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ORIGINAL ARTICLE

Assessing external factors on substitution of fossil fuel by biofuels: model perspective from the Nordic region

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Abstract The aim of this study is to develop a theoretical model by which to demonstrate how taxes and subsidies work as external factors to substitute fossil fuel by a forest-based biofuel. For biofuels, this study predominantly considers solid-form biomass that generates electricity; for fossil fuels, it considers coal. The model results explicated with three states by using various numeric values taken from the literature. Three states are as follows: a situation without a tax and subsidy, a situation with a biofuel subsidy, and a situation with a biofuel subsidy and a fossil fuel tax. The results of the first state exemplify current fuel market situation; those of the second indicate that the aggregate demand for biofuel has shifted upwards by around 15 % and that substitution has increased by around 18 % due to biofuel subsidies being offered. Under the third state, aggregate biofuel demand has shifted upwards by around 19 %, reduced the demand for fossil fuels by around 13 %, and increased substitution by around 31 %. This state relates to a greater sense of social welfare than other two states. It is conceivable that the joint application of taxes and subsidies will succour biofuel to supplant fossil fuel in the near future.

Keywords Forest-based biofuel · Substitution model · Fossil fuel · Tax · Subsidy

1 Introduction

Recent years have seen the brisk development of policy frameworks within the European Union (EU) with regard to energy markets and forestry. In 2007, EU member states settled on a biofuel technology road map (EC 2006). Insecure supply sources, broad environmental

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concerns, rising fossil fuel prices and price volatility have led to a burgeoning biofuel market (Ji and Fan 2012), thus pushing the EU and its national directors to consider biofuels a valid alternative to fossil fuels. In Finland, the prices of imported fossil fuels have increased to levels considerably higher than those of domestic biofuels (Energiakatsaus 2012); with the exception of Norway, the situation is quite similar in most of Finland's neighbouring countries (Pelletsatlas 2009a; Pelletsatlas 2009b). The study of Manuilova and Johnston (2011) found that worldwide bioenergy use is expanding rapidly due to the implementation of climate-change policies and the escalation of oil prices.

However, the key message is that by applying different technological forms, various biofuels are now replacing fossil fuels, even as the conventional gasoline and diesel (Chang and Su 2010). Wood resources are considered one of these biofuels; in fact, it is being used on a massive scale as raw materials that replace fossil fuels. In spite of this giant contribution in the growth of bioenergy sector, the path of utilizing wood fuel as an alternative of fossil fuel is not suave enough. Some influential facts and intricate issues are hindering expansions in the use of wood materials as a substitute for fossil fuels (Gustavsson et al. 2006); these factors are interwoven all along the wood supply chain. Additionally, some cultural and structural issues, technical changes and price dynamics are also substantial and are brought to bear on matters of fuel substitution (Gustavsson et al. 2006).

The cost of using wood biomass to generate energy is dependent on the technology being used, the haul distance, the cost and size of the facility and the quality and sizes of the wood resources being used (Power Scorecard 2007). Highly prioritized and significant improvements in the logistics sector have helped reduce biofuel production costs—making them even lower than those of fossil fuels, at times (e.g. Rosenqvist 2008). Hall et al. (1991) found that generating electricity and liquid fuel from wood biomass is less costly than many other alternatives (e.g. coal and petroleum) for mitigating greenhouse gas (GHG) problem.

The U.S. Energy Information Administration found, additionally, that the prices of wood fuels for residential heating purposes are substantially lower than alternative fuels (e.g. oil and natural gas except coal) (EIA 2008). Thus, biofuel production costs are changing in some areas—especially in the case of fuel from willow (Table 1). In spite of these developments, it is

Table 1 Production costs and prices of biofuel and fossil fuel

References	Country	Production Costs (EUR/L[a])
Rosenqvist (2008)	Sweden	Ethanol from Salix, 0.015/kwh
Sassner et al. (2008)	Sweden	Ethanol from Salix, 0.59 (base case) and 0.49 (pentose-fermenting) Spruce, 0.47 (base case) and 0.45 (pentose-fermenting)
		Price (EUR/kwh[b])
Snäkin (2000)	Finland	Direct electricity heating, 0.07 Wood chips, 48.58/1,000 kg Coal, 67.00/1,000 kg
Energiakatsaus (2012)	Finland	Consumer price of wood pellet, 8/2008—0.0426; 9/2009—0.052; 5/2012—0.051
Energymyndigheten (2010)	Sweden	Wood chips, 4/2009—0.036 Wood pellets, 4/2009—0.022
Pelletsatlas (2009a)	Denmark	Pellets price of 25-kg bags (EUR/kg), 2007—0.28; 2009—0.31
Pelletsatlas (2012)	Finland	Hard coal price in heat production (excluding VAT), 3/2000—0.010; 12/2007—0.015

[a] Non-mentioning cases are as L (litre)

[b] Non-mentioning cases are as kwh (kilowatt hour)

quite evident that, in general, biofuel costs do not yet promise a means of attaining emission targets (Forsström et al. 2012).

EU energy policies have mainly appeared in the form of production subsidies, which are now helping to promote biofuel production. The provision of an indirect subsidy for woody biomass would push landowners to transform their lands into forests (Favero and Mendelsohn 2014). In the Nordic region, production subsidy schemes are recurrently appearing in one of two common forms, namely feed-in tariffs and fixed production subsidies (EMV 2012). Under the feed-in tariff form in Finland, electricity must be produced from wind power, biogas, or timber chips, or from small-scale combined heat and power (CHP) facilities that are using wood fuel (EMV 2012). A fixed production subsidy was also made available for timber chip power plants, but only for the year 2011 (EMV 2012). In Sweden, during 1991–1996, the per-hectare subsidy for willow plantations was very high, but it fell sharply in 1996 and rose again after 1999 (Rosenqvist et al. 2000; Johansson et al. 2002) (Table 2). However, the findings of a study by Grafton et al. (2012) demonstrate that the provision of subsidies in the renewable energy sector may actually exacerbate climate-change damage by creating a rush to extract fossil fuels.

