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Holistic Assessment and Ethical Disputation on a New Trend in Solid Biofuels

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Abstract A new trend in the production technology of solid biofuels has appeared. There is a wide consensus that most solid biofuels will be produced according to the new production methods within a few years. Numerous samples were manufactured from agro-residues according to conventional methods as well as new methods. Robust analyses that reviewed the hygienic, environmental, financial and ethical aspects were performed. The hygienic and environmental aspect was assessed by robust chemical and technical analyses. The financial aspect was assessed by energy cost breakdown. The ethical point of view was built on the above stated findings, the survey questionnaire and critical discussion with the literature. It is concluded that the new production methods are significantly favourable from both the hygienic and environmental points of view. Financial indicators do not allow the expressing of any preference. Regarding the ethical aspect, it is concluded that the new methods are beneficial in terms of environmental responsibility. However, it showed that most of the customers that took part in the survey are price oriented and therefore they tend to prefer the cheaper—conventional alternative. In the long term it can be assumed that expansion of the new technology and competition among manufacturers will reduce the costs.

Keywords Ethics in decision making · Financial analysis · Cost breakdown · Subsidy policy · Biofuels

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Introduction

The economy of solid biofuels has to deal with many competing pressures (Maroušek 2013a). In particular it is the higher price and the scepticism regarding the possible subsequent increase of food prices (Brennan and Owende 2010). On the other hand, solid biofuels have been supported by many national governments of the European Union (EU) state members (Maroušek et al. 2015b). The inventive and political activities concerning solid biofuels have been intensified whenever the price of fossil fuels increased (Maroušek 2013b). The production boom of solid biofuels occurred in the late twentieth century when politically motivated interventions in the free market began to appear (Fantozzi and Buratti 2010). The most famous is the commitment of the European Union, which has undertaken to increase the share of renewable energy to 20 % by 2020 (Elmay et al. 2013).

The EU policy that included subsidy strategies for biofuels as such has encountered a number of negative responses within the professional community, though they also have many supporters (Maroušek 2014a). The ethical criticism was summarized by e.g. Kay and Ackrill (2012); the positives were viewed by e.g. Gomiero et al. (2010). Generally speaking, many authors agree that strictly from the economical point of view biofluel production on the whole is unprofitable if not subsidized. For instance, in the case of biodiesel Hill et al. (2006) and many others state, biofuel production provides sufficient environmental and ethical benefits to justify the governmental subsidy.

The EU supports the production and utilization of biomass energy in diverse forms, pursuing indicative European Union targets for renewable energy. In many developed countries biofuel production is supported mainly by means of tax advantages that are combined with e.g. new biotechnology investments and technological construction subsidies designated for biofuel production (Mardoyan and Braun 2015). Political goals that raise ethical questions are as follows: (1) utilization of fossil fuels; (2) nuclear energy; (3) energy savings; (4) renewable energy and overall social-economic aspects (Maroušek et al. 2015a). The last point concerns the solid biofuels for the following reasons:

The solid biofuels are known to have combustion values close to the lower quality of brown coal. Although pelleted or balled, the physical–mechanical properties of solid biofuels are naturally worse. From a technical point of view, it is necessary to take into account the specific temperature of melting ash and other corrosive factors. If the combustion of solid biofuels meets the required parameters, hazardous emissions are not usually produced. In addition to environmental benefits this can be considered ethically beneficial. However, if the temperature of combustion decreases, hazardous combustion products may be released, which depends on the nutrition of burned plants (the fertilizer that is used). This is obviously considered environmentally and ethically negative. If fertilized intensively it may contain increased amounts of sulphur, alkaline earth metals or organic chlorine, which brings even more ethical considerations. Solid biofuels harmless to health can then be reached only by using uncontaminated agro-industrial plant wastes in their production (Di Giacomo and Taglieri 2013). The condition of absence of chemical contamination would improve the physicochemical and environmental parameters in comparison to traditional charcoal agro-waste fuel of plant origin. Ethical questions concerning the diverse negative impacts of a solid biofuel production policy have been raised worldwide (see e.g. Soytas and Sari 2009; Alberola et al. 2008; Umbach 2010). Some European countries being beware of this have specified parameter standards in order to guarantee the effective and environmentally-friendly combustion of these kinds of biomass (García-Maraver et al. 2011). However, this approach adversely affects the consumer price of the product (Mani et al. 2006).

