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WP 6: Modelling Stakeholder Interplay and Policy Scenarios for Biorefinery and Biodiesel Production

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WP 6: MODELLING STAKEHOLDER INTERPLAY AND POLICY SCENARIOS FOR BIOREFINERY AND BIODIESEL PRODUCTION

D 6.5: A detailed description of the background literature on social network analysis of biodiesel and bio-refineries[1]

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1. Introduction

The management of technological progress is a long-standing question. Historically, there are two main policy concerns in this field: (1) to control the possible deleterious effects of new technologies and (2) to encourage technologies which bear wider social benefits (Bauer, 1995). In various periods and in various places such concerns have assumed several forms, such as social equity (Elliot and Elliot, 1976), gender equality (Wajcman, 1996), reduced unemployment (Freeman and Soete, 1987). Along with these traditional issues, the concept of 'sustainable development' has recently gained momentum among scholars and policy makers, affecting also the most recent debate on technological change. As a result, a wider vision of innovation has been promoted, where the aim has became to reshape entire technological

[1] The present WP is the result of a joint work of the authors. Nonetheless, paragraph 2 was written by Antonio Lopolito and Piergiuseppo Morone; paragraph 3 by Antonio Lopolito and paragraph 4 by Alessandro Grimaldi, Massimo Monteleone and Maurizio Prosperi. The authors' names appear in alphabetical order.

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configurations so that they are more responsive to environmental signals and ecological principles (Berkhout et al., 2003).

In order to better understand and make more effective this vision, technological transition theorists have developed a multi-level approach (MLA). Such approach is characterized by three levels of interaction (named respectively: micro, meso and macro) through which the management of technological change is undertaken. As noted by Berkhout et al. (2003: 6):

> "this multi-level model has already been influential in a number of ways. It has helped move forward notions of the wider institutional adjustments that are associated with major technical discontinuities. It has drawn continued attention to the importance of the interplay between the macro-level and meso- and micro-level changes in the unfolding of socio-technical change (systems innovation)".

This method of analysis has been applied to a wide range of cases and has helped to develop a set of fertile concepts and ideas. However, the spread of its use has only recently begun and there is still a need to improve and expand it. Improvements can be obtained by studying the determinants of the successful functioning of the networks of actors involved in technological transformation processes. More specifically, by employing the social network analysis (SNA) that is a key technique in organisational studies.

The aim of this work is to present a critical review of both MLA and SNA applied to socio-technical transition pathways; emphasizing all possible linkages among these two approaches. In our analysis we shall maintain that the former should be seen as the theoretical framework and the latter as the analytical tool, stressing the usefulness of the joint application of such approaches to the case of bio-fuel, an alternative to fossil fuel which has gained a lot of attention since the implementation of the 2003 European Directive (2003/30/EC) on bio-refineries.

The work is structured into four sections. In the following section the MLA of socio-technical transition pathways is presented; the role and the interactions among micro, meso and macro levels are explained, and gaps present in existing literature are highlighted. Moreover, the link with the SNA is outlined. The third section focuses on the SNA, several SN tools that can be applied to the case of bio-fuels are presented. The forth section is dedicated to the case of bio-fuels, pointing out that bio-fuel production can be seen as one of the three levels of MLA within a general framework of socio-technical transition. Finally, a summing up section concludes the work.

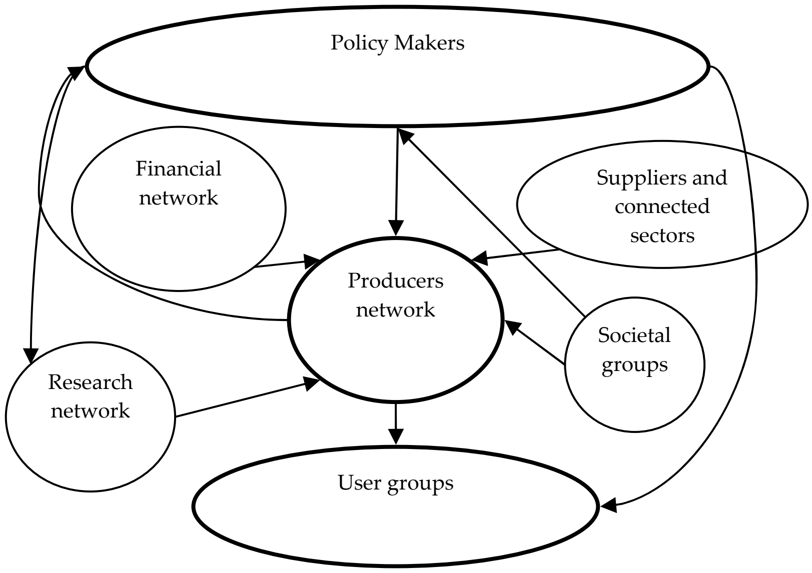
2. Socio-technical transition and the Multi-level approach

To explain the role of human activities in exerting socio-technical transition management and shaping technological configurations, some prominent scholars have developed a *multi-level approach* (MLA) – i.e. a model which can be seen as a nested framework formed by tree linked levels: socio-technical regime (henceforth ST-regime), socio-technical landscape and niche-innovations (see, among others, Berkhout et al., 2003). The ST-regime represents the meso-level unit of analysis. It can be defined as a relatively stable configuration of institutions, techniques and artefacts (such as hardware and infrastructures), as well as rules, practices and networks that determine the 'normal' development and use of technologies (Rip and Kemp, 1998). The ST-regime is identified by the socially-valued function it fulfils. Electricity and water supply, health care, education, food supply and building trades are all examples of socially valued functions which identify specific ST-regimes. This concept accounts for both technical and sociological elements of the community involved in these functions. In other words, technical trajectories are not only influenced by engineers and their practices, but also by users, policy makers, societal groups, suppliers, scientists, banks etc. (Fig. 1). Within such regime, the activities of these different groups are aligned to each other and coordinated (Geels, 2002).

The ST-regime concept sums-up the main features of this complex set of community and activities and represents it as "a configuration that works" (Geels and Schot, 2007). As noted by Rip and Kemp (1998), the term 'configuration' refers to the alignment of the heterogeneous elements involved in the technological trajectories and the expression 'that works' means that this set of elements fulfils a specific function.

The activities carried out by the ST-regime need to be situated in a wider context which influences its performance. Such context consists of a set of deep structural trends and variables which go beyond the direct influence of regime actors. Oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values or environmental problems are some examples of such exogenous variables.

