	**Natural gas**	**Coal–lignite**	**Wood logs**	**Wood chips**	**Wood pellets**	**Whole CC**	**Crushed CC**	**CC pellets**
MC, % (*w.b.*)	–	24.00	20.00	20.00	8.00	7.47	7.47	8.92
NCV, kWh kg^{-1}	9.30[a]	4.60	4.00	4.00	4.70	4.37	4.37	4.29

Purchase price, € t^{-1}	30.20[b]	115	105	75	180	30	100	140

CC: corn cobs; MC: Moisture content; w.b.: wet based; NCV: Net calorific value; [a]kWh Sm^{-3}; [b]€c Sm^{-3}.

In the Tab. 2 are given the technical data of analyzed heating appliances, as well as their investment and operating costs, collected from producers and traders of heating appliances [33-35]. The data variation, shown below the table, was conducted when two different fuels are used in the same appliance. All fuels and heating appliances data were further used to perform the profitability assessment.

Tab. 2 Technical data, investment and operating costs of assessed heating appliances

Appliance	1	2	3	4
Power, kW	24	30	29	25
Stoking	A	M	A	A
Fuel	Natural gas	Whole CC / Coal / Wood logs	Crushed CC / Wood chips	CC pellets / Wood pellets
Annual efficiency, %	90	55 / 60 / 50	60	90 / 92
Lifespan, years	20	12 / 10/ 15	12 / 15	15 / 18
Investment cost, €	550	680	2,100	2,580
Transport cost, €	0	0	121	0
Installation/testing, €	200	150	200	150
Maintenance, €	20	50 / 0	50	50
Material costs, €	20	50	50	100 / 50

A: automatic; M: manual; CC: Corn cobs.

2.2 Methods

2.2.1 Profitability assessment approach

Profitability assessment was conducted by means of the calculator and decision-aid tool named ***BiomasaPro***, developed by the authors of this paper [6]. The assessment approach is in line with the parameters, criteria and rules of the Ministry of Energy and Mining of Republic of Serbia, defined in the guideline intended for planning and construction of energy facilities [36]. The parameters and criteria for profitability assessment are presented in the Tab. 3, whereby they differ for the two considered investment options, which is more comprehensively explained in the further text.

The user-friendly environment of the calculator ***BiomasaPro*** is developed in the Microsoft Excel and adapted for potential biomass users (investors) allowing the profitability assessment of small appliances predominantly for residential heating. Therefore, the aim of this calculator is to support potential investors in their decision regarding investment. The investor should collect figures about heating appliances either from a producer or a trader (those shown in Tab. 2), assess the heating energy needs of a residential (by its own using the guidelines in [6] or other relevant literature, or consult an expert from the relevant field) and to obtain the economic prerequisites for the investment (interest rate, payback period) from the bank. All these should be used as input data in the calculator. Alternatively, the calculator could be used for research purposes, as in the presented study.

As a feedback, ***BiomasaPro*** user gets the results about NPV (option construction), and the results about NPV, IRR and PBP (option reconstruction), as explained in the next two paragraphs, depending on the investment option considered and analyzed. Based on the obtained results and the assessment of those by means of the criteria for positive assessment (Tab. 3), user also gets the assessment (answer, verdict) whether the investment under analysis is profitable or not (examples presented in the Fig. 2). Eventually, the conducted case study of the investment by this calculator and the obtained results could be submitted to a bank as a business plan needed to obtain a bank loan (the outline of the calculator is a ready-made report). These results were appropriately used for profitability assessment in this study as well, as presented in Tab. 4 and 5.

Parameter	Value	Criterion	VIABLE
NPV_1 - NPV_2	-8,707 €	< 0	YES

Investment ih the heating appliance that uses whole corn cobs comparing with one for wood logs is profitable

a)

Parameter	Value	Criterion	Complies
PBP	1.33 years	< 12 years	YES
NPV	7,833 €	> 0	YES
IRR	75.44 %	> 1%	YES

Investment ih the heating appliance that uses whole corn cobs comparing with one for wood logs is profitable

b)

Fig. 2 Profitability assessment examples in the option construction (a) and reconstruction (b)

Two investment options in biomass heating appliances were considered and accordingly the two ***BiomasaPro*** versions used. The first subsumes ***construction***, *i.e.* installing a new heating system that uses either corn cob (whole, crushed or pellets), or fossil (natural gas or coal) or woody biomass (logs, chips or pellets). In this case, positive assessment of the heating appliance that uses corn cobs is considered if the NPV of all generated costs is lower than for the comparative fuel, Eq. (1).

$$NPV = \sum_{i=0}^{n} \frac{B_i}{(1+d)^i} \tag{1}$$

Where, d is the discount rate, B0 is the investment cost, Bi (i = 1, 2, ... , n) is the generated cost in the n-th year, n is the project duration.

