REFUSA: IS-ENABLED POLITICAL DECISION SUPPORT WITH SCENARIO ANALYSES FOR THE SUBSTITUTION OF FOSSIL FUELS

Completed Research Paper

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Abstract

Fossil fuels in the transport and mobility sector can be replaced with several renewable fuels, such as renewable electricity, hydrogen and biomass-to-liquid. When these alternative fuels are used, aspects such as safeguarding supply, economic efficiency, and environmental protection must be taken into account to ensure sustainable change and to create a sustainable society. We introduce a scenario simulation, analysis and optimization prototype, called REFUSA (REnewable-FUels-Scenario-Analyses). The underlying optimization model that supports policy-making substituting fossil fuels with renewable fuels is outlined. To analyze future fuel markets, essential key factors and all major cause and effect laws are modeled and simulated holistically. To check feasibility, these key factors and their relationships were implemented with Microsoft Excel/VBA in the prototype system REFUSA. After each year is simulated, the consumption of different fuels, total emissions, fuel prices and total cost, subsidy costs, etc. are extracted and thus serve as a basis for political decision-making.

Keywords: Decision support system (DSS), Green by IS, renewable fuels, optimization model, transport and mobility

Introduction

Globally, the transport and mobility sector is one of the largest energy consumers, with about 27% of total final consumption. In 2010, energy demand in the global transport and mobility sector amounted to about 27561 TWh, of which 97% was met by fossil energy, 2% by bio-fuels and waste, and 1% by others (e.g., electricity) (IEA 2012). In recent years the rising cost of crude oil production, for example from unconventional oil such as oil shale, in addition to increasing demand, have resulted in higher prices. These increases had a positive effect on engine efficiency and the use of more economical, diesel-powered vehicles. Fossil fuels used in transport produce different emissions that are emitted by combustion, such as carbon dioxide.

In the area of information systems (IS) research, environmental sustainability and Green IS are gaining in importance (Dedrick 2010). Society has an energy consumption problem (Hoffert et al. 2002). The problem of increasing use of energy requires immediate action. Research in the field of IS can contribute to the body of knowledge about environmental sustainability and improve the sustainable change (Melville 2010). Additionally, the transformative power of IS can be used to create an environmentally sustainable society (Watson et al. 2010).

According to Nitsch et al. (2004), decisions must ensure that energy is available and environmentally friendly, can be used conveniently, and can be converted efficiently to become a sustainable change. One example of Green by IS is using information technology and IS to support political decision-making in reference to substitution of fossil fuels with renewable fuels while ensuring that the sustainability goals can be met. States and international organizations use a variety of political measures to ensure sustainable development, including safeguarding supply, environmental protection, and economic efficiency. This includes more than just financial support for the eligible bio-fuels. According to the EU Directive (European Union 2009) a bio-fuel is a "liquid or gaseous fuel for transport produced from biomass." Hydrogenated oil or fat, bio-butanol, bio-kerosene and renewable electricity can be used to regeneratively configure the energy consumption of transport from renewable sources. These fuels differ in emission content or production costs, not only amongst themselves, but also within an individual fuel, since they are made from various raw materials or products by different processes. The sheer number of fuel options alone creates a lot of information that must be considered when defining policies. The complexity of the decision problem increases with the cause and effect laws of the fuel markets, such as the development of production capacity. Green by IS: a complex IS that supports future-oriented decisions about political interventions in the fuel markets, considers both short- and long-term impact, and involves the feedback loops is required. This type of decision support system (DSS) must also fulfill the following requirements: it should be applicable to a class of problems, make a contribution to published knowledge, be plausibly justified, allow validation, and generate benefit for stakeholders, both now and in the future (Österle et al. 2011).

In the existing literature, little methodological support is available for political decisions that assist sustainable transformation of the transport and mobility sector. This lack of research is especially obvious with regard to political instruments that are to be employed to fulfill the aforementioned requirements while considering the variety of renewable fuel alternatives, various transport and mobility sectors, or even complex interactions and feedback effects of the fuel markets. Therefore, this paper aims to generate decision-relevant data that demonstrates the different effects of policies on the fuel markets, like the development of fuel quantities, the total emitted carbon-dioxide-equivalent (CDE), costs for both consumers and the state, and so on. An optimization model is formulated based on established operations research (OR) models. This model minimizes the total fuel cost by calculating the optimal fuel quantities, while satisfying consumer demand. The DSS prototype REFUSA (REnewable-FUels-Scenario-Analyses) allows users to quantitatively reproduce the short- and long-term impact of policies on the fuel markets as well as the main feedback effects. Furthermore, REFUSA helps them import, edit, export, and visualize data to improve usability. The DSS enables instant validation, comparison and assessment of results and scenarios. In this way, decisions can be made optimally and can also be readapted every year, so strategies (not only recommendations) can be developed and adapted specifically. This paper focuses on the following research questions:

(RQ1) How can fuel markets be modeled and what are the design parameters for efficient policy making to achieve desirable outcomes?

(RQ2) How can a quantitative Decision Support System enable scenario analyses of fuel markets and visualize their outcomes to optimize policies of states and international organizations?

The paper is organized as follows. First, the research background is presented, including the results of a literature review that examines research in IS and research design. Afterwards a quantitative approach to the fuel markets of one country is provided. A formal and verbal description of the optimization model is provided. The implemented prototype of the DSS REFUSA, which employs the underlying model, is presented. Then, within a representative application example, the optimization results for the German fuel market are shown and the feasibility is checked. The subsequent section provides a discussion about results, theoretical and practical recommendations, as well as limitations. The paper concludes by summarizing the contributions and limits of this research.

Research Background

The most critical stakeholders in the energy sector are suppliers, consumers, and governments. Well-designed policies help consumers and suppliers to act sustainably (Watson et al. 2010). Therefore, during IS design, attention should be paid to the information that the government receives. Consumers in the transport and mobility sector demand energy or fuels in different transport sectors, such as aviation and road transport. Suppliers provide these fuels, which have various origins, e.g., crude oil or biomass, and use different in production processes. The actions of suppliers and many consumers in the energy system are determined by their economic interest. However, some consumers are increasingly calling for a sustainable change and are in turn putting pressure on the government (Watson et al. 2010). But, green consumer behavior is also influenced by both the availability of sustainable products and by their prices, so rising prices lead to a reduction in sustainable decisions by consumers (Young et al. 2010). Thus, information that an IS should provide to support a sustainable change depends on the three sustainability goals: reduction of CDE emission as fast as possible, low costs for consumers and government, and creation of supply options, but it also depends on the key factors of the system and the cause and effect laws of those factors.