In this context, the following discussion aims at assessing the effects of a new trend in the technology of solid biofuel production. It covers the environmental and hygienic perspective as well as financial analysis and ethical questions related to customerś decision impulses at the time of buying a heating resource. The environmental and hygienic reasons stand behind the long inventive efforts to raise the temperature for the combustion of solid biofuels, which would solve the problems of undesirable combustion products. Coherently and in the larger context these reasons and suggestions of possible solutions are described e.g. in Van der Stelt et al. (2011) or Wannapeera et al. (2011). However, their suggestions are connected with a costly production process. Another suggestion involves the addition of coal dust to the biomass mixture for biofluel manufacture (Tumuluru et al. 2012). By this, however, the environmentally positive impacts of biofuels are reduced—for example, the resulting ash cannot rationally be used as a plant fertilizer.

To eliminate the above mentioned problems a technical solution has been suggested in Maroušek (2014b). The principle of it consists of enriching the lignocellulose with fine charcoal. The advantage of this mixture lies in the fact that (1) the charcoal is almost free of any pollutants; (2) it has a high energy density and (3) reaches very high temperatures. Low production costs can be achieved if waste materials and waste heat are used for the production of charcoal (Syred et al. 2006).

In relation to the above, the question was raised as to whether the new production method results in changes in hygienic, environmental and financial perspectives and whether the corresponding multidisciplinary analytical methods allow its assessment with statistical significance. Last but not least, the willingness of private customers to pay higher prices for a more ethically responsible product has been an additional subject of investigation.

Methodology and Results

The laboratory experiments were carried out in order to compare the conventional solid biofuels and the samples that were produced by the new production methods. The conventional biofuels were represented by straw (I), sawdust (II) and fermentation residues (III), which, according to market analysis (not stated), represent the most common solid biofuels in the EU. All the feedstocks were dried at 75 °C in the SD 1060 large volume laboratory dryer (SalvisLab AG, Switzerland) until the water content settled at 8 %. Subsequently the dried feedstock was subjected to the HLS 50 pelleter (Briklis Ltd., United Kingdom). The diameter of the pelletizing aperture was set to 6 mm to reflect the established practice.

The new type of biofuel was produced analogously, with the fact that a half (by weight) of the feedstock was subjected to low temperature pyrolysis according to Maroušek (2015). Briefly, the UHL—07 (Aivotec, s.r.o., Czech Republic) pyrolysing apparatus consists of the entrance hopper equipped with an inner vertical slow motion helix. The slowly rotating helix continuously compresses the material down into the disk mechanical turnstile located at the bottom of the hopper. The turnstile provides a minimum air leakage to minimize combustion and related ash formation. The turnstile leads to the pyrolysis chamber, which is made up from a thick-walled refractory horizontal wide cylinder, where the material was exposed to the waste heat from the biogas cogeneration unit. The operating temperature was set to 380 °C and the speed of the horizontal helix that is responsible for the hydraulic retention time was set to 0.5 Hz, which corresponds to the delay of the feedstock in the pyrolysis chamber for approximately 3 min. Subsequently the charred feedstock was mixed by the MX 1600 DP mixer (Extol Industrial a.s., Czech Republic) with the untreated feedstock.

The fuels were classified according to the European Committee for Standardization: European Norms 14961 (Fuel specifications and classes—Part 1: General requirements). The content of water (hereinafter referred as M) was double checked by the EN 14774-1 (Determination of moisture content—Oven dry method—Part 1: Total moisture—Reference method); 14774-2 (Determination of moisture content—Oven dry method—Part 2: Total moisture—Simplified method) and 14774-3 (Determination of moisture content—Oven dry method—Part 3: Moisture in general analysis sample). Nitrogen content (hereinafter referred as N), a prerequisite for the formation of nitrogenous flue gases was analysed using the 15104 (Determination of total content of carbon, hydrogen, and nitrogen—Instrumental methods). Sulphur (hereinafter referred as S) and Chlorine (hereinafter referred as Cl), both prerequisites for the formation of hygienically inappropriate combustion gases were measured using the 15289 (Determination of total content of sulphur and chlorine). The level of volatile organic compounds in the combustion gases (hereinafter referred as VOC), one of the most critical indicators of the quality of solid biofuels, was analysed according to the 15148 (Determination of the content of volatile matter). Heating value (hereinafter referred as HV), another indicator of biofuel quality, was analysed using the 14918 (Determination of calorific value). Given that heavy metals levels did not change during the pyrolysis, they were not analysed. Method 15370-1 was used to define the ash melting temperature (hereinafter referred as AMT) (Determination of ash melting behaviour, characteristic temperatures method). The density (hereinafter referred as D), respectively bulk density is an important logistic indicator 15103 (Determination of bulk density), other methods and routine operations were carried out according to established laboratory practice, all $n = 12$, $\alpha = 0.05$.