Fig. 1 – The multi-actor network involved in ST-regime



Adapted from Geels (2002)

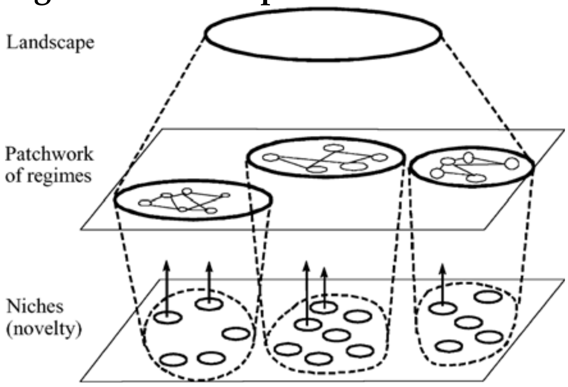
In the MLA these elements form the macro-level and represent a whole socio-technical landscape, which is the second level of the analysis. A landscape is an external structure or context for interactions of actors (Geels, 2002). Kemp and Rotmans (2001: 7) define landscape as a set of "…background variables such as the material infrastructure, political culture and coalitions, social values, worldviews and paradigms, the macro economy, demography and the natural environment which channel transition processes and change themselves slowly in an autonomous way". Geels (2002: 1260) notes that in this stream of literature the term 'landscape' is used "because of the literal connotation of relative 'hardness' and material context of society, e.g. the material and spatial arrangements of cities, factories, highways, […]".

Finally, the niche-innovations level represents the micro-level. Niches are "protected spaces for the development and use of promising technologies by means of experimentation, with the aim of 1) learning about the desirability of the new technology, and 2) enhancing the further development and the rate of application of the new technology" (Kemp et al, 1998: 186). We can see niches as 'incubation rooms' for novelties because they are protected or insulated from 'normal' market selection in the regime (Schot, 1998). Their operation relies on three main drivers: (1) the provision of locations for learning processes, (e.g. learning by doing, learning by using and learning by interacting) (Rosenberg, 1976; Von Hippel, 1988; Lundvall, 1988); (2) the provision of spaces to build social networks which support innovations, (e.g. supply chains, user–producer relationships) (Kemp et al., 1998; Geels 2002); (3) the fostering of convergence and alignment of expectations (Hoogma et al., 2002). Caniels and Romijn (2008: 615) point out that this niches' mechanism "refers to the importance of developing a common core view about where the participating actors are going with each other and with the technology. Actors' strategies, expectations, beliefs, practices, outlooks, perceptions and views must go in the same direction and become more specific and consistent". These internal niches processes have been analyzed and described within the so-called 'strategic niche management' literature (Kemp et al., 1998; Kemp et al., 2001; Hoogma, 2000).

The multi-level approach sees transitions as outcomes of the co-evolution of these three levels. Geels and Schot (2007: 405) sum-up the basic processes of this co-evolutionary dynamics as follows: "(a) niche-innovations build up internal momentum, through learning processes, price/performance improvements, and support from powerful groups, (b) changes at the landscape level create pressure on the regime and (c) destabilisation of the regime creates windows of opportunity for niche innovations". Indeed, transition is enabled from the alignment of these processes that facilitates the breakthrough of novelties in mainstream markets (Geels and Schot, 2007) and can be seen as changes from the incumbent regime to another (Fig.2).

In line with the MLA, the case of bio-fuel technologies can be seen as a specific element of the nested model. Such technologies are developed within the field of energy supply, while a major component of the energy supply field is represented by the fuel regime. Such regime, in turn, spans a variety of specific nested and subordinated configurations (niches), such as those based on renewable energy. In this perspective the community and the activities involved in the production of bio-fuel can be seen as one innovation-niche that competes with other renewable energy innovation niches within the fuel energy regime. Conversely, the fuel regime itself may be seen as nested within a global energy landscape, organised primarily around the extraction of, trade in, and combustion of fossil fuels.

Fig. 2 – The multiple level framework



(Geels, 2002)

One of the main contributions of MLA to understanding transition pathways is that it sheds light on the link between social interaction and technological transitions. As argued by Geels and Schot (2007), such link is reinforced by the fact that technological transitions are situated at the level of organisational fields defined by DiMaggio and Powell (1983: 148) as "those organizations that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services or products. The virtue of this unit of analysis is that it directs our attention not simply to competing firms […], or to networks of organizations that actually interact, […], but to the totality of relevant actors". Thus niches and ST-regimes can be seen as types of organisational structures which serve as a community within which groups of actors interact (Geels and Schot, 2007).

In this context, Geels maintains that (2002: 1257) "technology, of itself, has no power, does nothing. Only in association with human agency, social structures and organisations does technology fulfil functions". Such an agency is the way governance processes of technological transition take place and consists in the set of human actions seeking to guide the technical change in a socially and environmentally desirable direction (Smith et al., 2005). Agency emerges as a socially-defined concept and is intimately related with the web of power relationships among social actors. There are three elements related to the power relations that can shed light on the way governance of the regime transformation can be exerted (Smith et al., 2005): (1) the sharing of visions and expectations; (2) the resource interdependency; and (3) the group membership.

Regarding the first point, the power and its exertion by the human agency can be seen as a question of representation of problems and solutions. The different perspectives of actors involved in the regime transformation can generate conflicts which affect the way goals are defined and prioritised (Smith et al., 2005). As noted by Smith et al. (2005: 1503), "the challenge […] is to analyse how contrasting visions and expectations enrol actors into coalitions of support, come to define their interests, and shape the way that they seek to respond to selection pressures […]". Of course, different actors have different visions of the evolution of the regime and they would exert varying degrees of influence on the construction of this guiding vision (Smith et al., 2005). As a result, the vision of the core members of the community is likely to have a greater influence over the governance process than that of others. Furthermore, Caniels and Romijn (2008) stress the importance of the convergence of expectations and the development of a common core view for the success of innovation processes within technological niches. Following this line of reasoning, Geels and Schot (2007) propose the formation of strong expectation of future price/performance improvement as a proxy for the stabilisation of viable niche-innovations. These elements show how important it is, for the development of bio-fuels technologies, that farmers and transformation firms expectations converge on a common vision of future developments.

The second point - the resource interdependency - focuses on the source of power. For instance, one source of influence is the way important resources are distributed among actors (Smith, 2000). In this context, Smith et al. hold that "no single actor has sufficient resources on their own to coordinate responses to selection pressures". In other words, these resources are unevenly distributed among different actors. As a result, regime members are dependent upon each other for crucial resources in order to be able to respond to selection pressures. Smith et al. argue that "access to or denial of these resources can be one mechanism for exercise of power relations in regime transformation". Consequently, regime members can be seen as a network of relationships of resource interdependency necessary to control the regime. The predominant position within this network will most likely shape the transformation trajectories. This predominance can be seen as a dynamic attribute of each actor involved in regime transformation. Indeed, selection pressures can vary and their shift affects "the value of different resource configurations, and therefore the power of agents, also shifts" (Smith et al., 2005: 1504).

To understand such processes it is important to identify strategic resources and their owners. Smith et al. (2005: 1506) identify five groups of strategic resources: (1) control over financial revenues or capital stocks; (2) the ability to control material artefacts, such as hardware and infrastructures; (3) the ability to produce salient knowledge, (on this the authors argue that "expertise […] can be an important ingredient […] in the successful planning of particular system innovations [… and] in influencing the substance and direction of such transformation"); (4) legitimacy, credibility and authority (examples include competence in developing legislation and implementing regulations).

