Abstract
This paper contributes to Strategic Niche Management (SNM), an analytical technique designed to facilitate the introduction and diffusion of radically new sustainable technologies through societal experiments. According to SNM, intensive networking among social actors is a crucial process for the successful incubation of new technologies. However, the manner in which innovation success relates to different characteristics pertaining to the structure and functioning of these actor networks has remained rather unclear. In this paper we open up this 'black box' by bringing in Social Network Analysis (SNA), which allows for a more systematic analysis of this issue. We review theoretical SNA contributions that shed light on the link between actor network attributes and innovation outcomes. Then we elaborate a case study about the emerging biofuels sector in Tanzania. After analysing the case from a conventional SNM perspective, we apply SNA techniques to generate more in-depth insights into the composition and functioning of the actor network and how this affects the innovation performance and development prospects of the sector. Policy implications are also discussed.

Keywords:
Social Network Analysis; Strategic Niche Management; Learning; Innovation Networks; Biofuels
1. Introduction

Strategic Niche Management (SNM) is a recently developed analytical approach that is designed specifically to facilitate the introduction and diffusion of radically new sustainable technologies through societal experiments. Its ultimate aim is to contribute to a broad shift to more sustainable development, through an integral combination of technological progress and system-wide social-institutional transformation (Kemp et al. [1]; Elzen et al. [2]; Weber et al. [3]; Kemp et al. [4], Hoogma et al. [5]; Schot et al. [6]; Raven [7, 8]). Following the World Commission on Environment and Development, sustainable development is referred to as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. This implies the creation and maintenance of a good balance between economic, environmental and social/equity considerations (see Hoogma et al. [5], p. 6).

Initiating a broad societal movement in this direction is highly challenging. Potentially useful sustainable technologies often fail to get fully developed, or to catch on in the market, even though they promise superior performance compared to incumbent technologies. In order to address this problem, SNM advocates the creation of socio-technical experiments in which the various innovation stakeholders are encouraged to collaborate and exchange information, knowledge and experience. In this way, they embark on an interactive learning process that is expected to facilitate the incubation of the new technology.

The SNM framework has proven useful for the analysis of success and failure of experiments with a range of sustainable radical innovations, such as wind energy, biogas, public transport systems, electric vehicle transport, and eco-friendly food production. However, SNM has been developed only recently, and its writers have indicated the need for improvement and expansion.

In this paper we posit that, in particular, improvements can be expected from insights into the determinants of the successful functioning of the actor network that is involved in the creation of a new niche technology. While the SNM literature does emphasize the importance of networks of social actors for successful niche experimenting and ultimately the development of sustainable technologies, it has remained rather unclear how the incubation of new technologies relates to different characteristics of the structure and functioning of networks. The impression one gets from SNM studies is that the more intensive the networking activities and the larger the number of actors involved, the more experimentation and learning will occur, and the more likely it will be for a new promising technological idea to develop and gain ground in the market. However, there are other aspects that could be important, such as the nature and quality of the interactions and the morphology of the relationships in different parts of the network. These dimensions have not been systematically examined. We argue that it is possible to gain more in-depth insights into the determinants of a proper functioning of actor networks than what SNM studies have uncovered so far, and that these insights are needed for SNM to become more effective and applicable as a policy instrument. Without this, its usefulness will essentially remain limited to a research tool for historical (rather descriptive) analysis of cases, and as a management tool for isolated learning experiments.

In order to analyse different aspects of network functioning, we bring in social network theory. Social Network Analysis (SNA) has emerged as a key technique in modern sociology,
anthropology, geography, social psychology, information science and organisational studies. Social network theory views social relationships in terms of nodes and ties. Nodes are the individual actors within the networks, and ties are the relationships between the actors. The emphasis lies on the relationships and the ties between actors within the network, and the structure of the network and the quality of the relations are the main determinants of its usefulness to its participating individuals. By applying SNA to the networking function in SNM experiments, the network advantages that have remained implicit in the theoretical and empirical SNM publications to date are made more explicit.

In section 2, we briefly summarise the SNM approach. In section 3, we introduce basic principles of social network theory. In sections 4 and 5, we discuss a case about the emergence of a biofuels network in Tanzania. First we bring a conventional SNM perspective to bear on the case. Section 4 is devoted to the contextual factors (so called 'landscape' and 'regime' factors in SNM) that set the scene for the experiments at the level of the technological niche, applying the analytical framework furnished by SNM. In section 5 we discuss the actual niche processes, initially from a conventional SNM perspective, followed by a more detailed analysis of the network properties with social network techniques. In this way we demonstrate the value added of applying social network techniques to the question what makes social networks effective for innovation. In section 6 we draw conclusions.