Finland's energy tax structure changed many times in the 1990s (Eurostat 2003); the tax rate on carbon dioxide (CO_2) subsequently increased between 1990 and 2005 (Speck et al. 2006; Eurostat 2003). Denmark was one of the first countries to implement, in May 1992, CO_2-specific taxes on energy consumption among both residences and businesses (Wier et al. 2005). Norway's energy tax structure has undergone changes since 1999 and that country has introduced new and separate taxes on CO_2, sulphur dioxide (SO_2) and fuel oil (Eurostat 2003). Larsson and Rosenqvist (1996) point out that fossil fuel taxes have led in Sweden to a swap of oil boilers for wood-fuel-adapted technologies; concurrently, taxes on sulphur have helped put wood-based fuels in a more competitive position. Grafton et al. (2012) found that following a

Table 2 Subsidy and tax exemption on biofuel and tax on fossil fuel

References	Country/region	Tax (CO_2) (EUR/kg[c])
Watkiss et al. (2005)	EU	Electricity production, 0.09
EEA (2008)	EU	Average costs of electricity production, 0.18–0.59/kwh
		Tax exemption (EUR/hl[d])
IISD (2008)	Sweden	Biodiesel and ethanol, full exemption
	Denmark	Biodiesel and ethanol, full exemption
	Finland	Biodiesel and ethanol, no exemption
		Subsidy (EUR/ha-1)
Rosenqvist et al. (2000)	Sweden	Willow plantations (1991–1996)—1075.26
Johansson et al. (2002)	Sweden	Willow plantations (1999)—537.63
		Tax (EUR/kg)
Johansson et al. (2002)	Sweden	CO_2 and sulphur, 1991—0.027; 1996—0.039; 2001—0.056
Eurostat (2003)	Finland	CO_2 (1999)—0.019; excise tax on electricity (1999)—0.69
Eurostat (2003)	Denmark	CO_2 tax on oil, gas, coal and electricity (1999)—0.015; CO_2 tax on coal (1999)—0.036
Speck et al. (2006)	Finland	CO_2 (1990)—0.0013; CO_2 (2005)—0.020

[c] Non-mentioning cases are as kg (kilogramme)

[d] Non-mentioning cases are as hl (hectolitre)

ramp-type time path (i.e. slow to high rate) in imposing carbon taxes might lead to the aforementioned 'rush' by fossil resource owners to extract fuels, and thus actually increase carbon emissions (Grafton et al. 2012). They named this kind of outcome as Green Paradox, which is also epitomized by Sinn (2008; 2012). In Finland, the CO_2 tax rate increased subsequently between 1990 and 2005 (Speck et al. 2006; Eurostat 2003).

However, woody biomass is not completely carbon neutral as the harvesting, transporting and processing of it needs fossil fuels. Sedjo (2013) refers to several eminent scientists' outlooks regarding the concept of carbon neutrality within the biomass-based energy sector; that study found that in some cases, bioenergy releases more carbon on a per-unit basis than do fossil fuels. Yet another study found that as the release of waste and emissions depends upon transport distances, the pre-handling methods used, and equipment efficiency, *inter alia*, bioenergy is supposedly carbon neutral when these factors are in minimal state (Manuilova and Johnston 2011). The study also ascertains that in some situations, the net GHG reduction and waste emissions of bioenergy are even, 100 % lesser than fossil fuel. Gaudreault and Miner (2013) found, furthermore, that a system that uses residuals in energy production (without counting biogenic CO_2) generates 98 % less GHG emissions than systems that dispose of residuals (i.e. those that use fossil fuels to produce the same amount of energy). Previously, Hall et al. (1991) claimed that sustainably growing biomass with leveraging up-to-date conversion technologies are sometimes more operative in lessening global CO_2 than sequestering carbon by trees. However, it is quite evident that releasing CO_2 from combusting wood biomass is the part of global biogenic carbon process. Thereby, including biogenic process biofuel generates less amount of carbon emission than fossil fuel does (Sedjo 2013). Hence, as the carbon stock is counteracting by replantation process, it is possible that the net emissions could be turned into zero in the long-term periods (Sedjo 2013). The key notes from the previous study is that wood energy could be considered as carbon neutral, as the amount of CO_2 released by combustion is enthralling again by the next generation plantations. Conversely, Holmgren and Olsson (2008) importantly pointed out that biofuels are never fully GHG or climate neutral (i.e. when net emission=0), but they cause lower GHG emissions than fossil fuels. Hence, there are opportunities to replace fossil fuel by biofuel. Owen (2004) claimed that the pollution cost ratio in Europe for electricity generation from coal and biomass is about 8:2 in EUR/kwh in Europe. Since biofuels are exempt from taxation, they are becoming more competitive against fossil fuels (Nordh 2005). As a result, trade in fuel wood is increasing: from 1990 to 2006, for example, its trade volume increased by 208 %. This is happening not only on the account of EU market integration or the economic growth rate but it is also happening because of a sincere urge to substitute fossil fuels with biofuels. It is therefore important to undertake research from the perspectives of the forests' product market and linkages between economic and energy sectors that focus on interactions between multi-country market levels. Within this context, the current study aims to analyse how external factors impact the forest-based biofuel market and how they lead to the substitution of fossil fuels by forest-based biofuels.