Concerning the third point - the group membership - Smith et al. (2005: 1504) argue that "power relations can only be understood in relation with other actors". This means that in order to understand regime transformations, it is important to consider the basis, the nature and the bounding of regime membership (Smith et al., 2005). While the tissue that forms regime membership can be heterogeneous, actors can be involved in more than one regime. Consequently, regime bounds are not clearly defined. Smith et al. (2005) suggest a way to delineate regime boundaries, analysing the involvement of different actors in the regime processes. The authors argue that "those actors who contribute intensively to reproducing the regime will be *core members* of the regime. Actors whose involvement is less intensive will be *peripheral* members of the regime. […] The crucial determining factor in the effective operation and development of the regime lies not simply in the agency of individual core members, but in the norms and procedures governing their structured relationships and interdependencies" (Smith et al. 2005: 1505, enfaces added).

Following this framework, in the case of fuel regime, extractive companies and refineries are key actors, as they manage important infrastructures and make crucial investment decisions. Car owners and other final users, on the other hand, have a crucial role in the creation of fuel demand; they are, though, substantially 'price takers' and not directly involved in shaping rules or in the operation of the fuel regime. This latter aspect concerns another important question, that is the influence of non-core members on the regimes or niches processes. Smith et al. (2005) maintain that such actors are endowed with a wholly different form of power represented by a high degree of inertia to implementing changes. To attain a more sustainable fuel regime, for instance, car owners and other final users must be persuaded to reduce the demand they place upon the existing fuel system. Even if core regime members were able to introduce more sustainable, decentralised forms of fuel supply (e.g. bio-diesel, bio-gas, vegetable oil or other bio-fuel derived from biomass), the success of this transformation would depend upon its accommodation and use by final users.

As emerged from the discussion above, in order to understand transitional pathways, three critical steps should be undertaken:

1. identifying the regime members;
2. characterising the power relations among them;
3. recognising their expectations and visions about the regime's future.

MLA has proven useful in the analysis of regime transformation and of governance of technological pathways. It has been applied to a wide range of cases such as electricity systems, agri-food systems, transport systems, and ship system (Verbong and Geels, 2007; Thompson et al., 2007; Whitmarsh, 2006; Geels, 2002), but the spread of its use is recent and there is still a need to improve and expand it. In this regard, Caniels and Romijn (2008) argue that, especially in the case of niche-innovations management, improvements can be obtained by studying the determinants of the successful functioning of the networks of actors involved in transformation processes. They hold that such an examination can be based on the application of the social network analysis (SNA) that is a key technique in organisational studies. In our view, SNA is highly compatible with the ML approach as it allows representing the units of analysis of the model, such as regimes and niches, as a network of actors involved in technological transformation and studying their interaction and the morphology of their relations. We shall argue that the application of SNA to the ML approach makes some important features of the model - that usually remain in the dark - more explicit. In fact, without a more in-depth examination of network mechanisms, the ML approach remains limited to a historical and descriptive analysis of cases (Caniels and Romijn, 2008).

To the best of our knowledge, there are no studies which apply jointly SNA and ML approach to the bio-fuel field. Morover, a second gap (more general in scope) in the existing literature relates to the fact that most of studies focus solely on the structural elements of the networks that represent niches or regimes, neglecting the normative and the cognitive dimensions of the relationships – both of which are crucial to the dynamics of networks and innovation. In this perspective, Geels and Schot (2007) argue that niches and regimes are kinds of *structures* governed by rules that are not only regulative, as regulations, standards and laws, but also normative and cognitive. This former kind of rules includes role relationships, values, behavioural norms. Examples of the latter kind of rules are belief systems, problem definitions, guiding principles. According to the importance of these elements in the networking interactions and managing of innovation trajectories, Smith et al. (2005) point out that the 'functionalist' perspective on transition pathways raises important points such as partnership (which concerns more the structural dimension of the network), consensus building (which refers to the cognitive dimension of the network), and trust (which is a normative rule).

These observations highlight the importance of studying socio-technical transition by means of a network analysis that takes into account not only the structural aspects of the network but also its cognitive and normative dimensions. The tools to do this are illustrated in the next section.

3. Social Network Analysis – a valuable tool for our study

According to Granovetter (1985) and Coleman (1990), all economic behaviour patterns are embedded in a local social context, where actors and their goals are strongly interdependent. The overall social structure within which actors are involved can affect considerably their performance. This social base of economic action has led economists to include social interaction in their analysis. Social network analysis (SNA) has proved to be especially useful in taking into account such social elements, as it focuses on the relationships among actors and on the patterns and implications of these relationships. Such approach allows having more in-depth insights into the structure and functioning of groups of actors involved in economic activities, by giving precise formal definition to political, economic or social elements in their environment (Wasserman and Faust, 1994).

3.1 Key concepts in SNA

SNA can fulfil several functions within the process of model development, specification and testing. Overall, it is useful in expressing relationally defined theoretical concepts by providing formal definitions, measures and descriptions. It is functional to evaluate models and theories in which key concepts and propositions are expressed as relational processes or structural outcomes (Wasserman and Faust, 1994). The network perspective has proven fruitful in a wide range of social and behavioural science disciplines. Some of the main topics where SNA was applied are (Wasserman and Faust, 1994): occupational mobility, community elite decision making, group problem solving, diffusion and adoption of innovations, corporate interlocking, belief systems, cognition or social perception, markets, exchange and power, consensus and social influence, coalition formation

Essentially , SNA describes actors in terms of the relations they are involved in, and views the social context as a set of nodes and ties. Nodes are the individual actors within the networks, while ties represent the relationships between them. In this way, SNA introduces a new perspective of analysis into Social Sciences, which is founded on three crucial points (Wasserman and Faust, 1994): (1) actors and their actions are not independent – they influence each other; (2) relational ties between actors are 'channels' to transfer resources (either material or non material); (3) the structure of the network facilitates or constrains the individual action;

Network analysts identify several key concepts that are crucial in SNA. We note that actors and social ties are the two basic concepts of SNA. By the term 'actors' we characterize all fundamental social entities, which can assume various forms – e.g. single individuals, firms, corporations or other collective social units. In addition, it is not necessarily that 'actors' have expressed preferences or the ability to 'act' (Wasserman and Faust, 2004).

Social ties are the means through which actors are linked to each other. There are many types of such links. Some examples are:

- evaluation of one person by another (e.g. expressing friendship, liking, or respect);
- transfer of material resources (e.g. business transitions, lending or borrowing things);
- association or affiliation (e.g. jointly attending an event, or belonging to the same social club);
- behavioural interaction (e.g. talking together, sending messages);
- movement between places (e.g. migration, social or physical mobility);
- physical connection (e.g. a road, a river, or a bridge connecting points);

- formal relations (e.g. for example hierarchical relations);
- biological relationship (e.g. kinship or descent).