Nitsch et al. (2010) presented the results of a dynamic, partially broken down spatial simulation of the German power supply. Recommendations for policy makers were created from these results. In the long term, the simulation of the traffic is mostly restricted to electrically powered vehicles. Schmid et al. (2010) investigated the required changes and the accompanying effects that might arise from a complete transformation of the energy system by 2050 based on new technologies. From there, they deduced requirements related to energy policy and research policy, as well as recommendations for policy makers. Like the approach from Nitsch et al. (2010), this approach tried to abandon bio-fuels in favor of electrically powered vehicles as far as possible. Phdungsilp (2010) presented a DSS that supports policy decisions related to energy and carbon development. Here, all energy demanding sectors are observed. The model is limited to urban development in Bangkok. The investigation of the transport sector does not include aviation. The DSS "STEEDS," which focuses on interdependencies between transport, environment, and energy, and provides an assessment of policy and technical alternatives to the European transport system by 2030, was presented by Brand et al. (2002). Various submodels form the basis of the study. These models do not include the feedback effects of resources, such as existing and already utilized agricultural area. Furthermore, trade restrictions are not considered. Arampatzis et al. (2004) presented a DSS that is integrated into a geographical network. The aim is to assist policy makers in simultaneously improving the urban transport system, energy efficiency, and environmental friendliness. The policy measures apply only to the use of vehicles. A macro perspective consideration is not integrated. Ülengin et al. (2007) presented a DSS that shows the potential impact of a particular policy measure on the proportion of passenger and freight transport through the formulation of long-term scenarios. They use a system approach to investigate the links between transport, socio-economic, and demographic variables. Then they use a causal approach, a neural network, and a Bayesian network to analyze the impact of different scenarios on the future demand of passenger and freight transport. However, the model does not include the interactions between transport and environment. Perimenis et al. (2011) developed a DSS for the assessment of bio-fuels. Technical, economic, environmental and social aspects, as well as any production pathways are considered. Results only relate to one fuel: interactions with other fuels in demand are not considered.

The results of the literature research reveal that none of the systems or tools available today supports political decisions under the above-mentioned requirements. Further, none considers the variety of renewable fuel alternatives, various transport and mobility sectors, or even complex interactions and the feedback effects of the fuel markets. Design-oriented research aims to build artifacts and produce important contributions to IS theory and practice for innovative and new problems (Arnott and Pervan 2012; Hevner et al. 2004). In order to meet the above-mentioned problem-solving requirements, a design-oriented approach was chosen as the underlying research design. Design science research (DSR) principles help to ensure the rigor and relevance of the research process and results (Hevner et al. 2004; Peffers et al. 2007). According to these principles, a targeted literature review was performed within the IS and OR domain. After the problem domain was refined and more detailed requirements were defined, an initial optimization model was constructed. While the initial model included only a basis of factors and constraint, a multiple iteration of construction and evaluation enabled to refine the artifact iteratively. To support the definition of political measures in environmentally sustainable context and enable better usability of the model, REFUSA, a prototype of a DSS with a graphical user interface (GUI) was implemented as an instantiation. REFUSA and the underlying model were evaluated within a feasibility check for the German fuel market. This paper can trigger a broad discussion among renewable fuels experts, and that discussion can lead to a more professional political DSS.

Political Decision Support System

The basis of the DSS is the model of a fuel market and the scenario simulation, analysis and optimization prototype REFUSA. The REFUSA prototype was implemented in Microsoft Excel 2010. Visual Basic for Applications (VBA) was used to automatize the Excel add-in *Solver* for the simulation and optimization, as well as to provide a GUI. In the following sections, the structure of the underlying model, assumptions, all key factors, all major cause and effect laws, and the REFUSA prototype are described.

Underlying Model

Assumptions

The model describes political influence on CDE emissions and fuel consumption, or rather the economic consequences for the entire fuel market of one country. The current development of the fuel market is affected by many factors. The aim of the model is to generate an illustration of the medium-and long-term development of the fuel market in a realistic as possible way, so that statements can be made about the future distribution of fuel and the possible replacement of fossil fuels with renewable fuels. The reproduction of all factors creates a model that has a high computational complexity and thus takes a lot of time to be computed. Therefore the assumptions that only take the essential factors and contexts into account are summarized below:

- Fuels and engines used by the different transport and mobility modes are identical.
- Impacts of fuel on the refueling cycle and the tank volume are negligible, since these effects on the use of a fuel only arise at low price differences.
- The inflation factor is not included, since it affects the whole model and therefore trends remain unchanged.
- Purchase or re-equipping is done solely due to fuel prices and vehicle life cycle. The vehicles are equipped with an engine that uses the fuel that was the cheapest in average over a specific period, because the user has observed the fuel prices over a specific period. The total number of vehicles does not change according to purchase cost, re-equipping cost, or premature lack usability. This correlation is more present for consumers with high fuel consumption. Nevertheless, due to altered mobility patterns such as the use of sharing options, it is likely that these costs become less important for all consumers.
- It is assumed that existing plant capacity will not decline, which normally would be the case of aging processes or system failures.

- Competitive factors of production, such as heat or electricity consumption, are not included.
- Each user pays the same price. It is not possible to produce or to even obtain fuels or electricity cheaper.

Cause and Effect Laws and Key Factors

The assumptions lead to the exogenous and endogenous factors of the model listed in Table 1. To represent the composition of the total consumption, it is necessary to identify the individual fuel quantities for one time step. Figure 1 shows the cause and effect laws, by which the fuel quantities are determined for one time step. The boxes represent the individual factors. The arrows between the factors reflect the relationship, and the plus and the minus signs show the effect. A plus sign indicates a positive effect, i.e., the increase of a factor results in an increase of the related factor. This applies analogously to the reduction. In the case of a negative effect, the increase of a factor results in a reduction of the related factor. The upper part of Figure 1 shows the cause and effect laws of the major factors and their impact on a fuel in one time step. For example, if the net energy yield of the field increases, the primary energy costs and the food factor decrease, and the capacity of cultivation area increases. As the same amount of renewable fuel can be produced cheaper, less area is needed to feed the same number of inhabitants and per unit area a larger amount of renewable fuel can be harvested. The lower part of Figure 1 simplifies the interaction between the various fuels in a time step. Each cost and capacity factor of a fuel is subjected to the cause and effect laws of the upper part of Figure 1. To determine the composition of the fuel consumption and thus the fuel amount of the year, an order of costs is determined. The cheapest fuel is fully utilized until its capacity is exhausted. This process is performed for each additional fuel from the second cheapest to the most expensive. However, hereby the capacity for the following fuels is reduced. For example, fuel 1 and fuel 2 are made from renewable raw materials. Fuel 2 is the cheapest fuel as shown in the lower part of Figure 1 by the thick arrow. Consequently the capacity of the cultivation area, and thus the capacity of the fuel 1 is decreased. Also, it is possible that the cheapest fuel 2 uses the same engine as fuel 1, this also results in the decrease of the capacity, as the vehicle capacity decreases. The exogenously given factors are transport costs, storage costs, energy density, CDE, mobility factor, agricultural land, area for material usage, net energy yield oil, capacity of oil occurrence, increase in production, decrease in production costs, population growth, share of transport sector in total consumption, fallow land, and increase in yield. In addition, the control variables of policies, energy tax exemption, tax penalty on CDE emission, and import restriction are exogenous factors. The endogenous factors that are needed for the optimization of a time step to be calculated result from the exogenous given factors, the optimization results of the previous time steps, and the values of the endogenous factors of the previous time steps. First, the effect laws of the endogenous factors of one time step to the next are explained, followed by a description of the optimization model that is set up using the endogenous factors.