2 Methods

We aim to demonstrate how taxes and subsidies as external factors impact the substitution of fossil fuels with forest-based bioenergy products. We have ascertained that such substitution is taking place in the Nordic areas of Europe, mainly on account of the significance, abundance and multiple ways of using forest resources there. In the model proposed here, two final products, namely biofuels (mainly solid-form biofuel that generates electricity) and fossil fuels (mainly coal) are considered, especially when analysing environmental benefits and losses. Based on the findings of the several studies highlighted in the introduction, we assume that biofuel is not greenhouse gas (GHG) neutral. To accomplish our research objectives, in our duopoly market structure model (i.e. as there are only two final products in the market), we exploit a concave utility function used previously by several researchers (e.g. Shubik and Levitan 1980; Singh and Vives 1984; Liang 2012). Therefore, upon taking a number of mathematical steps, we look to derive the market equilibrium price functions and demand functions from the given utility function. Further, in deriving the price functions and demand functions, we use the substitution condition of Liang (2012). As in Dixit (1979) and Singh and Vives (1984), in our model, the two differentiated products could be substitutes (or complements).

Based on the available data (or numeric values), the resulting equations are means of explaining graphically three different sets of circumstances. Several studies within the literature use numeric values, as mentioned in the introduction. Wood-fuel production costs and price data are listed in Table 1, and tax and subsidy data are listed in Table 2; additionally, environmental benefit–loss data are provided within the text. Several numeric values drawn from different authors in different countries are used to calibrate local data into average values. Moreover, when considering country-specific data, the use of numeric values could not only narrow the scope of study but also prolong analysis. Therefore, as we aim to replicate the Nordic fuel market scenario, the use of average values is the best way of generating graphical representations. The remaining numeric values were decided based on researchers' suppositions.

However, the considering three circumstances are as follows: a situation without tax and subsidy, a situation with subsidy on biofuel and finally a situation with subsidy on biofuel and tax on fossil fuel. Therefore, by exploiting the same available data, we wish to measure social welfare (SW) and present it graphically. The study will roll out in three phases, with a focus on the utility function of a given consumer, on the nature of substitution between two fuel types and finally on a comparison of SW across various sets of circumstances.

In our study, some economic jargons are frequently used for model adaptation, result analysis and discussion representation. Although the definitions and demarcations of using those terminologies are available in several studies, for the better understanding of our readers, we are briefly epitomizing them here.

Satisfaction level It is a state of customer's gratification of a product after comparing customer's expectation with perceived performance. While customer's satisfaction is labelled with performance, then, substitutions occur.

Substitutability It is the replacing capability of a product by another. The capability of lesser level of substitutability is termed as imperfect substitution. The capability of complete substitution is termed as perfect substitution (for more about wood fuel substitutability, please see Gustavsson et al. (2006)).

Willingness to pay (WTP) It is the maximum amount or the worth of the product that an individual is willing to sacrifice instead of getting that product.

Consumer surplus (CS) It states while consumer's WTP become more than the product's market price.

Producer surplus (PS) It is the benefit attained by the producer; when he receives more than he would be willing to accept for a good.

Social welfare (SW) It states the well-being of the entire society through the welfare of each individual. While the utility associated with each individual is associated with society as a whole forms the notion of SW (Nicola 2013).

3 Modelling approach

Suppose an economy is consuming two final products, namely forest-based biofuels and non-forest-based energy product fossil fuels, the production of biofuels is fully based on domestic forest endowments, whereas the production of fossil fuels is dependent on importation and non-forest sources. Therefore, there are two external factors that are also common energy promotion tools (i.e. taxes on fossil fuels and subsidies for biofuels).

Now, let us denote a representative consumer's WTP for the fossil fuel producer services by f and biofuels services by b. WTP is the maximum amount that the customers are willing to pay to the producers for their differentiated fuel features. β is the satisfaction level of the corresponding representative towards the aggregate demand. γ is the substitutability between two energies, whether $\gamma \gtreqless 0$ entails that products might be independent, substitutes or complements. $\gamma>0$ implies that products are not complimentary, $\gamma=0$ implies that products are independent and each firm has monopolistic market power and $\gamma=1$ means products are perfect substitutes.

We assume that substitutability (γ) is dependent on the level of economic growth of the country and put into practice of policies over the energy sector with the state of $\gamma<\beta$ since both products have limitations into the satisfaction level. Higher economic growth ensures the development of technology and lowering the production cost and helps to reduce price level. Like economic growth, energy and climate policies also have a role to control over prices through their subsidy and tax policy. Thus, favourable policy in any particular energy sector will ensure higher WTP offered by the customers to that sector. The timing of the model are first, we will find out the market equilibrium price for both the products; second, we will apply the condition of substitution on equilibrium price and demand functions to illustrate the results graphically; and finally, we will measure SW.

The quadratic and concave utility function given by Singh and Vives (1984) is

$$U=f\,D_f+b\,D_b-{}^{1}\!/_{2}\left(\beta D_f{}^{2}\;+2\gamma D_f D_b+\beta D_b{}^{2}\right)-P_f D_f-P_b D_b \tag{1}$$

Inverse demand or price functions are given by using Eq. (1). Price functions for both energies are

$$\begin{aligned} P_f &= f-\beta D_f-\gamma D_b \\ P_b &= b-\beta D_b-\gamma D_f \end{aligned} \tag{2}$$

Here, P_f and P_b are the prices of fossil fuels and biofuels, respectively. The utility function also gives a linear demand structure; demand functions for the fossil fuels (D_f) and biofuels (D_b) are as follows:

$$\begin{aligned} D_f &= -\frac{-f\beta+p_f\beta+b\gamma-p_b\gamma}{\beta^2-\gamma^2} \\ D_b &= -\frac{-b\beta+p_b\beta+f\gamma-p_f\gamma}{\beta^2-\gamma^2} \end{aligned} \tag{3}$$

Demand for good is maintaining the law of demand. It is downward sloping in its own price and increases with the increase in price of other products when products are substitutes.