In response to the above analyses the financial standpoint was examined. It is based on the average prices of biomass pellets supplied in the Czech market and price estimates related to the components of mixtures in a one-to-one ratio as shown in Table 1. Default data of price per tonne and energy value originate from market prices in the period of 2014–2015 and averaged out in Table 2.

Table 1 Chemical and physical characteristics of solid biofuels, all $n = 12$, $\alpha = 0.05$

Characteristics/ samples	M (%)	N (mg g^{-1})	S (mg g^{-1})	Cl (mg g^{-1})	VOC (%)	AMT (°C)	HV (MJ kg^{-1})	D (kg m^{-3})
I. Straw	8.5 ± 0.4	36.3 ± 2.1	7.50 ± 1.2	4.36 ± 0.2	78.2 ± 2.1	733.4 ± 1.1	14.03 ± 0.0	901 ± 0.1
I. +Charcoal	3.9 ± 0.2	21.0 ± 3.5	5.33 ± 0.8	3.53 ± 0.5	41.1 ± 3.3	1004.7 ± 4.4	18.49 ± 0.0	900 ± 0.2
II. Sawdust	7.8 ± 0.3	63.4 ± 5.5	7.42 ± 1.0	3.96 ± 0.4	80.6 ± 2.5	749.5 ± 0.9	14.21 ± 0.0	901 ± 0.1
II. +Charcoal	3.8 ± 0.2	33.6 ± 2.6	4.26 ± 0.9	3.51 ± 0.7	39.8 ± 1.4	1077.9 ± 3.5	18.48 ± 0.0	900 ± 0.1
III. Fermentation residue	9.6 ± 0.2	42.3 ± 7.1	4.48 ± 0.4	3.21 ± 0.2	62.2 ± 2.7	864.3 ± 4.1	14.20 ± 0.0	902 ± 0.1
III. +Charcoal	4.2 ± 0.3	22.9 ± 3.6	4.14 ± 0.5	3.15 ± 0.3	31.7 ± 3.1	1116.2 ± 7.3	18.51 ± 0.0	900 ± 0.0

Table 2 Financial view on the examined pellet samples from the perspective of potential consumers

	Samples/price	PW (EUR t^{-1})	PE (EUR GJ^{-1})
1	I. Miscanthus straw	170	10.3
2	I. +Charcoal	185	9.4
3	II. Sawdust	155	10.9
4	II. +Charcoal	177.5	9.8
5	III. Fermentation residue	148	9.8
6	III. +Charcoal	174	8.7

PW price per weight (Euros per ton = 1000 kg), *PE* price per energy (Euros per GigaJoule)

From the consumerś view, the biofuel prices will be accepted if they are competitive with other fuels representing a substitute for a particular purpose (usually gas, electricity, brown coal, etc.). The rational decision-maker leans upon the estimates of total cost associated with purchasing and operating the heating system. For an averaged four member family house the average yearly heating costs (in EUR) are captured in Fig. 1 (the average costs correspond to the Czech market prices in 2015). They include investment (without subsidy), maintenance costs and fuel purchase including the lump sum payments.

Including the investment subsidy (biomass boiler: 80 %, coal boiler: 70 %, gas boiler: 75 % and heat pump: 80 % of eligible costs to a maximum of 30 thousand EUR according to the current legislative conditions in the Czech Republic) the optimal choice according to the criteria of cost minimization leads to the purchase of a coal or wood heating system.

The subsidizing of investments of heating fuels is apparent in many European countries (García-Maroto et al. 2015). Other significant factors influencing the final price, and hence the consumerś demand, are: the development of production technologies; cost of cultivation; harvest and collection cost; cost of transportation, etc. According to Lamers et al. (2015) the demand for solid biofuels is increasing