Basically, a social tie links two actors. The tie is inherently a property of the pair and therefore is not thought of as pertaining simply to an individual actor. Indeed, many studies of network analysis are concerned with understanding ties among pairs. All of these studies take the dyad as unit of analysis. A dyad consists of a pair of actors and the possible tie(s) between them. Dyadic analyses focus on the properties of pair relationships, such as whether ties are reciprocated or not, or whether specific types of multiple relationships tend to occur together. Many important social network methods and models focus on triad; a subset of three actors and the (possible) tie(s) among them (Wasserman and Faust, 1994).

Any network can be divided in subgroups. A subgroup is a relevant concept in SNA – that is any subset of actors, and all ties among them. Network analysis is not simply concerned with collections of dyads, or triads, or subgroups. As noted by Wasserman and Faust, "to a large extent, the power of SNA lies in the ability to model the relationships among systems of actors" (1994: 19). Such systems represent groups of social actors. According to its most straightforward definition, a group is the collection of all actors where ties are to be measured (Wasserman and Faust, 1994). Actors belonging to a group are treated as a finite set of individuals for conceptual, theoretical, or empirical reasons. On the base of these concepts, Wasserman and Faust provide the following definition of social network: "a finite set or sets of actors and the relation or relations defined on them" (1994: 20).

Hence, collecting relational information is a crucial step in defining and studying a social network. Social network data requires measurements of ties among social actors (relational data). Such data consist of at least one structural variable. Following theoretical guidelines (specific to the type of network under investigation), researchers typically determine which variables should be measured and identify the most appropriate techniques for such measurement. Some kinds of relational data can be collected simply using archival records whereas other kinds of data need an observational technique or the use of questionnaires and interviews. Furthermore, the nature of the case determines whether the entire set of actors can be surveyed or whether only a sample of the actors must be considered.

3.2 Relational data

Relational data can be distinguished into two fundamental types: structural and compositional. Structural data measures various characteristics of ties between pairs of actors, representing the fundamental component of the network. On the other hand, generally speaking, compositional data is quantitative description of the parts of a certain whole, conveying exclusively relative information. In the framework of SNA it refers to actors' attributes and is typically used to complete the knowledge framework.

The first step to gather relational data is to define the network boundaries. This allows the researcher to identify the population under investigation. This can be a relatively easy task in the case of small, closed sets of actors (such as all researchers in an academic department or all employees at a service station), but can become very hard – or even impossible – in the case of big, open and not well characterized groups. There are two different approaches to boundaries specification in social network studies named, respectively, realistic and nominalistic (Laumann et al., 1989). The former treats boundaries and membership as perceived by the actors themselves (e.g. in the case of a metropolitan gang the membership is the collection of people the members acknowledge as belonging to the gang). The latter is based on the theoretical concerns of the researcher. Following the nominalistic approach, the list of actors composing a social network is constructed by the researcher and might not coincide with the one perceived (by the actors)[7] (Wasserman and Faust, 1994). When network boundary is unknown, special sampling techniques can be used as *snowball network*, *chain method* and e*go-centred network*.[8]

Any relation can be either directional or non-directional, as well as dichotomous or valued (Wasserman and Faust, 1994). In a directional relation, the relational tie between a pair of actors has an origin and a destination; that is, the tie is directed from one actor to the other. In a non-directional relation the tie does not have a direction. Dichotomous relations are coded as either present or absent, for each pair of actors. Valued relations, on the contrary, provide information on the strength, on the intensity, and/or on the frequency of the tie between each pair of actors.

3.3 Graphs and matrices

SNA typically uses graphs and matrices to represent information about patterns of ties among social actors.

A graph is composed of nodes that represent social actors, connected by edges that represent the ties connecting such actors. Hanneman (2001)

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[7] It can even be the case that actors composing a SN do not perceive themselves as constituting a distinctive social entity at all.

[8] For further information on these sampling techniques see Wasserman and Faust (1994). See also Frank (2005).

distinguishes between simplex and multiplex graphs. The former represents a single type of relations among actors, whereas the latter describes more than one kind of relation. Another important issue is whether a graph is directed or not. Hanneman (2001: 24) holds that:

> "Each tie or relation may be directed (i.e. originates with a source actor and reaches a target actor), or it may be a tie that represents co-occurrence, co-presence, or a bonded-tie between the pair of actors. Directed ties are represented with arrows, bonded-tie relations are represented with line segments. Directed ties may be reciprocated (A chooses B and B chooses A); such ties can be represented with a double-headed arrow. The strength of ties among actors in a graph may be binary (represents presence or absence of a tie); signed (represents a negative tie, a positive tie, or no tie); ordinal (represents whether the tie is the strongest, next strongest, etc.); or valued (measured on an interval or ratio level)".

Graphs offer a very useful way of presenting information about social networks. However, when there are many actors and/or many kinds of relations, they can become so visually complicated that it is very difficult to see patterns.

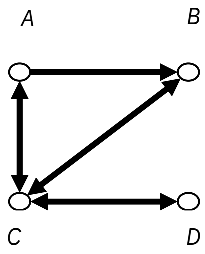
It is also possible to represent information about social networks in the form of matrices. Representing the information in this way allows the application of mathematical tools to summarize and find patterns. Social network analysts use matrices in a number of different ways. The most common form of matrix in social network analysis is composed of rows and columns as many as the actors in the data set, where the elements represent the ties between the actors. The simplest and most common matrix is binary (that is the cell assumes value one if a tie is present, and zero otherwise). This kind of matrix is called 'adjacency matrix' as it represents who is next or adjacent to whom in the 'social space' mapped by the relations measured (Hanneman, 2001).

Figure 3 shows a graph and the related adjacency matrix. In a directed graph, the sender of a tie is the row and the target of the tie is the column. Hanneman (2001: 28) defines also the 'asymmetric' adjacency matrix as one in which "the element i,j does not necessarily equal the element j,I". On the other hand, "if the ties that we were representing in the matrix were 'bonded-ties' or 'co-occurrence' or 'co-presence' (e.g. where ties represent a relation like: 'serves on the same board of directors as') the matrix would necessarily be symmetric; that is element i,j would be equal to element j,I". Furthermore, Hanneman (2001: 28) highlights substantial differences among various types of relational data:

> "Binary choice data are usually represented with zeros and ones, indicating the presence or absence of each logically possible relationship between pairs of actors. Signed graphs are represented in matrix form (usually) with -1, 0,

and +1 to indicate negative relations, no or neutral relations, and positive relations. When ties are measured at the ordinal or interval level, the numeric magnitude of the measured tie is entered as the element of the matrix".