Correspondingly, the demand is decreasing with an increase in the price of another product in the case of complementary products.

4 Model results

The profit functions are, respectively, Π_f and Π_b for the fossil fuel producer and biofuel producer.

$$\begin{aligned} \Pi_f &= \left(p_f - c_f\right) D_f \\ \Pi_b &= \left(p_b - c_b\right) D_b \end{aligned} \tag{4}$$

Where c_f and c_b are considered as constant marginal costs for producing each unit of fossil fuel and biofuel. Producer's profit will be maximized, if we put 1st order partial differentiation of the profit functions with respect to P_f and P_b equal to zero.

$$\begin{aligned} \left(\partial \Pi_f \middle/ \partial P_f\right) &= 0 \\ \left(\partial \Pi_b \middle/ \partial P_b\right) &= 0 \end{aligned} \tag{5}$$

Thus, the market equilibrium prices for biofuels and fossil fuels are, respectively,

$$\begin{aligned} P_f{}^* &= \frac{2\left(c_f + f\right)\beta^2 + (-b + c_b)\beta\gamma - f\gamma^2}{4\beta^2 - \gamma^2} \\ P_b{}^* &= \frac{2(b + c_b)\beta^2 + \left(c_f - f\right)\beta\gamma - b\gamma^2}{4\beta^2 - \gamma^2} \end{aligned} \tag{6}$$

Here, the price is increasing with the increase in cost and satisfaction level. The resulting proposition is that external factors impact on the price of the product and it has further impact on the quality of the product, which in turn impact on the substitution of fossil fuel by biofuel.

We stated earlier that f is the maximum WTP for f_f and b is the maximum WTP for b_f. Fossil fuel (f_f) and biofuel (b_f) can be characterized into two categories based on their price and quality. The low pricing approach offers positive signs for the satisfaction level; it is indicated by h. Low pricing approach means that the products are naturally low in its price because of its low fixed costs or because of its low marginal costs. Hence, h_f indicates the low pricing quality of fossil fuel and h_b indicates the low pricing quality of the biofuel.

With no loss of generality, we are assuming that f_f producer offers a larger amount of fuel than the b_f producer with the same price because of its low production costs. Thus, it is possible for the fossil fuel (f_f) producer to offer the fuel with lower price than the biofuel (b_f) producer. It can state like $h_f > h_b$. The situation asserts that based on only low pricing quality, consumer's WTP for biofuel is lower than WTP for fossil fuel.

Another characteristic is related to friendly operating environment. Friendly operating environment means that the fuel generating less pollution into the environment during its operation will be preferred over others. So, it is from the common understanding that b_f has more friendly operating environment than f_f. Friendly operating environment is indicated by e in which is e_f is for fossil fuel and e_b is for biofuel. Therefore, we can state the situation like this $e_f < e_b$. Thus, WTP for both fuels can be convoluted by replacing their two types of qualities in Eq. (1) as follows:

$$f = \left(h_f + e_f\right)$$
$$b = (h_b + e_b)$$

The substitution (γ) will occur when γ=(minimum h + minimum e). The combination of low price by biofuel and the higher friendly operating environment by fossil fuel can bring substitution. Thus, $\gamma=(h_b+e_f)$; the expression represents the substitutable constituent between two types of fuels with the condition of $\gamma<\beta$ (Liang 2012). The substitutability will increase when production components of both fuels will increase with (h_b+ e_f). If h_b and e_f become zero, then substitutability will be zero and when it implies that products are perfect substitutes.

The substitution of fossil fuels by biofuels will occur when the prices of fossil fuels are higher than those of biofuels. In other words, if a friendlier operating environment can be added to the characteristics of fossil fuels, a higher satisfaction level will be derived. However, it is difficult or virtually impossible to improve the friendliness of the operating environment of fossil fuel producers. On the other hand, technological developments could reduce biofuel prices and make them more environmentally friendly. However, reducing the production cost of forest-based biofuels through technological development and R&D enhancements occurs over a protracted period. Hence, an important inducement for reducing biofuel production costs can be derived from external factors, in other words, taxes and subsidies, which bear a substitution role.

After substitutions, the forms of equilibrium price functions are

$$P_f{}^* = \frac{-\left(e_f + h_b\right)^2\left(e_f + h_f\right) + (c_b - e_b - h_b)\left(e_f + h_b\right)\beta + 2\left(c_f + e_f + h_f\right)\beta^2}{-(ef + h_b)^2 + 4\beta^2}$$
$$P_b{}^* = \frac{-(e_b + h_b)\left(e_f + h_b\right)^2 + \left(c_f - e_f - h_f\right)\left(e_f + h_b\right)\beta + 2(c_b + e_b + h_b)\beta^2}{-\left(e_f + h_b\right)^2 + 4\beta^2} \tag{7}$$

The aggregate demands at equilibrium are

$$D_f{}^* = \frac{\beta\left(-\left(e_f + h_b\right)^2\left(-c_f + e_f + h_f\right) - (-c_b + e_b + h_b)\left(e_f + h_b\right)\beta + 2\left(-c_f + e_f + h_f\right)\beta^2\right)}{\left(e_f + h_b\right)^4 - 5\left(e_f + h_b\right)^2\beta^2 + 4\beta^4}$$
$$D_b{}^* = \frac{\beta\left((c_b - e_b - h_b)\left(e_f + h_b\right)^2 - \left(e_f + h_b\right)\left(-c_f + e_f + h_f\right)\beta + 2(-c_b + e_b + h_b)\beta^2\right)}{\left(e_f + h_b\right)^4 - 5\left(e_f + h_b\right)^2\beta^2 + 4\beta^4} \tag{8}$$

To analyse the first circumstances, the understandable values for demand and prices are considered as h_f=1, e_f=0.25, h_b=0.70, e_b=1, β=5 and c_f=0.50 and c_b=1. The numeric values hold the condition of $h_f > h_b$ and $c_f < c_b$ without tax and subsidy.