The second option subsumes ***reconstruction***, *i.e.* replacement of an existing heating appliance that uses fossil or woody biomass fuel, by new one that uses corn cob. The three parameters in the Tab. 3 were used for the profitability assessment. If values of all parameters satisfy defined criteria, the investment is considered to be economically viable, *i.e.* profitable. NPV here represents the savings generated during the project duration through replacement of fossil or woody biomass fuel by corn cob, Eq. (2). Internal Rate of Return (IRR) is the discount rate, for which the sum of net savings during the project duration is equal to the actual investment cost, Eq. (3a and 3b). The discount rate is calculated as the average weighted value of the interest rates of the total project financing sources (own resources and bank loan). In the case of financing from own resources the discount rate amounts

1% and in the case of bank loan of 100% of the capital costs it amounts 14.95% [37]. The project duration is adopted as the lifespan of heating appliance for corn cobs (see Tab. 2). Payback Period (PBP) is the last year in which the sum of investment cost and the savings generated after the investment is less than zero.

$$\mathrm{NPV} = \sum_{i=0}^{n} \frac{B_i}{(1+d)^i} \tag{2}$$

Where, d is the discount rate, B_0 is the investment costs, B_i (i = 1, 2, ... , n) is the difference in costs before and after the investment in the n-th year, n is the project duration.

$$\mathrm{IRR} = d \tag{3a}$$

$$\text{if it is:} \quad \sum_{i=0}^{n} \frac{B_i}{(1+d)^i} = 0 \tag{3b}$$

$$\sum_{j=0}^{m} \frac{B_j}{(1+d)^j} < 0 \tag{4}$$

$$\mathrm{PBP} = m + \frac{\mathrm{NPV}_m}{\mathrm{NPV}_m - \mathrm{NPV}_{m+1}} \tag{5}$$

Where, m is the last year in which the sum of investment cost and the savings generated after the investment is less than zero, NPV is the discounted cumulative generated savings in the last year (m) and the next one (m+1).

Tab. 3 Parameters and criteria for the profitability assessment, option *reconstruction*

Parameter	Criteria for positive assessment
PBP	Shorter than project duration
NPV	> 0
IRR	Higher than discount rate

PBP: Payback period; NPV: Net present value; IRR: Internal rate of return.

It was assumed that the appropriate corn cobs forms are fuels for users with different economic power, due to their lifestyle and comfort preference. Accordingly, users of corn cobs for heating the houses with the surface of 100 m^2 were assessed assuming their energy needs: of whole corn cobs 200 $kWh\ m^{-2}\ a^{-1}$, crushed corn cobs 150 $kWh\ m^{-2}\ a^{-1}$, and corn cob pellets 100 $kWh\ m^{-2}\ a^{-1}$. Assumption was made that all considered fuels, except the natural gas, are supplied twice before the heating season. Therefore, half of the annual fuel purchase costs for the first year, increased by 20% as uncertainty of the energy needs, including operating costs of the first project month, were considered as the current assets.

2.2.2 Sensitivity analysis

The sensitivity analysis was conducted to determine the highest acceptable purchase price that would allow for profitability, if the utilization of corn cobs was assessed as viable. In opposite, the minimal needed purchase prices of corn cob were determined. Further, the financing source was simulated by checking the influence of bank loan on the profitability of viable scenarios. Thereby, the loan of 100% of the investment costs, with the interest rate of 14.95% and the payback period of 7 years were used, which are valid for small projects in the field of renewable energy sources [37]. Finally, minimal needed subsidies were determined if the utilization of corn cobs was not assessed as viable, both for the generated renewable energy and for the investment cost.

Heating appliance for whole corn cobs combined with a heat accumulator was compared to the one using natural gas as well. The additional investment cost of heat accumulator was 500 €, increased by the installation costs of 100 €. The annual efficiency of the appliance with manual stoking of whole corn cobs thus increases to 65%. Therewith, it was determined whether the heating system automation with the cheapest corn cob fuel form could provide opportunity to replace fossil fuel, simultaneously retaining the comfort and attaining the increased efficiency and lower emissions.