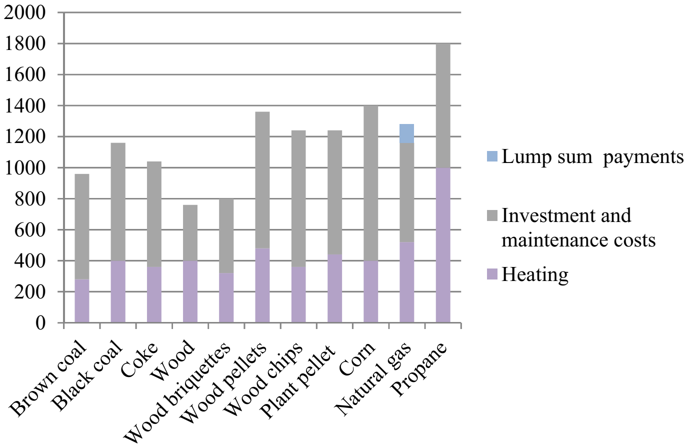

Fig. 1 Cost breakdown: investment in heating systems and fuel costs for a four member family house (yearly in EUR)

Table 3 A realistic scenario of price development for the selected solid biofuels in Euro/GJ (Analyses 2013)

Year/Euro/GJ	Straw	Wood chips	Wood pellets	Year/Euro/GJ	Straw	Wood chips	Wood pellets
2012	5.5	6.1	8.3	2025	6.1	6.8	8.7
2013	5.5	6.1	8.3	2026	6.2	6.9	8.7
2014	5.5	6.1	8.3	2027	6.2	6.9	8.8
2015	5.6	6.2	8.4	2028	6.3	7.0	8.8
2016	5.6	6.2	8.4	2029	6.4	7.1	8.9
2017	5.7	6.3	8.4	2030	6.4	7.1	8.9
2018	5.7	6.4	8.5	2031	6.5	7.2	8.9
2019	5.8	6.4	8.5	2032	6.5	7.2	9.0
2020	5.8	6.5	8.5	2033	6.6	7.3	9.0
2021	5.9	6.6	8.6	2034	6.6	7.3	9.0
2022	6.0	6.6	8.6	2035	6.7	7.4	9.1
2023	6.0	6.7	8.6	2040	6.9	7.6	9.2
2024	6.1	6.7	8.7	2045	7.1	7.9	9.4

worldwide annually. This view is also shared by Hoefnagels et al. (2014) who predicted the biomass resource development for the period 2010–2020. Consequently, the solid biofuel price, as an outcome of the demand and supply relationship, changes as well. Its development was predicted in Analyses (2013) for selected solid biofuels within realistic estimates—see Table 3.

In connection with diverse solid biofuel prices the ethical question was raised as to whether the customers have clear and comprehensive information about heating resources at the time of their purchase of their heating system and what are the main customerś preferences. The follow-up survey was conducted with the aim to estimate the future market position of innovative solid biofuel products analysed above (see Tables 1 and 2). The research covered private customers in the Czech market (n = 1021) who intended to purchase or who had purchased the heating systems for houses in the period 2014–2015 (the questionnaire data were collected in stores and via e-mails) and included the following questions:

1. What most influenced your choice of heating resource?
2. Were you informed about any limitations concerning the utilization of solid biofuels in terms of health and environment?
3. Were you informed about any technical problems in connection with the utilization of solid biofluels?
4. Did you hear about any research in the field of solid conventional fuel and biofuels?
5. Are you afraid of any side effects which can be caused by an inefficient energy subsidy policy?

Discussion of Results

The results in Table 1 indicate very similar behaviours when comparing the mixture biofuels versus one-component conventional biofuels—most of the characteristics of charcoal enhanced samples show better results. The increased concentrations of the chemical elements N, S, Cl in conventional bio waste are supposed to be the result of the application of fertilizers. There was nearly a 100 % drop in volatile organic compounds (VOCs) in the examined charcoal-mixed samples. Although, according to hygienic norms, none of the measures exceeded the approved limits, the harmful effects of controlled combustion to human health can be exhibited (irritation to the eyes, nose and throat especially with sensitive people (Avakian et al. 2002); more serious manifestations such as headaches, nausea, or nerve problems are described in Yu and Kim (2010)). Although it cannot be implied that a higher calorific value necessarily means a higher combustion temperature, in the examined cases this alternative obviously arises. We can deduce this not only from the operating data but also because of the new type of biofuel production, which was associated with lower VOC levels; these occur in particular under conditions of incomplete combustion at lower temperatures. From a *hygienic* and *environmental point of view* the mixed samples are socially more preferable.