From one time step to the next, population increases if more people are born or immigrated than emigrated or died. As formula (1) shows, the population size of the actual time step is the size of the population of the previous time step plus the change in population. Formula (2) represents the relation of the crop yield. The crop yield per unit of area of a time step is equal to the crop yield per unit of area of the previous time step, plus the increase in yield per unit of area. The food factor is negatively influenced by the change of the yield per unit area, because more people are saturated with less area if the yield per unit area increases. Thus, the food factor is calculated from the food factor of the previous time step divided by the change in the yield per unit area from the current to the previous time step, this effect is presented by formula (3). Formula (4) shows the calculation of the factor net energy yield field. Since the net energy yield of cultivation per unit of area of a renewable fuel i increases due to the increase in yield per unit of area, this net energy yield corresponds to the net energy yield per unit area of renewable fuel i of the previous year multiplied by the change in the yield per unit area from the current to the previous time step. The capacity of the cultivation area depends negatively on the competition factors fallow land, area of material usage, and the cropland to grow food, which in turn depends on population and the food factor. Furthermore the capacity of the cultivation area depends positively on the agricultural area and is calculated as formula (5) shows. The limit of a fuel i occurs at the factor vehicle capacity due to the suitability of an engine type k. Vehicles have a certain life cycle. This life cycle is based on c time steps. This means that vehicles that are purchased at time t are scrapped after the end of the life cycle in $t + c$. Hence the factor vehicle scrapping corresponds to the factor new vehicle registration of c time steps ago (formula (6)).

Table 1. Notation and Explanation of Exogenous and Endogenous Factors

Factor name and notation		Explanation
Agricultural land	L	Agricultural land
Area for material usage	M	Area for material usage
Capacity of cultivation area	-	Entire cultivation land that can be used to provide fuel
Capacity of oil occurrence	o	Oil occurrence that can be used to provide fuel
CDE	V^i	Amount of CDE that is emitted through the provision and use of a fuel *i*
Contribution margin	k^i	Transport and storage costs for a unit of fuel *i*
Efficiency gain	G^k	Increase in engine effectiveness of engine type *k*
Energy density	h^i	Energy density of fuel *i*
Energy tax	U^i	Energy tax of a unit of fuel *i*
Engine effectiveness	e^k	Efficiency of engine type *k*
Fallow land	B	Fallow land
Food factor	F	Area that is used to feed an inhabitant
Gross costs	-	Cost of a unit of fuel
Import volume	i^i	Maximum quantity of fuel *i* that can be imported
Net energy yield field	$n1^i$	Amount of fuel *i* that can be provided from one hectare
Net energy yield oil	$n2^i$	Amount of fuel *i* that can be provided from oil
Net capacity	-	Capacity of a fuel *i*
Net costs	-	Cost of the fuel of a drive unit
New vehicle registration	$N^{j,k}$	Additional available amount of fuel due to a certain number of newly registered or re-equipped vehicles in transport sector *j* with engines suitable (*k*) for using this fuel
Population	A	Size of the population
Primary energy costs	r^i	Cost of the raw material of a unit of fuel *i*
Production capacity	p^i	Total amount of fuel *i* that can be produced at existing production facilities
Production costs	j^i	Production costs of a fuel *i*
Storage costs	S	Costs of storing fuel
Subsidy	u^i	Amount of the subsidy for a unit of fuel *i*
Tax penalty on CDE emission	W	Tax levied on the CDE emissions
Tax penalty	-	Resulting tax amount on the emission of a unit of CDE
Transport costs	T	Cost of transporting fuel
Value added tax	z	Value added tax
Vehicle capacity	$v^{k,j}$	Total amount of fuel that can be used, based on the number of suitable vehicles (*k*) in transport sector *j* for this fuel
Vehicle scrapping	$a^{k,j}$	Amount of fuel that is no longer needed, because certain number of vehicles equipped with engine type *k* are no longer available (because of scrapping or re-equipping) in transport sector *j*
Winning quantity	-	Amount of fuel available after the according of the harvest or oil production
	d	Change of population
	D	Total consumption
	I	Increase in the harvest
	J^i	Change of production costs of a fuel *i*
	m	Amount of mobility cause by an inhabitant
	P^i	Increase of production capacity of a fuel *i*
	$q^{i,j,k}$	Amount of fuel *i* used by engine type *k* in the transport sector *j*
	s^j	Share of the transport sector *j* in total consumption
	y	Crop yield per unit of area

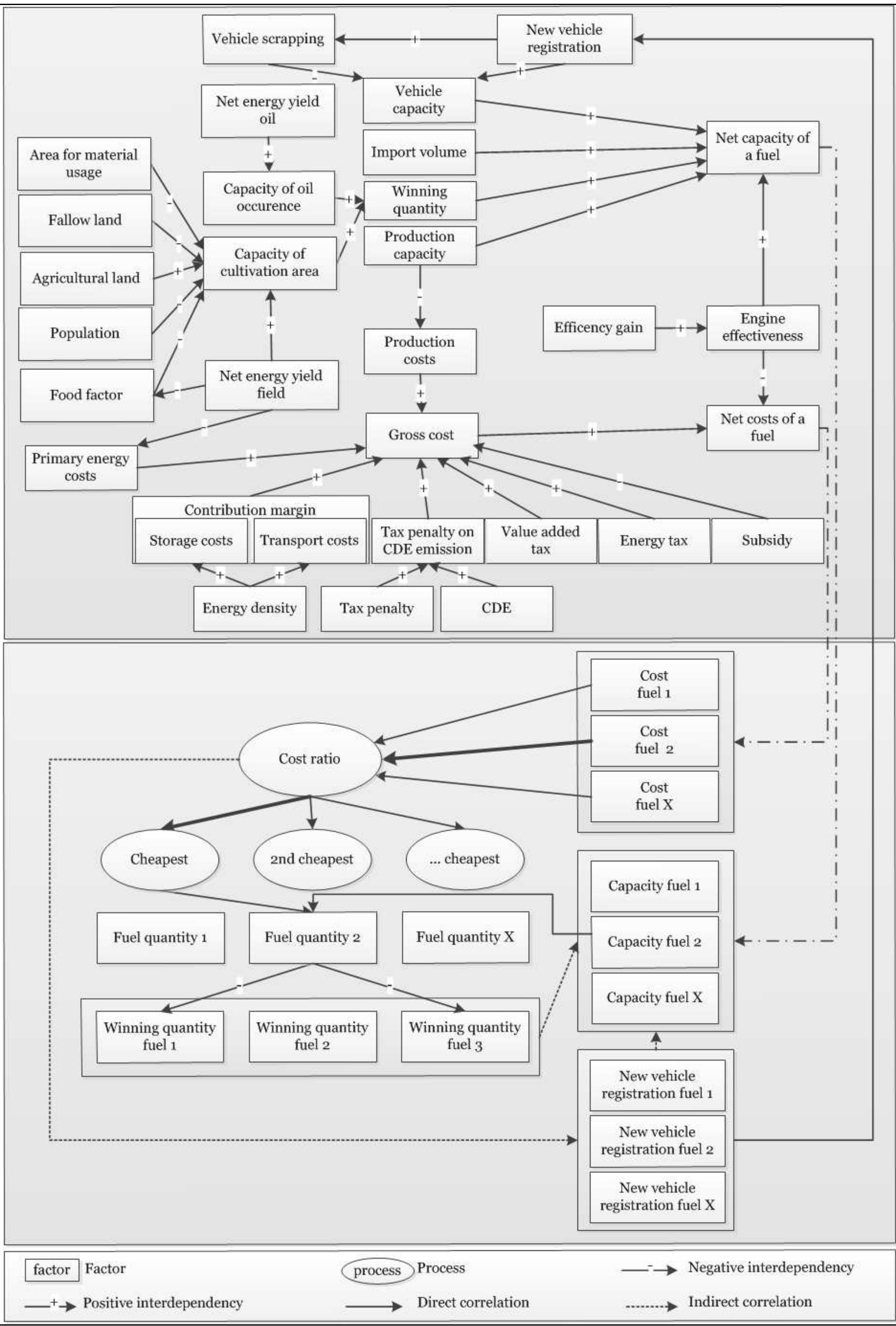

Figure 1. Upper Part: Cause and Effect Laws of the Fuel Market to One Fuel; Lower Part: Mutual Effects of the Quantification of the Fuels