The price and demand as the functions of WTP for cost of biofuel (c_b) is represented in Fig. 1a. The expression WTP for cost of biofuel (c_b) shows the maximum amount that customers are willing to pay to the fuel producers when the c_b is fixed at 1. The demand curves are illustrated in the left side and the price curves are illustrated in the right side. The biofuel price curve indicates that since c_b is a double of c_f, the price of biofuel becomes more than fossil fuel. This increases the demand for fossil fuel and customers are more WTP for it, whereas an inverse situation will happen for biofuel.

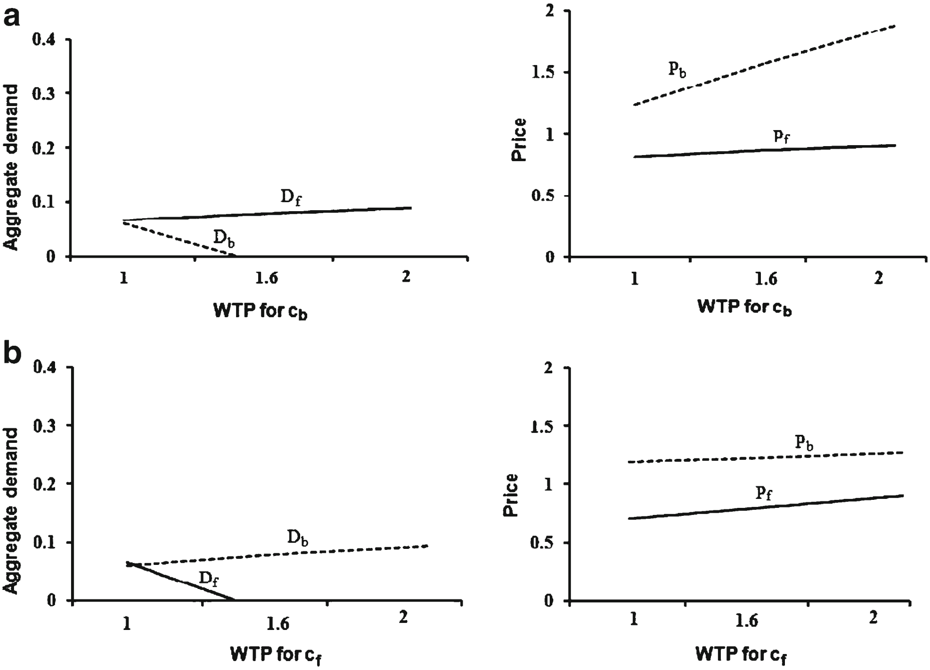

Fig. 1 **a** Demand and price function for cost of biofuel (c_b) without subsidy and tax (*above*). **b** Demand and price function for cost of fossil fuel (c_f) without subsidy and tax (*below*)

We also observe that the total demand for biofuel and fossil fuel is less than 1 (i.e. $D_f + D_b < 1$). It states that demand for biofuel and demand for fossil fuel are exclusive since our total market size is 1. The extension of this illustration is that there are no double (both fossil fuel and biofuel) users, either a consumer is using fossil fuel or biofuels. It also implies that biofuel (i.e. solid biomass that generates electricity) and fossil fuel (i.e. coal) are neither complementary nor perfect substitutes.

The same analysis was performed to examine the WTP for the cost of fossil fuel (c_f). Following the previous analysis, we also consider the marginal cost of fossil fuel to be one half the marginal cost of producing biofuels. The other values remain the same in deriving demand and price as functions of WTP for the cost of fossil fuel (c_f). The analysis illustrated in Fig. 1b illustrates that with the mentioned values, the demand for biofuels and the prices of biofuels are quite stable, whereas demand for fossil fuels decreased with price increases.

Let us move to the second circumstance, suppose now a subsidy that is provided to the biofuel sector. We are assuming that due to offering a subsidy on biofuel, the marginal cost of biofuel (c_b) will decrease; and consequently increase the value of h_b (i.e. low pricing quality of biofuel). It is because when subsidy will be provided to biofuel production sector, the marginal cost of biofuel (c_b) will decrease, and consequently, the price will decrease if other things remain same. The satisfaction level for h_b will increase and consumers will tend to buy more b_f. Therefore, the production cost of biofuel is now lower compared to the previous case but still exceeding the marginal cost of fossil fuel. The numeric values are now h_f=1, e_f=0.25, h_b= 1, e_b=1, β=5 and c_f=0.50 and c_b=0.65, which holds the idea that $h_b = h_f$.

The result is analysed in Fig. 2a, the maximum amount that the customers are WTP to the fuel producers with the increase of h_b (h_b=h_f=1). The figure illustrated that the demand curve and the price curve of biofuel are moved upwards with the increase of h_b compared to Fig. 1.