Fig. 3 - a graph and the related adjacency matrix



	A	B	C	D
A	-	1	0	0
B	0	-	1	0
C	1	1	-	1
D	0	0	1	-

These tools are particularly useful in the study of ST transition. In this regard the entities discussed above, as innovation-niches and regimes, can be represented as networks whose nodes are the actors involved in the ST transition. The measurable relationships among these actors can be various and concern the information and knowledge flow, affinity relations seen as the level of convergence of their expectations and visions, the resource interdependency, the resulting power relations and so on.

3.4 SNA indices

In the SNA individuals and structure represent two fundamental levels of analysis: actors and network. Such entities affect each other: the network structure generates constraints and opportunities for actors embedded within it, whilst the interactions among actors as a whole produce the overall structure.

3.4.1 Size and density

Focusing first on the network as a whole it is possible to characterize two basic properties: *size* and *density*. The former concerns the number of actors in the network that is the *size* of the network. The size of a network is often very important. Hanneman (2001: 41) mentions the following example:

> "Imagine a group of 12 students in a seminar. It would not be difficult for each of the students to know each of the others fairly well, and build up exchange relationships (e.g. sharing reading notes). Now imagine a large lecture class of 300 students. It would be extremely difficult for any student to know all of the others, and it would be virtually impossible for there to be a single network for exchanging reading notes".

This example highlights that size is a critical component of the structure of social relations and affects the overall network performance. Usually, the size of a network is indexed simply by counting the number of nodes.

The networks density, on the other hand, relates to the number and proportion of the ties. As noted by Hnneman (2001: 41), "fully saturated networks (i.e. one where all logically possible ties are actually present) are empirically rare, particularly where there are more than a few actors in the population. It is useful to look at how close a network is to realizing this potential. That is, to examine the density of ties, which is defined as the proportion of all possible ties that are actually present in the network". Density is calculated as the ratio of the number of ties present, L, to the maximum possible. The maximum possible number of ties is determined by the number of actors. If there are *g* actors in a network, there are g(g-1)/2 possible unordered pairs of actors and thus g(g-1)/2 possible ties among them. Thus the network density is calculated as:

(1) $D = L/ g(g-1)/2$

The maximum value that this measure could assume is 1 and this is when the network is fully saturated, i.e. all possible ties actually exist. The minimum value for density is 0; that is there are no ties present.

3.4.2 Punctual centrality indices

Looking at the individual position, it emerges that actors have different roles and power. "The network perspective suggests that the power of individual actors is not an individual attribute, but arises from their relations with others" (Hanneman, 2001: 75). Power arises from occupying advantageous positions in networks of relations; hence, it can be measured looking at the *centrality* of an actor in the network. Freeman (1979), in a seminal paper, identifies three basic sources of power: high degree, high closeness, and high betweenness.[9] Indeed, all these sources are measures of the centrality of an actor.

The concept of degree is associated with the number of ties that the actor has. Actors who have a high number of ties may be in an advantaged position : as they have many ties, they may have alternative ways to satisfy needs, and hence are less dependent on other individuals. Moreover, having many ties

[9] For an extensive discussion on these concepts see Everett and Borgatti (2005). See also Degenne and Forsè (1994).

gives access to more of the resources of the network as a whole. Hanneman (2001: 65) identifies a basic measure of centrality:

> "a very simple, but often very effective measure of an actor's centrality and power potential is their degree. In undirected data, actors differ from one another only in how many connections they have. With directed data, however, it can be important to distinguish centrality based on in-degree from centrality based on out-degree. If an actor receives many ties, they are often said to be prominent, or to have high prestige. That is, many other actors seek to direct ties to them, and this may indicate their importance. Actors who have unusually high out-degree are actors who are able to exchange with many others, or make many others aware of their views. Actors who display high out-degree centrality are often said to be influential actors".

High degree of centrality can generate high degree of power as far as actors who have more ties have greater opportunities and this makes them less dependent on other actors (Hanneman, 2001).

Closeness centrality emphasizes the distance of an actor from all other actors in the network by focusing on the geodesic distance[10] . One could consider either directed or undirected geodesic distances among actors. Following Hanneman (2001: 65), "the sum of these geodesic distances for each actor is the "farness" of the actor from all others. We can convert this into a measure of nearness or closeness centrality by taking the reciprocal (that is one divided by the farness) and norming it relative to the most central actor". The underlying logic is that actors who are able to reach other actors at shorter path lengths, or who are more reachable by other actors at shorter path lengths have favoured positions. This structural advantage can be translated into power (Hanneman, 2001).

Betweenness centrality of an actor expresses the potential intermediary value of that actor to all network members. The higher this value is, the greater is its control over communication flow. The betweenness of a given actor to any two other actors is a measure of its capacity of standing on the paths or geodesics distance that connects them.

These three indices of centrality can be measured in absolute terms and in relative terms. Absolute measures of the centrality of an actor refer to the absolute position of that actor in the network. Such measures of centrality can be normalize with respect to the size of the overall network, hence obtaining a relative measures of centrality (Maggioni, 1994).

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[10] For both directed and undirected data, the geodesic distance is the number of relations in the shortest possible walk from one actor to another. The geodesic distance is widely used in network analysis.

3.4.3 Network centrality indices

The description above focuses on the centrality and power of individuals in terms of how close they are to the 'center' of the action in a network; these measures are therefore known as *punctual* measures of centrality. However, since power, calculated as centrality, is a consequence of patterns of relations, we can see it as a property of the overall network structure. Hanneman (2001: 62) argues that "the amount of power in social structures can vary. If a system is very loosely coupled (low density) not much power can be exerted; in high-density systems there is the potential for greater power. Thus, power and centrality are both a systemic (macro) and relational (micro) property". To measure centrality as a macro property network centrality indices are formulated. Basically, the way this occurs is through a normalization of punctual centrality indices with respect to the most central actors in the network (Maggioni, 1994).

Such indices can be especially relevant with respect to the MLA discussed in the previous section. The punctual centrality indices can be used to investigate the presence of powerful actors which are crucial in shaping the ST dynamics within the niche. Furthermore, network indices can shed light on the state of niches development (whether a niche is ready to break through widely) (Geels and Schot, 2007).

The analytic formulation of both punctual (in the form of relative and absolute formulation) and network indices are summarized in the following table.