The demand for vehicles in the transport sector j in time step t is determined by the population, which has a certain mobility demand in the amount of mobility factor and the share of the transport sector j at this mobility demand. Further, these newly registered vehicles are equipped with an engine type k, which can be used by certain fuels i. The decision to purchase this particular vehicle is determined by the fuel prices of the last time steps. Thus, the vehicles that can be driven with the fuel i are registered, which was average at best in the considered time steps. As formula (7) shows, the factor new vehicle registration in the transport sector j corresponds to the mobility demand of the transport sector j of this time step minus the mobility demand of the transport sector j of previous time step minus the vehicle scrapping of the last time step, if these vehicles are suitable for the in average cheapest fuel i. Vehicle capacity in a transport sector j, which means the vehicles that are equipped with a suitable engine type k for fuel i, corresponds to vehicle capacity of the previous time step plus new vehicle registration minus vehicles scrapped from the previous time step, as shown by formula (8). As formula (9) shows, production capacity increases by the production capacity change in time step only if production capacity is completely utilized in the previous time step. The primary energy costs are also affected by an increase in yield, since higher yields per unit area reduces the cost of harvesting. Formula (10) shows that if yield from the previous year rises, the primary cost decreases from the current to the previous time step. The contribution margin of a fuel i corresponds to the transport costs and storage costs of a unit and depends positively on the energy density (formula (11)). Production capacity increases as production costs fall. Therefore, the production costs of the current time step correspond to the costs of production of the previous time step, or if the production capacity increases, the costs of production decrease by the production cost decrease, as formula (12) shows. The gross costs of fuels i depend positively on the individual cost factors, the tax penalty from the emissions of CDE, energy tax, and value added tax, which is levied as a percentage of the other costs, and negatively depends on the energy tax exemption. The efficiency gain of the current time step, formula (13), is calculated using learning curves, according to formula (13). Efficiency gain of an engine type k corresponds to the efficiency gain of the previous time step, including the experience curve for this time step. This experience curve is calculated using the efficiency gain of the time step of invention of the motor, the time steps that have elapsed since invention, and the learning effect x of the engine. If the efficiency gain increase from one time step to the next, the efficiency of the engine increases. Therefore, as formula (14) shows, the efficiency of the current time step corresponds to the efficiency of the engine of the previous time step and the change in the efficiency gain.

$$A_t = A_{t-1} + d_t \tag{1}$$

$$y_t = y_{t-1} + I \tag{2}$$

$$F_t = \frac{F_{t-1}}{\frac{y_t}{y_{t-1}}} \tag{3}$$

$$n1_t^i = n_{t-1}^i * \frac{y_t}{y_{t-1}} \tag{4}$$

$$f_t = L_t - M_t - B_t - A_t * F_t \tag{5}$$

$$a_t^{j,k} = N_{t-c}^{j,k} \tag{6}$$

$$N_t^j = \begin{cases} A_t * m * s_t^j - A_{t-1} * m * s_{t-1}^j + \sum_{k=1}^{K} N_{t-1-c}^{j,k}, * b_1 \\ 0, \text{otherwise.} \end{cases} \tag{7}$$

$$v_t^{k,j} = v_{t-1}^{j,k} + N_t^{j,k} - a_{t-1}^{j,k} \tag{8}$$

$$p_t^i = p_{t-1}^i + P_t^i * b_2 \tag{9}$$

$$r_t^i = \frac{r_{t-1}^i}{\frac{y_t}{y_{t-1}}} \tag{10}$$

$$k_t^i = (S_t + T_t) * h_t^i \tag{11}$$

$$j_t^i = j_{t-1}^i - J_{t-1}^i * b_3 \tag{12}$$

$$G_t^k = G_{t-1}^k + \frac{G_{t_0}^k * 1^{\left(\frac{log\,(x)}{log\,(2)}\right)}}{t - t_0} \tag{13}$$

$$e_t^k = e_{t-1}^k * \frac{G_t^k}{G_{t-1}^k} \qquad (14)$$

Where:

$$b_1 = \begin{cases} 1, \text{if engine type } k \text{ is suitable for fuel } i, \text{and fuel } i \text{ has on average the lowest net cost of the last } x \text{ time steps} \\ 0, \text{otherwise.} \end{cases}$$

$c =$ Length of the life cycle time steps of the engine type k in transport sector j.

$$b_2 = \begin{cases} 1, \text{if } \sum_{j=1}^{J} \sum_{k=1}^{K} q_{t-1}^{j,k} = p_{t-1}^i \\ 0, \text{otherwise.} \end{cases}$$

$$b_3 = \begin{cases} 1, \text{if } p_t^i > p_{t-1}^i \\ 0, \text{otherwise.} \end{cases}$$

Optimization Model

The aim is to determine the gross amounts of fuel and the total gross consumption for each year. Total gross consumption can be computed by using the results of the optimization with engine effectiveness. The objective of the optimization is to meet the demand of fuels as economically as possible, so that the cheapest fuel is used. The maximum usable amount of fuel corresponds to either the maximum capacity of available cultivation land, the maximum production capacities, or the consumption capacities of the vehicles. Since the demand is to be met at lower cost, the goal for each simulation year is the minimum cost distribution of fuel supply to fuel demand (objective function of the optimization). It is necessary to involve the capacities of the fuels. Furthermore, the net quantity of the fuel i that has to be produced, suitable for engine type k, for transport and mobility sector j in year t is limited to certain fuels i:

$$q_{t,net}^{i,j,k} = \begin{cases} q_{t,net}^{i,j,k} & \text{if fuel } i \text{ can be used by engine } k, \\ 0, & \text{otherwise.} \end{cases}$$

$$\min \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \frac{\left(\left(r_t^i + j_t^i + k_t^i + U_t^i - u_t^i + V_t^i * w_t\right) * (1 + z_t)\right)}{e_t^k} * q_{t,net}^{i,j,k} \qquad (15)$$

with the constraints

$$\sum_{i=1}^{I} \sum_{k=1}^{K} q_{t,net}^{i,j,k} \geq A_t * m_t * s_t^j \qquad \forall j \qquad (16)$$

$$q_{t,net}^{i,j,k} \geq 0 \qquad \forall i,j,k \qquad (17)$$

$$\sum_{i=m+1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \frac{q_{t,net}^{i,j,k}}{(e_t^k * n1_t^i)} \leq f_t \qquad (18)$$

$$\sum_{i=1}^{m} \sum_{j=1}^{J} \sum_{k=1}^{K} \frac{q_{t,net}^{i,j,k}}{(e_t^k * n2_t^i)} \leq o_t \qquad (19)$$

$$\sum_{j=1}^{J} \sum_{k=1}^{K} q_{t,net}^{i,j,k} \leq p_{t,net}^i + i_{t,net}^i \qquad \forall i \qquad (20)$$

$$\sum_{i=1}^{I} q_{t,net}^{i,j,k} \leq v_{t,net}^{j,k} \qquad \forall j,k \qquad (21)$$