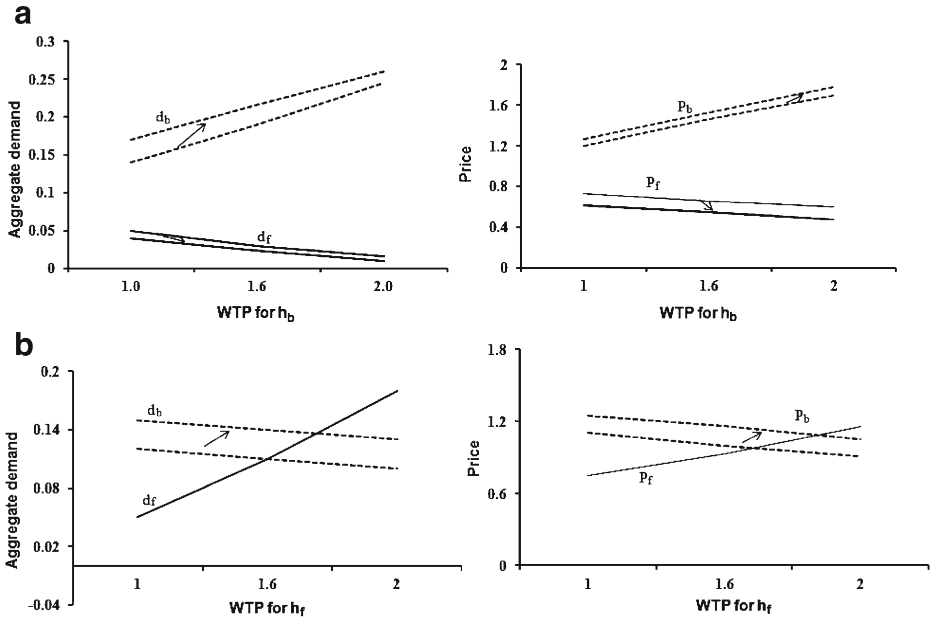

Fig. 2 **a** Demand and price function for low price of biofuel (h_b) with subsidy (*above*). **b** Demand and price function for low price of fossil fuel (h_f) with subsidy (*below*)

At this state, the consumer is still willing to pay for fossil fuel, because c_b is higher than c_f. Holding this situation, offering further subsidy on biofuel sector will reduce the marginal cost of biofuel from 0.65 to 0.60. As a consequent, the price of biofuel will reduce again if the values of other variables and economic situations remain same. Thereby, offering the product with a lower price will increase customer's satisfaction level for biofuel. So, previous analysis is executed again by considering h_b at 1.10 with c_b 0.60 while c_b is still higher than c_f. In this situation, the figure illustrates that price curve and demand curve of biofuel is shifted upwards when h_b increases from 1 to 1.10. The figure also illustrates that due to decreasing marginal cost of biofuel (c_b) by around 7.7 % (i.e. 0.65 to 0.60), the aggregate demand for biofuel shifts up around 15 % (i.e. 0.13 to 0.15, which is shown in the corresponding figure by an upward-directed arrow).

In return, as the marginal costs and the low pricing quality (h_f) of fossil fuels did not change, customers' WTP for fossil fuel will decrease. Furthermore, increasing customer satisfaction vis-à-vis biofuels and reducing the demand for fossil fuels compel fossil fuel producers to reduce their price levels. As a consequence, the price curve and demand curve of fossil fuel will be shifted downwards, although the rate of changing price level has less impact on the changing rate of demand for fossil fuel.

We executed the same analysis of customers WTP for h_f. We found that due to the provision of subsidy to the biofuel sector, the demand for biofuel shifted upwards and the demand for fossil fuel remains fixed. The figure illustrates that due to an increase of h_b by around 10 % (from 1 to 1.10), the demand curve of biofuel shifts up around 25 % and the substitutability of fossil fuel by biofuel increased around 18 % (Fig. 2b).

In case of last circumstance, i.e. imposing tax on fossil fuel, we hold that after imposing tax on fossil fuel, marginal cost of fossil fuel will increase from 0.5 to 0.6. Therefore, as a consequence, we assume that h_f will reduce from 1 to 0.90. Thereby, when h_f will decrease, people will move to biofuel, and as a subsequent effect, h_b will perk up and move at 1.30. The situation is now c_f=c_b and h_f<h_b, and the numeric values are h_f=0.90, e_f= 0.25, h_b= 1.30, e_b= 1, β=5 and c_f=0.60 and c_b=0.60. The result is illustrated in Fig. 3a, whether it illustrates that WTP for biofuel is increasing very quickly as the demands for fossil fuel are decreasing with the decrease of its price level. At this moment, if we further increase the rate of imposing tax on fossil fuel, marginal cost of fossil fuel will increase from 0.60 to 0.65 and h_f will go down at 0.85. As a consequence, h_b will increase further from 1.30 to 1.50 because their marginal cost remaining fixed (i.e. c_b at 0.60). The situation is now h_f<h_b and c_b<c_f, and the trend of price line for both the fuel types are remaining the same. The figure illustrates that the demand for biofuels shifted upwards and becomes steeper although the price curve is shifted upwards. The figure also demonstrates that due to the decreasing marginal cost of biofuel (c_b) by around 7.7 % and increasing marginal cost of fossil fuel (c_f) by around 8.3 %, the aggregate demand for biofuel shifts up around 19 % and the demand for fossil fuel shifts down by around 13 %.

Like the subsidies' circumstances, we executed customers' WTP for h_f again, holding taxes and subsidies together (Fig. 3b). The research outcome indicates that the imposition of a tax on fossil fuels and the offering of a subsidy for biofuels shift the price curve and the demand curve of biofuels upwards. On the other hand, the opposite situation is seen in the fossil fuel market, where the price and demand curves both shift downwards. The figure also clearly approaches that demand for biofuels and fossil fuels have a tendency to become close. Hence, it could be that the substitution of fossil fuels by biofuels will become quite certain and obvious in the long term. The figure indicates that, due to a 15 % increase in h_b (i.e. from 1.30 to 1.50), the substitutability of fossil fuels by biofuels shifts upwards by around 31 %.