Table 1 – Indices of centrality

	Punctual centrality indices		Network centrality indices
	Absolute measures	Relative measures	
Degree centrality	$C_d = \sum_i L_A$	$C_d^{'} = \frac{\sum_i L_A}{(n-1)}$	$C_d^{''} = \frac{\sum_i \lfloor C_d^{*} - C_{di} \rfloor}{(n-1)}$
Closeness centrality	$C_c = \sum_i d(i,A)^{-1}$	$C_p^{'} = \frac{(n-1)}{C_p}$	$C_c^{''} = \frac{\{\sum_i \lfloor C_c^{*} - C_{ci} \rfloor (2n-3)\}}{(n^2-3n+2)}$
Betweenness centrality	$C_b = \sum_i \sum_j p_{ij}(A)$	$C_b^{'} = \frac{2C_b}{(n^2-3n+2)}$	$C_b^{''} = \frac{\sum_d \lfloor C_b^{*} - C_{bi}^{'} \rfloor}{(n-1)}$

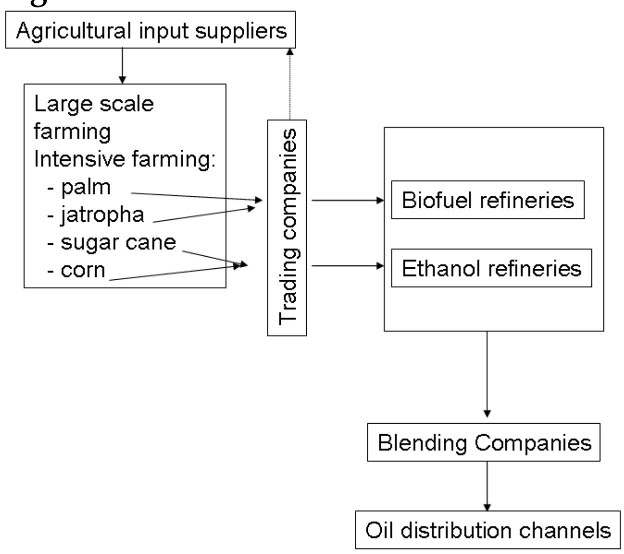
Adapted from Maggioni 1994. - L_A stands for the number of links of actor *A*, *n* is the number of actors in the network, C^*_d is the measure of degree centrality of the most central actor, *d(i, A)* is the geodesic distance between the generic actor *i* and *A* is the proportion of geodesic distances between actors *i* and *j* on which *A* lies.

4. The case of Bio-fuel

The current situation of the bio-fuel industry is characterised by a large scale production, based on massive investments in countries endowed with natural resources (e.g. Latin America for bio-ethanol). Investors from industrialised countries are promoting on large scale intensive farming systems with high productivity in terms of energy. At present, palm trees, jatropha and algae are the most promising crops for vegetable oil, while sugar cane and corn are the most exploited inputs for the production of bio-ethanol. Raw materials are shipped to industrialised countries, where they are processed by bio-refineries and converted into bio-fuel or ethanol.

The existence of relevant economies of scale and the massive investments in agricultural inputs explains the large scale of bio-refineries and blending companies. The final output is distributed through the available fuel channels. This system is depicted in Fig. 4.

Fig. 4 – Current situation of the bio-fuel industry



Besides the crop yield, an other important factor for the development of a bio-fuel economy is the exploitation of the by-products of the production processes, the main ones being: (1) the fibrous remains (e.g. the seed husks and stalk) in the grain-to-ethanol production and oil seed cake (a protein rich animal feed); and (2) glycerine in the bio-diesel case.[11] This brings into the picture the

[11] In particular, glycerine is a valuable chemical used for making many types of cosmetics, medicines and foods, and its co-production improves the production process of bio-diesel. However, markets for its use are limited and under high-volume production scenarios, it could end up being used largely as an additional process fuel in making bio-diesel, a relatively low-

concept of 'advanced bio-refinery': this is conceived as an integrated cluster of bio-industries, using a variety of different technologies to produce energy (fuels, power and heat), food and bio-products (chemicals and/or materials), making optimal uses of the side streams generated during farming/harvesting as well as during primary and secondary processing activities.

In this way, high-value products increase profitability, the high-volume fuel helps meeting energy needs, and the power production helps to lower energy costs and reduce greenhouse gas emissions from traditional power plant facilities. Thus, the bio-fuel arena consists of a large variety of key players that have their own perspective on the development of the bio-fuel market. These may include: producers, small farmers, fuel industry, vegetable oil purchases, manufactures, and etcetera

In such a production system a key role is played by financial groups (which are often the shareholders of trading companies and bio-refineries) and large corporations that perceive such investments as a way to reduce their risk by means of business diversification.

Following the social network approach discussed above, financial groups and multinational corporations are among the most *powerful* actors of such a system; other actors may only have a marginal role, being perceived as *peripheral members* of the network (e.g. farmer groups and policy makers of countries devoted to the agricultural phase). However, the system might generate environmental externalities (Elbersen et al., 2005), causing discontent and turmoil in local communities. Under such circumstances other actors might play a relevant role. For instance international environmental groups and movements for human rights may intervene to preserve natural resources and to defend local communities.

Along with this 'global model', an alternative industrial model, based on a smaller scale of production, is gaining momentum and might evolve into something similar to the niche of innovation described in section 2 above.

In this work, we shall refer to this second model as the 'local model', to emphasise the fact that, as oppose to the 'global model', all phases of the production process are located in the same geographical area, in order to reduce the economic and thermodynamic inefficiencies related to transportation costs or storage operations.

In the case of Europe, since the amount of land is limited, and the demand for land for different purposes is steadily increasing, the land that can be made available for producing energy-crops would be the one with the lowest opportunity costs, i.e. the area where alternative crops have the lowest expected

value application. Research is under development for other high-value product options for glycerine, like fine chemicals, polymers or propylene glycol.

gross margin (Patyk and Reinhardt, 2000: 22). In turn, such production might play a relevant role in sustaining the economy of some rural areas. It is the case of many backward regions of the EU, where agricultural industry is not competitive due to some constraints (e.g. climate, lack of human resources and mechanisation, remoteness from resources and commodity markets).

The hilly and mountainous area of the province of Foggia is a case in point, where a 'local model' of bio-fuel production has showed some potential and might, eventually, become an innovative niche.

In this area the emergence of a new industry could respond to the need of crop diversification, accordingly to the multifunctional role of the agricultural system. The concept of multifunctionality is a key feature of the so-called 'European Model of Agriculture' (CEC 1997, 1998, 2001). According to this model, the agricultural sector is not only producing food but is also sustaining rural landscapes, protecting biodiversity, generating employment and contributing to the viability of rural areas. These functions depend on the survival of large numbers of marginal agricultural units and their continued presence in rural land. Consequently, marginal farming deserves a permanent support in that, as the EU Agriculture Commissioner asserted, ''[T]he countryside is more than just a physical place on a map. It represents an economic and social model, a constituent part of our European social order. For that reason we cannot stand idly by and watch while the social and environmental balance of our rural areas is destroyed'' (Fischler, 1998: 1).

The EU has emphasised the relevance of multifunctionality for the European model of agriculture, by stressing the strong interdependency of the agricultural sector with all other sectors operating in rural areas, inspired by industrial ecology concepts (Allenby, 1966; Graedel and Allenby, 1995; Hawken et al. 1999). This model can be considered sufficiently well defined, representing what Coleman (1998) calls a reference system or a policy paradigm, embodying values, norms and assumptions.