The results of the simulation and optimization are the single net quantities of a fuel of the respective transport and mobility modes. The "net" implies that each of the quantities is adjusted to the conversion losses of the use by the engine. Formula (15) specifies the objective function of the optimization of a simulation time step, which is used to minimize total net costs of the fuel quantities. More precisely, the gross energy costs in time step t result from the value added tax of time step t multiplied by the term of the costs in time step *t*. These costs include primary energy costs, cost of production, contribution margin, energy tax, energy tax exemption, and penalty on emissions of CDE. The tax penalty on CDE is calculated from the tax penalty on the output of a unit of CDE in time step *t*, and output of CDE of a fuel *i*. To adjust gross cost of fuel *i* to the conversion losses, the cost are divided by the efficiency of the fuel-suitable engine type *k*. Thus, if the efficiency of the engine using this fuel increases more demand for mobility can be satisfied at a lower net cost. The constraint (16) ensures that the sum of all net fuel quantities used by a transport and mobility sector *j* in time step *t* complies with the share of the transport and mobility sectors *j* in time step *t* of the total net consumption in time step *t*. This total net consumption or demand corresponds to the population and the mobility factor, as described above. Because the net amounts of fuel used cannot be negative, inequality (17) restricts them to positive values. To perform the optimization, it is also necessary to compute the optimization determining factors first. These factors include the various capacity constraints, as well as the fuel price. The determination of the capacity constraints is described as follows: to represent the dependencies of fossil fuel quantities (fuel $i = 1$ to m) on oil resources and the dependencies of renewable fuel volumes (fuels $i = m + 1$ to I) on the capacity of the cultivation area, it is necessary to separate the direct correlation from the production capacity. The constraints (18), (19), (20), and (21) reflect the capacity constraints. Inequality (18) refers to renewable fuels; it indicates that the sum of the renewable fuel volumes, each of which includes the conversion losses of the use by an engine type *k* in time step *t* and the provision (net energy yield of the fuel *i* in time step *t*) of all transport and mobility sectors and fuels must not be larger than the area available for cultivation of renewable fuels. With inequality (19), the fossil fuel quantities are limited. In this case, the sum of the quantity of fossil fuel, which includes the conversion losses for each over all transport and mobility sectors and fuels, must not be greater than the available oil reserves in time step *t*. Furthermore, the sum of a fuel of all transport and mobility sectors must not exceed the net production capacity and the policy-dependent specification of the net import share of a fuel *i* in time step *t*, as inequality (20) shows. The constraint (21) states that the amount of fuel of a transport and mobility sector that can be used by the number of vehicles with a suitable engine type *k* must not be greater than the net vehicle capacity.

Prototype of a Scenario Simulation and Optimization Tool

The DSS REFUSA integrates the optimization model and the cause and effect laws to enable decision support and is implemented in Excel 2010. The advantages of using a well-known and well-accepted Excel/VBA are easy usability and the fact that it can be used locally and offline. REFUSA is only a prototype for implementing and testing the model and scenario simulation and optimization, and for checking the feasibility of the decision support. To solve the model, it is necessary to use Excel *Solver*. The *Solver* must be called up again for each time step by using VBA because Excel only enables users to perform one optimization with the *Solver*. If further optimizations are performed, the decision variables are deleted, so it is necessary to program a sequence of multiple *Solvers* to avoid having to manually create the optimization for the individual time steps, thus facilitating the creation of different scenarios.

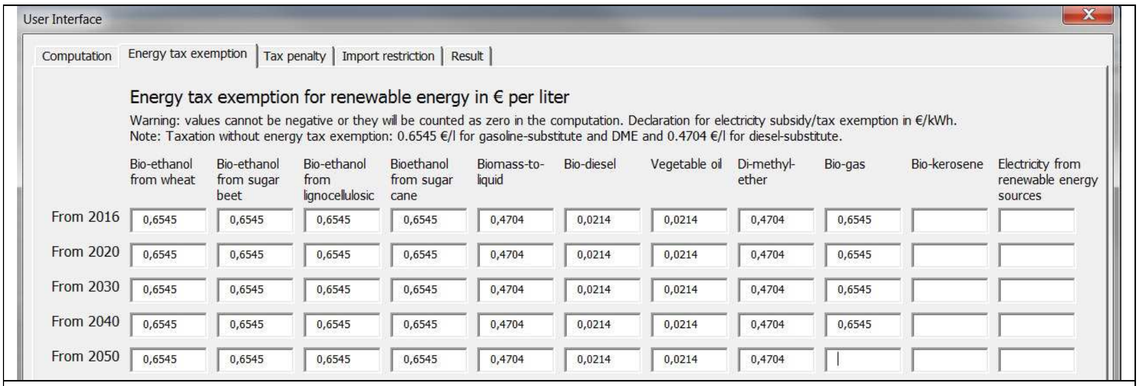

Figure 2. Example of REFUSA GUI for the Possible Input of Energy Tax Exemption

The model is set up for each time step, so that the REFUSA prototype computation of the fuel distribution can be performed for each time step by using the *Solver* (scenario simulation and optimization). The integrated optimization problem has a high computation complexity. Thus, it is hard to solve and computationally expensive. An optimal solution is hard to determine, particularly for large problems. It can be proven that the DSS provides an optimal solution, where the runtime depends on the size of the input instance, i.e. number of fuels, as well as the settings. The data and the time series have to be integrated into the spreadsheets once and are automatically used by the computations that require them in the REFUSA. The data that depends on the simulation and optimization is computed after each iteration and is provided for the next iteration. This data includes the endogenous factors. Not only can users configure parameters, they can also specify exogenous values and time series of the exogenous factors on the GUI (causes in the model above, which describes the cause and effect laws). Here, these inputs, all of which are valid for each decade, represent the amount of energy tax exemptions on different fuels, the amount of tax penalties on the emission of one ton of CDE, and the share of total consumption, which might be covered by imported bio-fuels. For example Figure 2 shows the prompt for the energy tax exemption on the REFUSA GUI. The data entered by the user form the basis for computation of the scenario. REFUSA visualizes all required data for decision making.

Application Example and Feasibility Check

To demonstrate the DSS prototype REFUSA, a check of applicability was conducted using Germany as an example. It demonstrated the feasibility of the model and enabled a comparison of generated alternatives. The reasons for selecting Germany are as follows. Like the USA or Japan, Germany is a highly developed country with high mobility and energy demand. Energy demand in the German transport and mobility sector amounts to about 706 TWh (26%), of which 93% was met by mineral oil, 2% by electricity, and 5% by renewable energy sources in 2010. The fraction is composed of 36% motor fuel, 49% diesel fuel, and 15% aviation fuel (IEA 2012; Radke 2011). In Germany, about 20% of carbon dioxide emissions are caused by traffic (Walter 2006). In recent years, Germany tried to achieve a sustainable change by means of political interventions, i.e., a lower energy tax is already levied on renewable fuels. Furthermore the use of crude oil in Germany leads to a dependency on other countries, due to the fact that crude oil imports cover almost 100% of the demand (Henke and Klepper 2006).