3. Results and Discussion

Profitability assessment results for the three corn cob fuel forms are presented in the following Tab. 4 and 5, for the options *construction* and *reconstruction*, respectively. The results show that investment in a heating appliance with manual stoking of whole corn cobs (the first case, Fig. 1) is profitable comparing with appropriate appliance for wood logs and coal. Thereby, around 8,700 and 7,000 € could be saved after the project duration (12 years), respectively. Additional comparison with natural gas shows that the investment is viable as well, saving more than 4,000 after 12 years without, and more than 4,700 € and after 15 years with heat accumulator. The worst economic parameters were obtained comparing with natural gas, although the used price of natural gas is rather low. Among remaining fuel forms, utilization of corn cob pellets comparing with wood pellets show similar results but generating about 300 € more costs after 15 years.

Tab. 4 Profitability assessment, option *construction*

Whole corn cobs		**$NPV_1 - NPV_2$, €**	**Viable**
CC	W logs	–8,707	YES
CC	Coal	–6,978	YES
CC	NG	–4,105	YES
CC+HA	NG	–4,751	YES
Crushed corn cobs		**$NPV_1 - NPV_2$, €**	**Viable**
CC	NG	4,714	NO
CC	W chips	1,625	NO
Corn cob pellets		**$NPV_1 - NPV_2$, €**	**Viable**
CC	NG	5,666	NO

CC	W pellets	315	NO

NPV_1 – NPV_2: Difference of NPV of generated costs between corn cobs and comparative fuel; HA: Heat accumulator; CC: Corn cobs; W: Wood; NG: Natural gas.

The results for the *reconstruction* are similar. Only a heating appliance for whole corn cobs could profitably replace an old one either for wood logs or coal, with generated savings around 7,800 and 5,500 €, respectively, whereby payback periods are shorter than 2 years. In comparison with natural gas, the additional investment in a heat accumulator resulted in higher savings due to extended lifespan of the heating appliance, but also longer PBP and lower IRR. These results are more favorable comparing with investigation conducted by Las-Heras-Casas *et al.* [23], where biomass pellet boiler that replaced a natural gas boiler had a PBP between 12 and 20 years and IRR between 5% and 13%.

Tab. 5 Profitability assessment, option *reconstruction*

Whole corn cobs		**PBP, a**	**NPV, €**	**IRR, %**	**Viable**
CC	W logs	1.33	7,833	75.44	YES
CC	Coal	1.72	5,526	57.90	YES
CC	NG	2.44	3,613	38,66	YES
CC+HA	NG	3.56	4,633	25.63	YES
Crushed corn cobs		**PBP, a**	**NPV, €**	**IRR, %**	**Viable**
CC	NG	nr	–3,758	<0	NO
CC	W chips	nr	–3,897	<0	NO
Corn cob pellets		**PBP, a**	**NPV, €**	**IRR, %**	**Viable**
CC	NG	nr	–4,465	<0	NO
CC	W pellets	nr	-193	<0	NO

PBP: Payback period; NPV: Net present value of generated savings by fuel replacement; IRR: Internal rate of return; HA: Heat accumulator; CC: Corn cobs; W: Wood; NG: Natural gas; nr: not relevant.

Sensitivity analysis of fuel purchase prices on the profitability, for the option *construction* is presented in the Tab. 6. Shown are relative increase and decrease of corn cob fuel prices that allow for profitable investment, depending whether the case is viable or not. The results show that prices for whole corn cobs could be approximately 2.4 to 4 times higher than actual prices on the market. In opposite, prices for crushed corn cobs should be decreased around 70% and 25%. Any price decrease of corn cob pellets could not allow for profitable investment comparing with natural gas, whereby price of corn cob pellets should be even slightly decreased in comparison with wood pellets.

Tab. 6 Sensitivity analysis of corn cob fuel purchase prices, option *construction*

Case: whole corn cobs			
CC – W logs	CC – Coal	CC – NG	CC+HA – NG
+297	+237%	+140%	+157%

Case: crushed corn cobs	
CC – NG	CC – W chips
–71%	–25%

Case: corn cob pellets

CC – NG	CC – W pellets
nr	-6%

CC: Corn cobs; W: Wood; NG: Natural gas; HA: Heat accumulator; nr: not relevant.

Sensitivity analysis of fuel prices for the *reconstruction* is presented in the Tab. 7. The results show that prices for whole corn cobs could be 1.9 to 3.1 times higher, whereby for crushed corn cobs prices should be around 10 times lower. Pellet prices should be decreased 11% when comparing with wood pellets, whereby any price decrease of corn cob pellets could not allow for profitable replacement of natural gas.