The outcomes shown in Table 2 reveal the higher costs relating to average prices per weight for mixed samples (row 2, 4 and 6) as a result of the higher charcoal market price compared to one-component products. As for the unit energy price, the mixed samples show a slight cost advantage because of the enhanced energy value that results from the addition of charcoal. As for the *financial aspect* the results do not allow the determination as to whether the innovative production technologies represent cost savings. The reason is as follows: although the new biofuels are technologically advanced, the purchase price of the production apparatus is influenced considerably by the prices of the production technology. Thus, this micro-economical effect makes the overall cost of the conventional and the new biofuels currently similar. In the long term the development of biofuel technology costs strongly depends on the state of competition between the heating technology producers. This issue, however, is difficult to predict; Table 3 shows forecasts up to the year 2045 that evidently involve only the expected inflation rate. The difficulty of any long-term price prediction regarding the future cost of an energy technology was justified in Neij (2008) who confirmed large uncertainties in cost prediction for some bioenergy technologies that had not been captured by the curves based on historical data. However, taking into account the global market behaviour over the past ten years covering either the development of cost-saving technologies and strong competition among manufacturers it can be assumed that this effect is temporary and the production costs of the new biofuels will become more favourable in the near future.

The related ethical concern was examined as to whether the customers will have clear and full information about heating sources at the time of their purchase and what would their preferences be? The research was focused on respondentś knowledge about the effects of solid biofuel use from different points of view:

Regarding *question 1* (*What most influenced your choice of heating resource?*), most respondents (86 %) primarily took costs into account (heating system purchase price, expected yearly maintenance costs, expected yearly fuel costs and subsidy access). A minority of responses reflected characteristics such as good energy value, quality of heating devices used, previous practices or distrust of the positive effects of biofuels.

Question 2 (*Were you informed about any limitations concerning the utilization of solid biofuels in terms of health and environment?*) generated a negative response (84 %). Only a few of the subjects recognised information as sufficient concerning the awareness of lower energy value, storage space demand, and a special heating system.

As for *question 3* (*Were you informed about any technical problems in connection with utilization of solid biofluels?*), the majority responded positively to this (91 %) feeling that the heating system suppliers had informed them adequately.

The *question 4* (*Did you hear about any research in the field of solid conventional fuel and biofuels?*) was positively responded to by 8 %; the rest of respondents were either not interested in scientific research or did not have any access to it.

The last *question 5* (*Are you afraid of any side effects which can be caused by an inefficient energy subsidy policy?*) was assessed positively by 58 % of respondents for these reasons: wasted money spent on the administration; expensive self-promotion and propaganda of the projects supported by EU grants; the subsidies lead to corruption; a massive influx of subsidies result in an increase of money volume in the economy, i.e. an inflation rise; subsidy distribution can cause producers providing the best services to fail in the market at the expense of the ones who obtain the greater subsidies.

Questionnaire evaluations allows us to conclude that the majority of responders either did not know the relevant facts or were not interested in them at the time of decision making regarding the consequences of their choice of their solid heating resource; they were predominantly price-oriented. The price preference, from the *ethical* viewpoint, leads them to less responsible decisions. The purchasing power of respondents, which was not examined, played obviously significant role in it. Moreover, the price preference could partially result from the lack of information about solid biofuel combustion effects. Therefore, we can regard the EU energy policy as insufficient in terms of promoting important information of a hygienic and environmental character to the general public.

Conclusion

Following the results of chemical and physical analyses, particularly in the production of air pollutants, it might be concluded that the new production methods of solid biofuels production are hygienically and environmentally favourable. For instance, the production of VOC (group of air pollutants currently causing the highest concern) might be reduced by more than 59 %. This phenomenon is explained by higher combustion temperatures that occur during the burning of the biofuels made according to the new production technology. Higher energy density represents secondary environmental benefits because of savings both from the environmental and financial points of view. However, regarding the financial aspects the results do not allow a decision on whether the innovative technologies represent cost savings nowadays. The reason is as follows: although the new biofuels are technologically advanced the purchase price of the production apparatus is currently high. This microeconomic effect makes the overall costs of the conventional and the new biofuels similar. From the global market behaviour over the past 10 years regarding the rapid development of cost-saving technologies it can be deduced that this effect is temporary and the production costs of the new biofuels will become more favourable in the future. The questionnaire survey of private customers in central Europe indicates little willingness to pay higher prices for more ethically responsible products. The respondentś strict price-orientation may be due to the lack of relevant information about the solid biofuel combustion effects. Admittedly the low purchasing power obviously also plays a role. Better information, competition among manufacturers and positive macroeconomic development can stimulate changes towards more responsible consumer behaviour regarding the use of solid biofuels.

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