Data Basis

The scenario simulation and optimization prototype REFUSA includes all the necessary exogenous data and time series for simulation and optimization up to the year 2050. In addition to domestic production, the import of bio-fuels is considered. The study investigates the following fuels or energy sources: gasoline, diesel, aircraft fuel, electricity, bio-ethanol, biomass-to-liquid (BtL), rapeseed methyl-ester, di-methyl-ether (DME), vegetable oil from rapeseed, bio-gas, and bio-kerosene. Bio-kerosene and ethanol from sugar cane cannot be produced in Germany and therefore have to be imported. Here, aircraft fuel and kerosene are equal. In addition, the subdivision is on the origin of electricity from fossil or renewable energy sources and bio-ethanol from wheat, sugar beet, sugar cane, and lignocelluloses. Transport and mobility is divided into the sectors of road traffic, railways, aviation, and inland waterway transport. A further division of the transport only affects road traffic into the sectors freight and passenger transport, due to the small differences in fuel consumption, as in transportation of passengers or goods by rail or combination of goods and passengers in the aviation industry, as well as a small portion of passenger traffic on the inland waterway transport. Furthermore, the temporal frame of reference amounts to 38 years. The data and time series are in the form of a value series, partly over the whole analysis period. The data used is country-specific (e.g., population) or universally valid (e.g., fuel properties) and may be looked up in detail at: Allgeier and Ullmann (2008), Andruleit et al. (2011), BAFA (2010), BMU (2011), Bühler (2010), Edward et al. (2006), Edward et al. (2008), Eichlseder and Klell (2010), Eisenmenger et al. (2006), Exxon (2008), FNR (2011), Geitmann (2005), Geitmann (2008), Gemis (2011), General Aviation (2010), § 2 and § 50 of the German Energy Tax Act (2006), the German Federal Bureau of Statistics (2012), IWR (2010), Kost and Schlegl (2010), Lahl (2009), MWV (2011), Pridmore et al. (2010), Radke (2011), Schmidt and Mühlenhoff (2009), Schmitz (2006), Schmitz et al. (2009), Tetzlaff (2005), VDB (2010), Watter (2009), Wengenmayr (2011), Winter et al. (2007) and Wissel et al. (2008). The integrated data is subject to the following, briefly introduced assumptions:

- Every inhabitant causes the same fuel consumption, passengers and freight alike.
- With the exception of road transport, the transport of goods generates combined transport. For example, after something is transported by ship, truck transport is necessary if the destination of the goods is not a port. To fulfill those dependencies, it is assumed that there is no change in the existing preferences for transportation of freight. Thus, the shares of the various modes of transport and mobility in transportation of freight are constant. The model does not take public transport into account.
- The mobility preferences of a human being remain constant over the analysis period. The result is that fuel consumption is linked to the population.
- BtL is only used by diesel engines. Vegetable-oil-compatible engines can also use diesel fuel. It is assumed that vegetable oil engines are able to use every fuel suitable for a diesel engine in case of insufficient fuel capacity. The vehicles can only use one fuel. The use of hybrid vehicles is not possible and the admixture of bio-diesel to fossil diesel and bio-ethanol to gasoline is not possible either.
- Due to a lack of experience in the mass production of renewable fuels, increases in production capacities are based on plausible assumptions.
- Efficiency gains only affect the engines and their effectiveness, because efficiency gains from lightweight vehicle constructions, for example, would cover all transport and mobility sectors. The bulk of electrically powered vehicles do not have a continuous supply of energy, for example through overhead lines. Although some can be supplied continuously, the effectiveness of the engines in these vehicles also includes the effectiveness of battery.
- It is assumed that the price of crude oil and therefore price of fossil fuels will increase in the future. With some exceptions, there is no tax imposed on aviation fuel in Germany (German Energy Tax Act § 27 2006). Therefore, it is assumed that no tax is levied on aviation fuel by 2050.
- An unchanged value added tax and an unchanged contribution margin of the fuel prices are assumed as of the year 2011.
- In relation to the price of electricity, production costs, transportation costs, and storage costs are being considered. The various production cost are averaged. Government support for renewable electricity is not included.
- The consideration of the greenhouse gases is collectively subject to the harmfulness of each gas and to the emissions of all, the "well-to-wheel". It is assumed that these CDEs are constant over the simulation period, although it is possible to modify them, as fuels with a lower CDE are being used in the production or transportation of a fuel.

First Results and Recommendations

Four relevant and important scenarios were computed using the REFUSA prototype. The impact of energy tax exemptions, tax penalties on emissions of CDEs, and import restrictions on the German fuel market were analyzed and evaluated. Currently, renewable fuels can be imported by Germany and the fuel price is charged without tax penalty on the emission of CDE. However, renewable fuels are completely exempt from energy taxes until 2016. The energy tax on renewable gasoline substitutes is 0.65 €/l and on renewable diesel substitutes 0.47 €/l. But for biodiesel and vegetable oil, the energy tax exemption is already aimed to be reduced (by 2014 for bio-diesel to 0.30 €/l and for vegetable oil to 0.30 €/l, and for the years to 2016 for both to 0.02 €/l).

The reference scenario is scenario 1, in which the energy tax exemption is lowered linearly to zero until the year 2023. To show the effect of the control variables, three more scenarios are presented, in which only one control variable is changed, wherein their selected values are relatively high and stable over the observation period. These scenarios were chosen in order to strengthen this effect, and because there is a variety of input options and combinations. In scenario 2, the energy tax exemption is maintained until 2050. This means from 2016 until 2050 the energy tax exemption amounts to 0.65 €/l for bio-ethanol, bio-gas and DME, 0.47 €/l for BtL, and 0.02 €/l for bio-diesel and vegetable oil. In scenario 3, a tax of € 100 per ton CDE emission is levied, and in scenario 4, the imports are prohibited.