Tab. 7 Sensitivity analysis of corn cob fuel purchase prices, option *reconstruction*

Case: whole corn cobs			
CC – W logs	CC – Coal	CC – NG	CC+HA – NG
+210%	+150%	+87%	+100%

Case: crushed corn cobs	
CC – NG	CC – W chips
–90%	–92%

Case: corn cob pellets	
CC – NG	CC – W pellets
nr	–11%

CC: Corn cobs; W: Wood; NG: Natural gas; HA: Heat accumulator; nr: not relevant.

Sensitivity analysis with respect to financing sources for the option *reconstruction* is presented in the Tab. 8. Despite additionally generated costs by the bank loan that worsened the three economic parameters, all analyzed cases remain profitable. Thereby, replacement of natural gas by whole corn cobs including heat accumulator is a boundary case since the achieved IRR is slightly higher than the discount rate (14.95%).

Tab. 8 Sensitivity analysis of financing sources, option *reconstruction*

Whole corn cobs		**PBP, a**	**NPV, €**	**IRR, %**	**Viable**
CC	W logs	1.96	2,396	64.07	YES
CC	Coal	2.78	1,608	46.87	YES
CC	NG	4.73	797	27.63	YES
CC+HA	NG	8.80	475	15.92	YES

PBP: Payback period; NPV: Net present value of generated savings by fuel replacement; IRR: Internal rate of return; HA: Heat accumulator; CC: Corn cobs; W: Wood; NG: Natural gas.

The following two tables (Tab. 9 and 10) show the sensitivity analysis with respect to minimal needed subsidies for profitable investment. The subsidies for the generated renewable energy could allow the viability, whereby all annual amounts, except for the comparison with wood chips (*construction*), and with wood pellets (*reconstruction*), are higher than 400 €/a. Such high subsidies could not be expected to be approved. In contrary, the subsidies for the investment cost could allow viable investment for the option of a new heating appliance for the crushed corn cobs in comparison with one for the wood chips or for the comparison of corn cob pellets with wood pellets. The first needed minimal share of around 40% could be approved only for the reason of rural development (agricultural region), since both compared fuels are biomasses.

Tab. 9 Sensitivity analysis of subsidies, option *construction*

		Subsidy: energy		Subsidy: investment
Crushed corn cobs		**€/MWh**	**€/a**	**%**
CC	NG	28,3	425	nr
CC	W chips	9,8	147	41
Corn cob pellets		**€/MWh**	**€/a**	**%**
CC	NG	41,3	412	nr
CC	W pellets	3	30	7

CC: Corn cobs; W: Wood; NG: Natural gas; nr: not relevant.

Tab. 10 Sensitivity analysis of subsidies, option *reconstruction*

		Subsidy: energy		Subsidy: investment
Crushed corn cobs		**€/MWh**	**€/a**	**%**
CC	NG	37,6	564	nr
CC	W chips	38,5	576	nr
Corn cob pellets		**€/MWh**	**€/a**	**%**
CC	NG	51,8	517	nr
CC	W pellets	5	50	nr

CC: Corn cobs; W: Wood; NG: Natural gas; nr: not relevant.

4. Conclusions

The conducted profitability assessment shows that only whole corn cobs are profitable for utilization in small residential heating appliances in Serbia. This is valid for the utilization of corn cob pellets comparing with wood pellets in option *construction* as well, but the profitability is highly sensitive on the purchase price increase. However, utilization of corn cob pellets could be profitable in option *construction*, if purchase prices would be decreased more than 5%. Alternatively, subsidies for investment in *construction* of heating appliance based on crushed corn cobs, in comparison with wood chips, could result with profitable investment. Additionally, replacement of wood pellets with corn cob pellets could be also profitable with subsidies to support rural development. The bank loan, as a financing option, does not change profitability of option *reconstruction* of a heating appliance by the one for whole corn cobs. The stated findings are valid only for the comparative assessment with appropriate woody and fossil fuel forms.

Future investigation should focus comprehensive sustainability assessment comprising, beside economic, also social and environmental aspects. Therewith, the assessment would be based also on the fuel availability on the market and its acceptability by biomass users (social aspect), as well as on the climate change impact and emission of pollutants caused by combustion (environmental aspect). This would enable to draw the conclusions if a corn cob fuel is sustainable to generate heat energy in residential area. Thereby, improved fuel forms, *i.e.* crushed and corn cob pellets, should be promoted and possibly subsidized to achieve profitability, if they enable trading on the market and contribute to the air quality improvement. The approach used and shown is applicable for profitability assessment in other regions, and for other fuels and their forms.

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