As discussed above, the relevance of, and the ability to exploit by-products in the production of bio-fuel is a key factor in assessing the overall competitiveness of the system. Hence, it should not be disregarded when studying the 'local model' of bio-fuel production. Small scale producers could (and should) maximise the exploitation of biomass by means of cooperative agreements which would allow them to overcome possible limitations deriving from the scale of production. In this respect, the SNA provides a very powerful tool in assessing the potential for cooperation in the network.

The emergence of an innovating niche in backward rural areas provides an opportunity to be considered both within the EU agricultural policy framework and within an overall sustainable energy policy framework. The potential for a self sustainable niche and its evolution into a new regime should then be assessed.

With respect to our case study, new crops have recently been introduced into many farms and included in the crop rotation; this has several expected benefits.

1. Environmental issues: soil protection from erosion (e.g. hydrological control related to the cultivation of sloped fields); control of the full functionality of streams and rivers; absorption sinks for CO_2;
2. Landscape elements: enhancement of rural amenities (e.g. colourful patterns consequent to sunflower blossom);
3. Stewardship: farmers operate in vast areas and may monitor the presence of uncontrolled wildlife in anthropic environment (e.g. wild pig population growth; bear incursion into urban fringe areas)
4. Depopulation: lack of economic opportunities and the scarcity of diversification causes the outflow of the youngest population. In the long run, this phenomenon will lead to farming abandonment, with consequences in terms of land degradation and desertification. By introducing a new bio-fuel industry, new competencies are required to strengthen the social relations with urban centres, and to revitalise remote areas.

Fig. 5 – The 'local industry' model

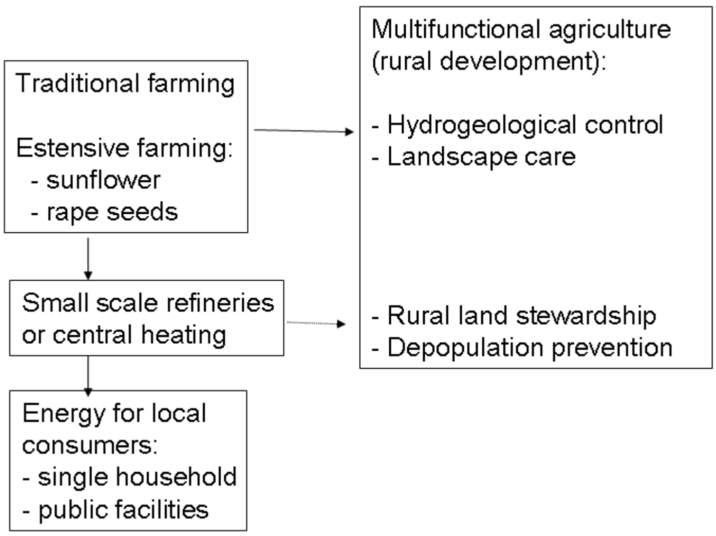


Figure 5 illustrates the 'local industry' model as it has been described so far. While such farming systems, in most cases, cannot compete in an open competitive market, they may still be economically sustainable in the case a closed system is conceived. More precisely, there are some chances that local bio-fuel crops are cultivated in order to satisfy the needs of small scale refineries or central heating systems, at the service of the local community. By drastically reducing transportation costs, the small scale local system may become energetically and economically sustainable. In order to achieve this objective, a large consensus among all main social groups is required.

In such a framework, a key role is played by local decision makers. However, their efforts have to be coordinated with those of the farmers associations, both of which are the *powerful* actors of such a social network. Other agents (*peripheral members*) should also cooperate in order to reduce any cause of inefficiency:

a. Professionals operating at local level, spreading information about the most suitable technology for specific needs;
b. Managers of public facilities (e.g. schools, hospitals, pools);
c. Households, accepting to convert their heating systems to the central system.

In this context, a theoretical model grounded on the multi-level approach discussed in section 2 could be developed. The model should focus on social networks consisting of actors operating in backward rural areas where crops for bio-fuel production are cultivated; it will be calibrated using qualitative and quantitative data gathered on the field and analysed through Social Network Analysis (as described in section 3). Overall, this analysis should allow us to understand how local small producers can coexist (and compete) with large fuel producers, and how (if at all) such production systems can gain momentum and turn, eventually, into a consolidated niche first and a new regime subsequently.

5. Summing up

- To explain the role of human activities in promoting socio-technical transition management and shaping technological configurations, some prominent scholars have developed a *multi-level approach* (MLA) – i.e. a model which can be seen as a nested framework formed by tree linked levels: socio-technical regime (ST-regime), socio-technical landscape and niche-innovations.
- In line with the ML approach, the case of bio-fuel technologies can be seen as a specific element of the nested model. These kinds of technologies are developed within the field of energy supply, while a major component of the energy supply field is represented by the fuel regime. Such regime, in turn, spans a variety of specific nested and subordinated configurations (niches), such as those based on renewable energy. In this perspective the community

and the activities involved in the production of bio-fuel can be seen as one innovation-niche that competes with other renewable energy innovation niches within the fuel energy regime.

- Niche-innovations can be seen as "protected spaces for the development and use of promising technologies" (Kemp et al., 1998: 186). Their operation relies on three main drivers: (1) the provision of locations for learning processes, (e.g. learning by doing, learning by using and learning by interacting) (Rosenberg, 1976; Von Hippel, 1988; Lundvall, 1988); (2) the provision of spaces to build social networks which support innovations, (e.g. supply chains, user–producer relationships) (Kemp et al., 1998; Geels 2002); (3) the fostering of convergence and alignment of expectations (Hoogma et al., 2002). These internal niches processes have been analysed and described within the so-called 'strategic niche management' literature (Kemp et al., 1998; Kemp et al., 2001; Hoogma, 2000).
- Especially in the case of niche-innovations management, new insights can be obtained by studying the determinants of the successful functioning of the networks of actors involved in transformation processes. Such a study can be based on the application of the social network analysis (SNA) that is a key technique in organisational studies.
- SNA is highly compatible with the ML approach as it allows representing the units of analysis of the model, such as regimes and niches, as a network of actors involved in technological transformation and studying their interaction and the morphology of their relations.
- SNA tools are particularly useful in the study of ST transition. In this regard, innovation-niches and regimes can be represented as networks whose nodes are the actors involved in the ST transition. The type of relationships among these actors can be various and concern the information and knowledge flows, affinity relations seen as the level of convergence of their expectations and visions, the resource interdependency, the resulting power relations and so on. All of these types of relations could be measured applying SNA tools.
- Network centrality indices and punctual centrality indices can be especially relevant with relation to the MLA. The punctual centrality indices can be used to investigate the presence of powerful actors which are crucial in shaping the ST dynamics within the niche. Furthermore, network indices can shed light on the state of niches development (whether a niche is ready to break through widely).