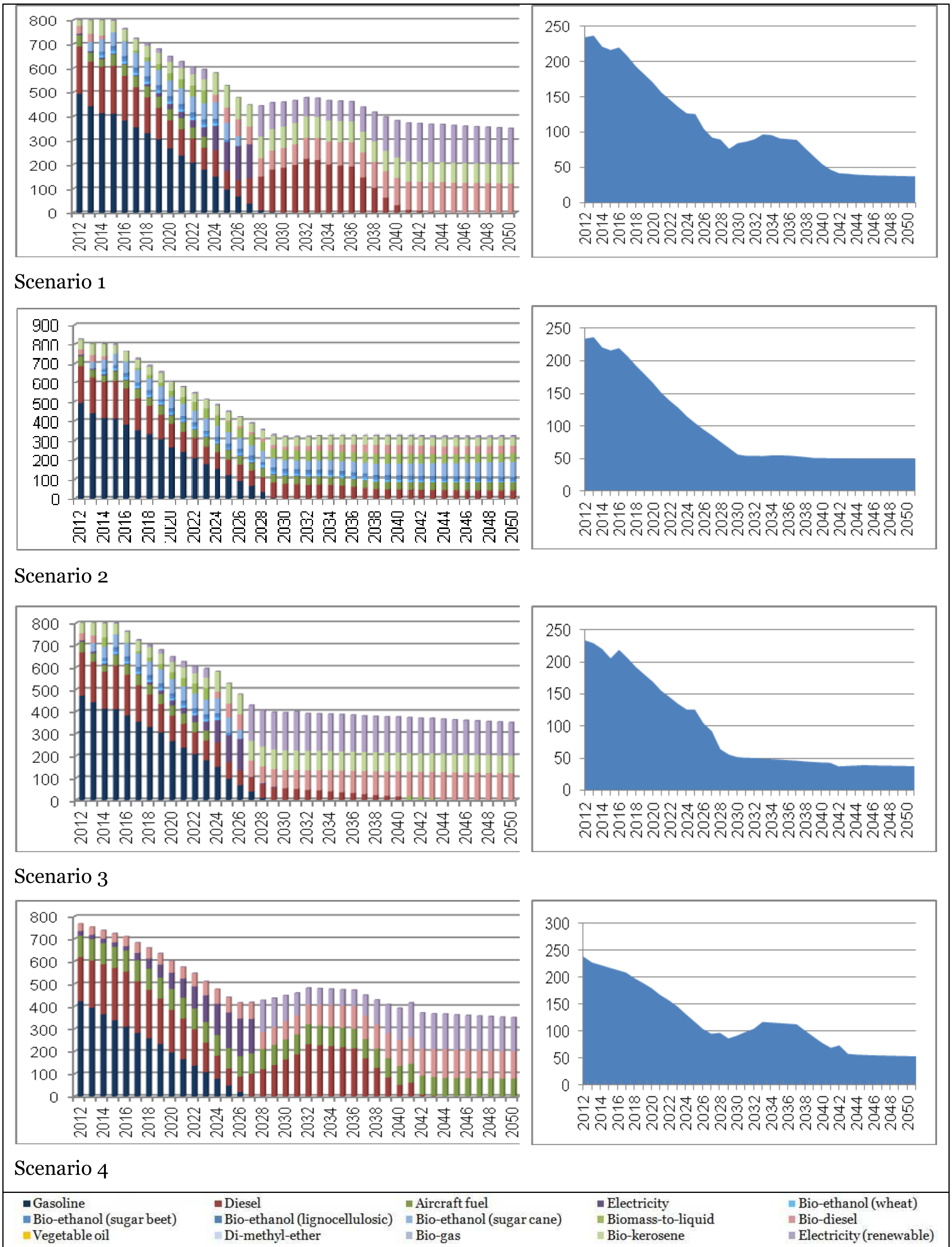

Figure 3. Scenarios up to 2050. Left: Total Fuel Consumption (TWh); Right: CDE Emission (Million Tons)

The criteria according to which the scenarios are analyzed and evaluated refer to sustainable change. This means that the supply has to be ensured in the scenarios, and, the lower the cost to the government, the lower the expenses for consumers. Also the lower the emissions, the better the results of the scenarios. Figure 3 shows the fuel consumption and total CDE emissions of the different scenarios.

Security of supply is ensured in all scenarios. In general, the total consumption and the CDE emission decrease, but decline in the German population is also a reason for this. In comparison with the reference scenario, in which the state collects € 932 billion by taxes in the transport sector, the least decreased tax revenues for the government are in scenario 4. However, with € 1260 billion, much more tax is collected in scenario 3 due to the penalty tax on the CDE emissions. The total expenditure over the period under consideration is the lowest for consumers, in scenario 2 at € 4274 billion. However, this is also the scenario in which the government collects the least amount of taxes. Looking at the CDE emissions, scenario 4 is the worst. In scenario 1, the emissions increase again in the meantime, but not as much: this is due to the fact that part of the consumption is replaced by less efficient, CDE-poor fuels, because they are cheaper. In addition, in scenario 4 the exhaust of emissions by 2050 is the lowest. This is, because no renewable fuels can be imported. This is the case even though these imported fuels are less expensive and have lower emission levels than those produced in Germany. In scenario 2, with continuous energy tax exemption, much more electricity is used. This utilization leads to a faster reduction in CDE emissions, as in scenario 3. The consumption of bio-kerosene is equal to the production capacity of foreign countries in scenarios that allow renewable fuel import. Due to an increasing production capacity, consumption of bio-kerosene increases and leads to a lowered CDE emission.

Considering the different IS-based scenario results of the application check of the model in the example of Germany it can be concluded that the political measure of the energy tax exemption have been used as a cornerstone for sustainable change. However, it is important to ensure that this goal will continually be pursued. It should be noted that in cases of excessive falling tax revenues in the transport sector, the government will try to compensate this lack of revenue. For example, they might increase this tax or other taxes, such as increased road tax. Furthermore, the scenarios show that the government also introduced penalties help to reduce emissions. This supports both the provision and use of more efficient and lower-emission renewable fuel alternatives. Nevertheless, a lower tax penalty should be chosen to reduce the pressure on the consumer. Also note, that fuel imports are allowed. It is likely that fuels that can be produced efficiently and more cheaply are imported, such as bio-diesel from soy or palm oil. However, this often causes problems. These are, firstly, the dependence on other countries. Secondly, in these countries often the sustainability of harvest and environmental and climate protection are neglected. So it is possible, as is taking place in Brazil, that land used to meet the increasing global demand is overexploited or that land grubbing is occurring for the cultivation of bio-ethanol from sugar cane. There the sustainability of resource extraction should also be taken into account, in that the observed additional land use changes these fuels. Furthermore, it is possible that this change in land use in some countries is to the detriment of food production and it is thereby possible that in these countries the food price increases and thus the famine. However, policies should be broader and relate not only to one single renewable alternative in order to avoid supply uncertainty. Since alternatives could not be obtained more cheaply through import, or if the harvest is poor, the result is insufficient supplies to meet the demand.

Discussion and Limitations

To provide decision support for states and international organizations, the constructed and evaluated IS-artifact REFUSA determines the development of the fuel market of a country (consumption of various fuel and fuel substitutes in the various modes of transport). Based on existing OR models, an optimization model was formulated to fit this task. The model was implemented and the results include the essential factors for decisions related to the sustainable change of the transport and mobility sector. The most important parameters and time series were included, such as import restrictions, engine effectiveness, and capacity of cultivation area. The system was implemented using Excel/VBA: REFUSA is tailored to the customer. Using Excel means that license, implementation, training, operation, and maintenance costs are low. Any user who has a good working knowledge of Excel and is familiar with the structure of the application can conveniently adapt and operate the system and the parameters of the simulation and optimization. The output of REFUSA results on an Excel spreadsheet ensures that the generated data can be easily reprocessed. The data is also visualized on the spreadsheets and if necessary, they can be exported easily. Users can change import restrictions, energy tax exemptions and tax penalties on CDE emission, and are able to adapt to different scenarios of their interests. Even users with minimal Excel/VBA skills can work with the REFUSA GUI. This ensures the use by the target group, especially by policy-makers, but also by industrial and environmental associations or managers of companies. This system provides a long-term representation of the most important ecological and economical fuel market data and thus a response to the effectiveness of policies. It supports efficient decision making by generating scenarios with different parameters and a visual representation of results. Due to the fact that transformation of the fuel market system is moving toward ecological sustainability, REFUSA is "Green by IS" and also "Green by DSS," and, as defined by Watson et al. (2010), belongs to energy informatics.