Let's go to the analysis of SW, whether we know that

SW=consumer surplus (CS) + producer surplus (PS)

CS=U (From Eq. 1)

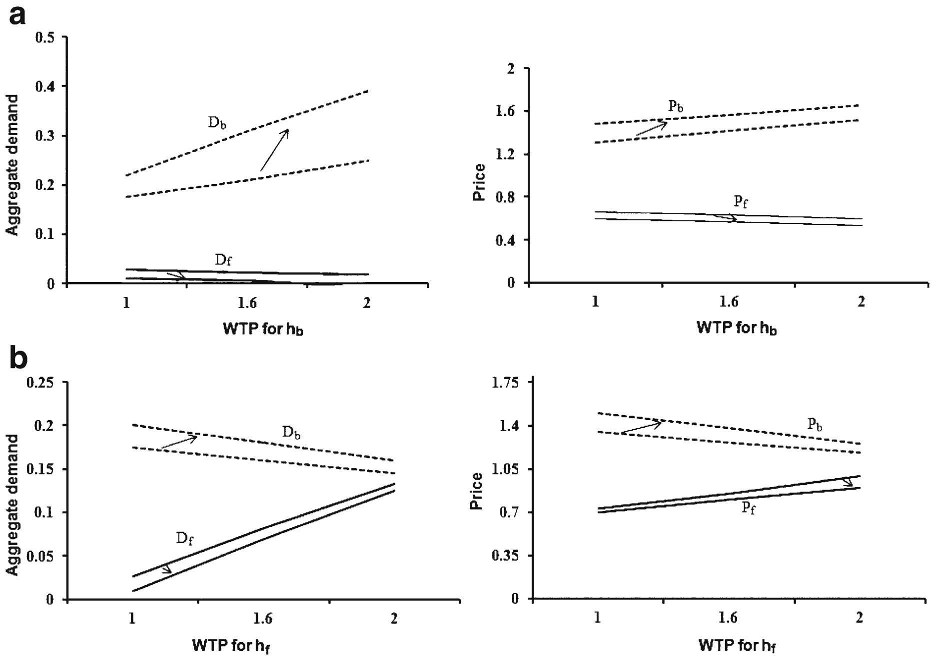

Fig. 3 **a** Demand and price function for low price of biofuel (h_b) with subsidy and tax (*above*). **b** Demand and price function for low price of fossil fuel (h_f) with subsidy and tax (*below*)

Table 3 Social welfare at different situations[a]

Implications	Situation 1	Situation 2	Situation 3
CS	0.027	0.074	0.104
Π_f	0.024	0.015	0.001
Π_b	0.020	0.101	0.176
PS	0.044	0.116	0.177
SW	0.071	0.190	0.281

[a] For situation 1, h_f=1, e_f=0.25, h_b=0.70, e_b=1, β=5 and c_f=0.50 and c_b=1. For situation 2, h_f=1, e_f=0.25, h_b=1.1, e_b=1, β=5 and c_f=0.50 and c_b=0.60. For situation 3, h_f=0.85, e_f=0.25, h_b=1.50, e_b=1, β=5 and c_f=0.65 and c_b=0.60

PS=profit of biofuel producer (Π_b) + profit fossil fuel producer (Π_f)

Therefore, by using Eq. 1, the SW at equilibrium state is

$$\begin{aligned} SW* = & \frac{1}{2(e_f+h_b-\beta)(e_f+h_b+\beta)\left((e_f+h_b)^2-4\beta^2\right)^2} \\ & \beta\left(-2\left(-c_b(e_f+h_b)^2+(e_b+h_b)(e_f+h_b)^2+(e_f+h_b)(-c_f+e_f+h_f)\beta+2c_b\beta^2-2(e_b+h_b)\beta^2\right)^2\right. \\ & -2\left((e_f+h_b)^2(-c_f+e_f+h_f)+(-c_b+e_b+h_b)(e_f+h_b)\beta-2(-c_f+e_f+h_f)\beta^2\right)^2 \\ & +\beta(-2(c_b-e_b-h_b)(e_f+h_b)^3(-c_f+e_f+h_f)+3(e_f+h_b)^2\left((-c_b+e_b+h_b)^2+(-c_f+e_f+h_f)^2\right) \\ & \left.\beta-4\left((-c_b+e_b+h_b)^2+(-c_f+e_f+h_f)^2\right)\beta^3)\right) \end{aligned} \tag{9}$$

Therefore, we attempted to get the changes of CS, PS and SW at corresponding three circumstances. However, after maintaining the different stages of computation, we got the following results of CS, PS and SW (Table 3).

The results shown in the above table demonstrate that situation 3 (with a tax on fossil fuels and a subsidy for biofuels) generates a higher level of SW than situations 1 (no tax or subsidy) or 2 (subsidy for biofuels). To explore the graphical results further, we executed the same analysis, based on Eq. (9). The results suggest that a situation, in which there is a tax on fossil fuels and a subsidy for biofuels, engenders a higher SW than the other two situations (Fig. 4).

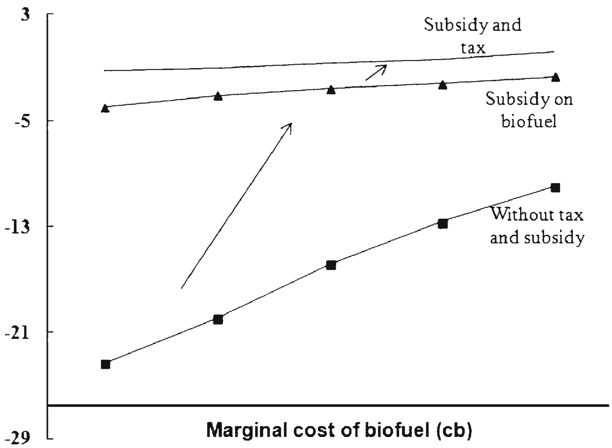

Fig. 4 Social welfare at different circumstances

It is apparent that subsidizing biofuels and imposing taxes on fossil fuels, when executed together, can work to increase the customer satisfaction level for biofuel and incur a substitutability of fossil fuels by forest-based biofuels.