References

Allenby B., 1966. A design for environment methodology for evaluating materials. Total Quality Environmental Management 5(4):69–84.

Bauer, M., 1995. Resistance to New Technology. Cambridge University Press, Cambridge.

Berkhout, F., Smith, A., and Stirling, A., 2003. Socio-technological regimes and transition contexts. SPRU Electronic Working Paper n. 106, June. Brighton, University of Sussex.

Caniels, M.C.J., and Romijn, H.A., 2008. Actor networks in Strategic Niche Management: Insights from social network theory. Futures 40, 613-629.

Coleman, R., 1990. Foundation of social Theory. Cambridge, Cambridge University Press.

Coleman, W., 1998. From protected development to market liberalism: paradigm change in agriculture. Journal of European Public Policy 5, 632–651.

Commission of the European Communities (CEC), 1997. Rural Developments. Working Document from Directorate General for Agriculture, Brussels.

Commission of the European Communities (CEC), 1998. Agenda 2000: Commission Proposals. COM, Vol. 98. Final, Brussels, p. 158.

Commission of the European Communities (CEC), 2001. The Agricultural Situation in the Community 2000 Report. Office for Official Publications of the European Communities, Brussels.

Degenne, A., and Forsè, M., 1999. Introducine Social Networks. London, SAGE.

DiMaggio, P.J., and Powell, W.W., 1983. The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. American Sociological Review 48, 147–160.

Elbersen. B.; Andersen; E; Bakker. R.; Bunce R.; Carey, P.; Elbersen. W; Eupen M. van; Guldemond. A.; Kool A..; Meuleman B.; Noij G. & Roos Klein-Lankhorst, J. (2005). Largescale biomass production and agricultural land use – potential effects on farmland habitats and related biodiversity. Consultancy report to the EEA. (Contract EEA/EAS/03/004)

Elliot, D., and Elliot, R., 1976. The Control of Technology. Chapman and Hall, London.

Everett, M., and Borgatti, S.P., 2005. Extending Centrality. In Carrington, J., Scott, J., Wasserman, S., (Eds.). Models and Methods in Social Network Analysis. New York, Cambridge University Press.

Fischler, F., 1998. Text of a speech on Future of European Agricultural Policy given at the University of Wageningen, April 16 1998.

Frank, O., 2005. Network Sampling and Model Fitting. In Carrington, J., Scott, J., Wasserman, S., (eds.). Models and Methods in Social Network Analysis. New York, Cambridge University Press.

Freeman, L.C., 1979. Centrality in social networks: I. Conceptual clarification. Social Networks 1, 215-239.

Freeman, C., and Soete, L., 1987. Technical Change and Full Employment. Basil Blackwell, Oxford.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy 31, 1257–1274.

Geels, F.W., and Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy 36, 399–417.

Graedel T., Allenby, B., 1995. Industrial ecology. New Jersey: Prentice Hall.

Granovetter M., 1985. Economic action and social structure: the problem of embeddedness. American Journal of Sociology 91, 481–510.

Hanneman, R.H., 2001. Introduction to Social Network Methods. Department of Sociology University of California, Riverside.

Hawken P., Lovins A, and Lovins L., 1999. Natural capitalism: creating the next industrial revolution. London: Earthscan.

Hoogma, R., Kemp, R., Schot, J., and Truffer, B., 2002. Experimenting for Sustainable Transport: The Approach of Strategic Niche Management. Spon Press, London and New York.

Hoogma, R., 2000. Exploiting Technological Niches: Strategies for Experimental Introduction of Electric Vehicles. PhD thesis, Twente University Press, Enschede.

Kemp, R., Schot, J.W., and Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Technology Analysis and Strategic Management 10, 175–196.

Kemp, R. and Rotmans, J., 2001. The management of the co-evolution of technical, environmental and social systems. International Conference Towards Environmental Innovation Systems, Garmisch-Partenkirchen, September.

Kemp, R., Rip, A., and Schot, J.W., 2001. Constructing transition paths through the management of niches. In: Garud, R., Karnoe, P. (Eds.), Path Dependence and Creation. Lawrence Erlbaum, Mahwah, NJ, pp. 269–299.

Laumann, E.O., Marsden, P.V., and Prensky, D., 1989. The boundary specification problem in network analysis. In Freeman, L.C., White, D.R., and Romney, A.K. (eds.). Research Methods in Social Network Analysis, pages 61-87. Fairfax, V.A.: George Mason University Press.

Lundvall, B.A., 1988. Innovation as an interactive process: from user-producer interaction to the national system of innovation. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L. (Eds.), Technical Change and Economic Theory. Pinter, London, pp. 349–369.

Maggioni, M.A., 1994. Metodologie reticolari per l'analisi della dinamica industriale e delle politiche regionali. In Garofoli, G., e Mazzoni R. (a cura di). Sistemi produttivi locali: struttura e trasforamzione. Milano Franco Angeli.

Patyk, A., and Reinhardt, G. A., 2000. Bioenergy for Europe: which ones fit best? A comparative analysis for the community. Research funded in part by the European Commission in the framework of the FAIR V Programme. Project co-ordinators: A. Patyk, G. A. Reinhardt (IFEU,Institute for Energy and Environmental Research Heidelberg). Final report.

Rip, A., Kemp, R., 1998. Technological change. In: Rayner, S., Malone, E.L. (Eds), Human Choice and Climate Change, Vol. 2. Battelle Press, Columbus, OH, pp. 327–399.

Rosenberg, N., 1976. Perspectives on Technology. Cambridge University Press, Cambridge, England.

Schot, J.W., 1998. The usefulness of evolutionary models for explaining innovation: the case of The Netherlands in the nineteenth century. History of Technology 14, 173–200.

Smith, A., Stirling, A., and Berkhout, F., 2005. The governance of sustainable socio-technical transitions. Research Policy 34, 1491–1510.

Smith, A., 2000. Policy networks and advocacy coalitions: explaining policy change and stability in UK industrial pollution policy? Environment and Planning C 18, 95–114.

Thompson, J., Millstone, E., Scoones, I., Ely, A., Marshall, F., Shah, E. and Stagl, S., 2007. Agri-food System Dynamics: pathways to sustainability in an era of uncertainty, STEPS Working Paper 4, Brighton: STEPS Centre.

Verbong, G., and Geels, F., 2007. The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). Energy Policy 35 (2007) 1025–1037

Von Hippel, E., 1988. The Sources of Innovation. Oxford University Press, Oxford.

Wajcman, J. (1996). Feminism Confronts Technology. Polity Press, Cambridge.

Wasserman, S. and Faust, K., 1994. Social network analysis: Methods and application. New York, Cambridge University Press.

Whitmarsh, L., Bergman, N., Haxeltine, A., Nykvist, B., and Wietschel, M., 2006. Modelling and assessing transition pathways to hydrogen society. SERI, Matisse Working Papers 3, 9/2006.