REFUSA provides users with the flexibility to use the original exogenous data and time series or to work with other data. Initial values must be set for some factors, and in some cases, units must be adapted. In addition, the scenario-dependent parameters for the exogenous factors of energy tax exemption, tax penalties on emissions of CDEs, and import restrictions (political options) are recorded. Reliability and accuracy are ensured by the use of Excel. Also the local installation provides confidentiality and information security. However, with regard to efficiency, it has to be observed that the foundation of the software, the spreadsheet program Excel, is not designed for high-performance computing operations. With the number of fuels and simulation years of the application example a REFUSA simulation and optimization run takes about 15 minutes (reference system: Intel Core i3 M330, Windows 7, 64-bit, 4 GB RAM). As McCullough and Heiser (2008) described, Excel is not necessarily the most suitable tool for theoretical formulation and simulation. To increase efficiency and performance, an implementation in GAMS or MATLAB is conceivable, but this requires more knowledge on the user's part and reduces the level of usability. Users can implement other enhancements without extensive programming knowledge with Excel/VBA. Precisely because REFUSA should support policy-makers, the advantage of Excel is that user with very little programming knowledge can easily adapt data, formulas, etc. Furthermore, they are able to use or adapt parameters or formulas other than those given on the GUI. It should be considered that in addition to the advantages of Excel/VBA such as easy usability, the number of variables and formulas to be computed was able to be handled as well. It should be noted that there are limitations to using the *Solver* in Excel/VBA for more extensive models, because it is limited to 100 constraints and 200 variables. The software is also attached to a specific version of Microsoft Office and therefore can only be used in environments that have this version installed.

The significance of the factors in the model depends on the objective pursued and on the stakeholders of the transport and mobility sector. To reshape society to a more ecologically sustainable one, these objectives become the sustainability goals. Since the actions of the suppliers and the consumers are influenced by their own economic interests, the net fuel costs and the capacities are the main factors to achieve these sustainability goals. To ensure the livelihoods of future generations, spending and revenue, and the exhaust CDE emissions are important for the government. Thus, the factors of political options and of emission content are important. If only one fuel is considered, the essential factors are net costs, CDE content, and the different capacities. However, these factors are determined by other factors, some of which have less impact. Different factors vary in importance for other factors like different fuels. If many fuels are considered simultaneously, the net energy yield of the fuel or the competition for cultivation area are important factors, too. Thus, different conditions lead to different factors being affected more strongly. The effects of the factors of policy options are: energy tax exemptions support the use of renewable fuels and the increase of production capacities, but they also increase government spending. The tax penalty on CDE emission strongly supports the availability and use of low-emission fuels, but leads to higher costs for consumers. Depending on the starting values, import restrictions support or threaten the security of supply. However, the strength of the effect depends on the feedback effects of the respective fuel factors. This suggests that all factors that affect the net costs of fuels, the different capacities, the CDE emissions, and government spending and government revenue are essential. Thus, an appropriate combination of these factors allows low cost for both government and consumer, low CDE emissions, and ensures security of supply.

Generally there are a variety for input options for the control variables. The input of the application example of Germany was chosen to give an overview of the effect of each parameter. Considering the different scenario results, it can be concluded that the total consumption, the use of various fuels, the emission levels, the cost for the government and for consumers all depend on the input of the control variables. Thus, these control variables have an impact on the economy, securing supply, and on the environmental extent of sustainability. To facilitate decision-making, various scenarios can be developed, analyzed and visualized. But, it is necessary to correctly communicate to consumers to avoid uncertainty and to simultaneously increase acceptance. REFUSA is able to support this communication process.

In addition to important and elusive topics, DSR should make interesting and major contributions to IS theory as well as IS practice (Arnott and Pervan 2012). Besides the topics of renewable fuel and sustainable mobility as well as Green by IS, the artifact considers essential and future-oriented topics. Thus, this artifact and research contributions belong to design science, due to these topics and the rigorous research process. Furthermore, the prototype of the DSS REFUSA enables the comparison of generated alternatives and, as Hevner (2004) states, demonstrates feasibility and allows evaluation of the suitability for the envisaged purpose of the underlying model.

With regard to the IS-artifact, certain limitations were identified. REFUSA was evaluated within one country. The DSS REFUSA and the underlying optimization model should be evaluated for other countries. Further REFUSA evaluations with historical data could be useful, but today it is difficult because few renewable fuels are used. To increase rigor for the approach and to achieve the goal of DSR that practitioners take on the artifacts (Arnott and Pervan 2012), an empirical evaluation by politicians is necessary. Additionally, in certain aspects the model could be expanded by adding extra variables and constraints. The existing model considers the respective monetary impact on the fuel market. Other aspects like soft factors are largely neglected. It is possible that the public is more influenced by its routine or through ignorance of a fuel, and will continue to purchase vehicles that run on fuels with which they have experience. It should also be noted that in the model, the refueling cycles and the infrastructure are not observed. Substitute fuels will be considered by customers less frequently if they find a lack of nationwide retail network. The result is that certain fuels are used later, as calculated by the model. These additional cause and effect laws are not as essential as they that are already integrated.

Nevertheless, the results of the literature research in the second section show that no contribution is available that meets the terms of the above-mentioned requirements: aggregated data that supports a decision for the selection on policy measures that have mid- and long-term impact, involves many different fuel alternatives, observes feedback loops, and so on. The outlined, underlying model meets these requirements and allows users to draw theoretical and practical implications. First, the quantitative approach can be used by researchers as a base to further increase and evaluate the sustainability of the fuel markets. Second, the DSS REFUSA provides a contribution that adds to the current state of knowledge and allows decision support by instant visual representation of optimization results. REFUSA assists politicians in selecting combinations of policies and enables faster and better decision making and thus enables to create an environmentally sustainable society.

Conclusions and Outlook

Politicians influence the behavior on the fuel market by using political measures. Any political measure used by REFUSA could have positive and negative effects on the sustainability goals and therefore on the environmentally sustainable society. Thus, using one political measure is not sufficient to ensure all the sustainability goals. Uncertainty about the impact of state policies results due to the different combinations of individual policies and the large number of parameters influencing the fuel market. These parameters are the number of fuels, their fuel properties, existing capacities, etc. The input of parameters and time series through the scenario simulation, analysis and optimization prototype REFUSA allows users to simulate the impact of state policies on the fuel market in one country for a desired time frame. Simulation and optimization results show the distribution and use of fuels by different transport and mobility sectors, fuel prices and total cost, required capacities, and total CDE emissions for each time step. With these IS-enabled results, conclusions can be drawn on the effects of various inputs. They enable and simplify political decisions made on a quantitative basis. By improving procedures for political decision making, REFUSA provides the ability to achieve desirable outcomes. This is because an appropriate combination of political measures allows a faster minimization of CDE emission at low cost for the stakeholders without threatening the security of supply. REFUSA allows politicians to easily adapt these policies of states and international organizations to changing conditions. Thus REFUSA enables them to create an environmentally sustainable society and could also secure the livelihoods of future generations.

Further REFUSA research steps are based on the above-mentioned limitations. To assert the validity of results, REFUSA assumptions should be reduced or adapted if the assumption basis changes, or if errors are detected, e.g. if new competitive factors arise. REFUSA is just a well-tested prototype to check the feasibility. Validation by experts and more complex tools as well as another implementation are considered. These might include, for example, a server-based tool with a GUI implemented in Ruby or Java and running MATLAB that also allows faster processing, including coarse-grained and fine-grained parallelization. Further research is also planned to compare REFUSA and the underlying optimization model with other "new energy"-planning tools (especially for electricity). It is conceivable to expand the system by adding a user-adjustable rating system to simplify and speed up the user-specific decision-making even more. Another option is to transfer and adapt REFUSA and the underlying optimization model for other issues relating to the transformation of national or the global energy systems. REFUSA could be used in other countries to support political decision-making in the domain of fuels as well as for broader topics or even different domains.

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