5 Discussion and conclusions

The purpose of this study was to illustrate how external factors cause the substitution of a non-forest energy product by forest-based bioenergy products. The problem was resolved and adapted by using the concave utility function of Shubik and Levitan (1980), which was applied by Singh and Vives (1984) in a duopoly market structure and by Häckner (2000) in an oligopoly market structure. Furthermore, this utility function was used by Liang (2012) in both duopoly and oligopoly market structures. We assumed in our model that the two differentiated products could be either substitutes or complements (Dixit 1979; Singh and Vives 1984).

This study considered two EU energy promotion tools, namely taxes and subsidies as external factors and Nordic countries as the study area. The selection of Nordic countries as the study area is justified by their abundances of forests, their affluence in terms of multiple uses of forest products, and the appropriate implementation of EU policies. The approximated numeric values used to generate graphical representations were drawn from the results of a literature review. Therefore, the application of methods executed in other study areas would necessarily require calibration with local data. We deem that our proposed model sufficiently capable of considering all biofuel and fossil fuel forms (e.g. solid, liquid, gaseous or processed) by altering the environmental benefit–loss ratio. For an illustrative graphical analysis, given the limitations of data availability, this study focused solely on woody biomass that is used to generate electricity. Hence, as biofuel, we considered mainly the solid form of biofuel that generates electricity, and for fossil fuel, we considered coal for numerical analysis. We did so because the incorporation of numeric values for all kinds of fuel types into a single figure may fail to offer a true and fair depiction. Therefore, to preclude complexity within the model for graphical representation, we ignored other fuel markets. Forsström et al. (2012) claims that the intention to supplant fossil fuels with wood fuels may increase both the demand for and the price of wood use in biofuel production. We incorporated this possibility into our analytical results when we decided upon the numeric values used in graphical analysis. Nonetheless, it is important to clarify that we had (and have) no intention of justifying arguments for different or better applications of taxes or subsidies.

Our results were analysed in two phases. The results in the first phase (aggregate demand) were utilised for analysing the second phase (substitution phase). The resulting equations considered three sets of circumstances, namely one in which there is no tax or subsidy, one in which there is a subsidy for biofuels and one in which there are both taxes and subsidies on biofuels and fossil fuels. We believe these three sets of circumstances illustrate the differences between a situation before and after the implementation of policies. To represent the entire analysis—especially that pertaining to substitution and SW—we followed the methodology and strategy of Liang (2012). We categorized fossil fuels and biofuels based on their prices and the degree to which they have a friendly operational environment. We considered whether a low pricing approach and a highly friendly operational environment offer positive signs vis-à-vis satisfaction level. We assumed that unit cost of fossil fuel is less than biofuels; on the other hand, biofuels offers friendlier operating environment than fossil fuel. We also ascertained that increasing customers' satisfaction level towards biofuel pricing and increasing the friendly operating environment of fossil fuel could lead to substitution. Therefore, we assumed that achieving friendly operational environments for fossil fuels is not currently possible. In addition, we found that the provision of a subsidy for biofuels can reduce the unit price of biofuels and lead to the substitution of fossil fuels by biofuels (Löfgren 2008).

The results of this study indicate that providing subsidies for biofuels shifts the aggregate demand curve upwards and increases the possibility of substitution. The outcomes also indicate that due to the provision of a subsidy for biofuel, the marginal cost of biofuel can be decreased by around 7.7 % and the aggregate demand for biofuels can be shifted upwards by around 15 %. Therefore, imposing a tax on fossil fuels will shift the demand for fossil fuels further downwards. However, implementing both tools concurrently—e.g. a tax on fossil fuels and a subsidy for biofuels—was found to shift both the price curve and the demand curve of biofuels upwards. The opposite happened for fossil fuels, with an increase in the low pricing quality of biofuels of around 15 %, the substitutability of fossil fuels by biofuels increased by around 31 %. With respect to SW analysis, we determined that the maximum SW value is gained with situation 3, namely concurrently providing a subsidy for the biofuel sector and imposing a tax on fossil fuels. Our results align with those of several empirical studies, including those of Larsson and Rosenqvist (1996), Johansson et al. (2002) and Mola-Yudego and Pelkonen (2008). Larsson and Rosenqvist (1996) point out that a tax on sulphur brought the use of wood fuels into a more competitive position in Sweden and thereby increased demand for wood-fuel biomass throughout the country. Timilsina et al. (2011) demonstrated that carbon tax alone is not sufficient enough to stimulate biofuel market penetration significantly; a carbon tax on fossil fuels, along with a subsidy for biofuels, was found to have a significant influence on this penetration.

The cost of fuel has a very significant inference on the market price of biofuels, which in turn has an effect on fuel consumption levels and GHG reduction (Chen et al. 2012). On the other hand, offering subsidies to the renewable energy sector has both direct and indirect effects; these include reductions in demand and in the existing equilibrium price level of fossil fuels. As a consequence, it tends to escalate demand for fossil fuels (Grafton et al. 2012). It is clear that, on its own, offering biofuel subsidies are not ample to mitigate problems relating to substitution or climate change. Hence, our findings clearly indicate that concurrently imposing a tax on fossil fuels and providing a subsidy for biofuels has a noteworthy impact, by shifting demand for biofuel upwards and substituting fossil fuel by biofuel. Indeed, although this study focused on Nordic countries and made use of local data, the conclusions herein have broad economic and policy implications in other locations.

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