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A conceptual framework for the analysis of the effect of institutions on biofuel supply chains

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HIGHLIGHTS

- Proposes a conceptual framework to analyze biofuel supply chains.
- The German biodiesel supply chain was formalized into an agent-based model.
- Patterns in production capacity result from investors' perceptions of the market.
- This methodology could be used to analyze different deployment strategies.

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ABSTRACT

The economic performance of biofuels supply chains depends on the interaction of technical characteristics as technological pathways and logistics, and social structures as actor behavior, their interactions and institutions. Traditional approaches focus on the technical problems only. Little attention has been paid to the institutional analysis of biofuel supply chains. This paper aims to extend the analysis of the effect of institutions on the emergence of biofuel supply chains by developing a conceptual framework that combines elements of complex adaptive systems, (neo) institutional economics and socio-technical systems theory. These elements were formalized into an agent-based model. The proposed method is illustrated by a case study on a biodiesel supply chain in Germany. It was found that the patterns in production capacity result from investors basing their decisions on optimistic perceptions of the market development that increase with a favorable institutional framework. Conversely, patterns in biodiesel production cannot be completely explained by this mechanism. The proposed framework assisted the model conceptualization phase and allowed the incorporation of social structures into the agent-based model. This approach could be developed further to provide insights on the effect of different future deployment strategies on bioenergy systems emergence and development.

1. Introduction

The depletion of fossil fuels, growing concerns about energy security and global climate change have led to growing worldwide interests in biofuels [1]. In fact, the substitution of fossil fuels with biofuels has been proposed by the European Union (EU) as part of a strategy to reduce greenhouse gas emissions from road transport, enhance energy supply and support development of rural communities [2].

One of the fundamental barriers to the establishment and development of biofuels supply chains is related to economics. Biofuels are not cost competitive with their fossil fuel counterparts and thus they need governmental intervention. Formal institutions such as mandatory blending targets, tax exemptions, subsidies and import tariffs are some of the government interventions widely used to stimulate production and increase consumption of biofuels around the world [1].

The economic performance of biofuels supply chains depends on the interaction of technical characteristics (technological pathways and logistics) and social structures (institutions and actors behavior). Technological learning mechanisms such as learning-by-searching and economies of scale depend on investment in research and development as well as on production capacity by

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Nomenclature

a	parameter used in Eq. (11), $0 \leqslant a \leqslant 1$
blc	base land conversion factor. It defines the initial fraction of arable land to be used to produce rapeseed allocated by the farmer
C^{+}	value of the currency evaluated in the point $P^{+} = P + dP$
C	value of the currency evaluated in the point P
C^{e}_{t-1}	estimate for the variable C in the time $t-1$
C_{t-1}	actual value of the variable C from the time $t-1$
C^{e}_{t}	updated estimate of the variable C for the time t
c_{b_j}	fixed cost of the refinery operated by the biofuel producer j, [euro/l]
Cap_j	capacity of the refinery owned by the biofuel producer j, [Ml/year]
L	distance calculated in the simulation between either a farm and a biodiesel plant or between a biodiesel plant and a distributor center [km]
lc	Conversion factor to account for the different scale between the spatial dimensions used in the simulation and the real ones in Germany
MC_{b_j}	marginal cost of producing biodiesel in the refinery owned by the biofuel producer j, [euro/l]
MSE	mean squared error
n	number of predictions
P_b	wholesale biodiesel prices, [euro/l]
P_d	diesel price, [euro/l]
P_g	glycerol price, [euro/t]
P_{rm}	rape meal price, [euro/t]
P_{r}	rapeseed price, [euro/t]
$\mathrm{P}^{bid}_{r_j}$	rapeseed price bid in the market for the biofuel producer j, [euro/t]
$P^{bid}_{bp_k}$	biodiesel producer price bid into the market by the distributor k, [euro/l]
$P^{\exp}_{b_k}$	expected biodiesel price of the distributor k, [euro/l]
$\mathrm{P}^{\exp}_{bp_j}$	expected biodiesel producer price of the biofuel producer j, [euro/l]
$\mathrm{P}^{\exp}_{r_j}$	expected rapeseed price, [euro/t]
PM_j	profit margin for the biofuel producer j
PM_k	profit margin for the distributor k
pmd	perception of the biodiesel market development. This parameter is used to simulate the perceptions of investors in the German biodiesel market. This parameter is translated into the number of new plants to be built and it is a function of the biodiesel tax and quota
q_b	biodiesel quota, [Ml/year]
q_{b_j}	volume of biodiesel to be produced, [l]
q_r	mass of rapeseed to be processed, [ton]
rlc	rate land conversion factor. It defines the rate of expansion of the fraction of arable land to be used for rapeseed production allocated by the farmer
S^{+}	partial derivative of the currency C with respect to the parameter P
TC_{b_j}	total production cost of biodiesel, [euro/l]
tc	unit transportation cost of the good b or r, [euro/l, euro/t]
t_b	biodiesel tax, [euro/liter]
tc_p	transportation cost of the product b or r, [euro/(l km,), euro/(t km)]
Y_{b-g_j}	yield glycerol of the biofuel producer j, [kg glycerol/kg biodiesel]
Y_{o-b_j}	yield of biodiesel from oil rapeseed of the biofuel producer j, [kg biodiesel/kg oil rapeseed]
Y_{r-o_j}	yield of oil from rapeseed of the biofuel producer j, [kg oil rapeseed/kg rapeseed]
Y_{r-rm_j}	yield of rapeseed meal from rapeseed of the biofuel producer j, [kg rapeseed meal/kg rapeseed]
$\hat{Y}_i$	vector of n predictions
Y_i	vector of observed values

Greek symbols

ρ_b	biodiesel density, [kg/l]
λ	miles per gallon diesel equivalent.

Abbreviations

b	biodiesel
g	glycerol
$i \in I$	set of all farmers
$j \in J$	set of all biofuel producers
$k \in K$	set of all distributors
r	rapeseed
rm	rapeseed meal
ro	rapeseed oil

financial actors (public or private). In turn, the decision to invest depends on the institutional framework. A stable and supportive institutional framework might reduce actors' risk perceptions and thus increase investment.

The scientific literature has been mainly focused on the technology [3–5], logistic [6,7], and availability of feedstocks [8,9] or some combination of them [10,11]. In general, these studies leave aside the institutional framework and make normative assumptions on actors' behavior (*homo economicus*), or where the institutional framework is included, the focus is limited to formal institutions [12,13].

The influence of institutions on the economic performance of biofuel supply chains is not only limited to the use of policy instruments. Institutions such as governance structures have proven to be an important barrier in the deployment of biofuels supply chains [14–16]. The selection of governance structure is crucial to competing on transaction costs. Similarly, the selection of technology is also pivotal to competing on production costs [17]. Indeed, the economic performance of a biofuel supply chain is the result of the interaction among technology, policy and management.

The interaction among institutions, actors' behavior and technical elements make the supply chain in general, and the biofuel supply chain in particular a complex adaptive system.[1] This inherent complexity calls for a multi-disciplinary approach and comprehensive conceptual analysis framework. To the best knowledge of the authors, a conceptual framework that encompasses institutional, technical and social elements in the analysis of the emergence of biofuel supply chains is still missing.

[1] Complex adaptive systems (CAS) refer to those systems whose overall behavior is intractable even when their components are very simple. The system behavior emerges as a result of the interactions between and adaptation of the individual components [18]. Examples of such systems are: ecologies, immune systems, the brain, and economies.

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