2. Brief overview of Strategic Niche Management

Strategic Niche Management (SNM) is rooted in evolutionary innovation economics. It posits that successful radical innovations emanate from socio-technical experiments in which various stakeholders collaborate and exchange information, knowledge and experience. This induces a learning process that will facilitate the incubation of a new technology. Experiments occur in protected spaces called 'niches', specific application domains for the new technology. Experiments create 'proto-markets', in which connections with market parties are made even when the technology is still in a laboratory phase. When incubation goes well, an actual market niche will develop in due course, in which the innovation can sustain itself commercially (Hoogma et al. [5]).

Experiments take place in the context of a broader complex system, a 'socio-technological regime'. This comprises "… the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures" (Hoogma et al. [5], p. 19). In turn, the regime is embedded in a wider contextual 'landscape', which consists of societal factors that can change only slowly over time, such as demographics, political culture, lifestyles and the economic system (Raven, [8]).

Mature incumbent technologies form an integral part of the dominant regime and the overarching landscape as a result of a long process of incremental co-evolution of technological and societal factors in which they get attuned to one another. Innovations with radically new features do not rub well with extant socio-technical regime characteristics. Their successful development, market introduction and diffusion require simultaneous adaptations in all major parameters of the regime.

The purposive creation of socio-technical experiments that are in one way or another shielded from commercial market conditions can help overcome the innovation inertia that emanate from the existence of an incumbent dominant regime. Protection can take several forms, e.g. government tax exemptions, R&D commitments by firms, or prospective adopters' willingness to participate in trials on an unpaid basis. The point of protection is that it creates some kind of shelter in which various individuals and groups can become engaged as participants in the innovation process without being subject to immediate market pressures. In
this way they have opportunities to interact and learn about the innovation, and about their own preferences and attitudes in relation to the innovation.

For this experimentation and learning to be successful, it has to be an interactive process. Niche creation is widely seen to require a broad and diverse co-operating actor network (Kemp et al. [4]). Following Von Hippel [9], SNM authors advocate that users have an especially important role to play. They should be far more than mere sources of market information (Weber et al., [3]; Hoogma and Schot [10]). A third niche process comprises the convergence and alignment of expectations. This 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 (Hoogma [11]).

SNM authors have pointed to the close interdependence and intertwining of these three niche processes (Raven [8]). In this paper, we single out one of these processes, networking, for in-depth treatment because there is a reasonable amount of evidence that this particular function is also critical for experimentation and learning, and for the formation and convergence of expectations concerning new technologies among different parties. In other words, the development and implementation of innovations is largely a social process. For example, it has been argued that close interaction between actors is essential because important tacit, informal and uncodified elements in new knowledge can only be absorbed and shared by means of intensive - indeed direct - communication and learning by doing. Communication also helps to reduce uncertainty and complexity that are inherent in radical innovation processes. Furthermore, innovative activity is cumulative in nature. This means that new innovations build upon scientific knowledge generated by previous innovations (Dosi [12]; Von Hippel [13, 14]). Indeed, networking is seen to be so crucial for learning and innovation that a whole school of evolutionary innovation writers has been formed around the concept of the innovation system (Freeman [15], Nelson [16]; Lundvall [17]; Edquist [18]). We can conclude that successful experimentation and learning, as well as formation and convergence of expectations, is highly dependent on the successful functioning of innovation networks, and that all three processes must go well for radically new sustainable technologies to be incubated successfully.

3. Insights from Social Network Theory

According to Social Network Theory, all economic behaviour is embedded in a local social context (Granovetter [19]), and actors' social connections have a certain value for their performance, individually and jointly. There are a wide range of performance variables that have been studied in this literature, including such things as power, leadership, mobility, employment, entrepreneurship and team performance. In the context of this paper we limit ourselves to innovation-related performance factors, commensurate with the focus of the SNM literature.

We now address the question what insights can be derived from different SNA approaches for the effectiveness of SNM niche processes. Our primary focus is on the niche process of networking because this is the core phenomenon discussed in SNA. However, SNA also has things to say about the relationship between networking and the other two SNM niche processes of learning and convergence of expectations. Hence, we examine these three processes in mutual interaction, and how they jointly affect the successful incubation of new technologies. Figure 1 shows the relevant concepts and relationships. Our discussion draws heavily on the well-known survey of SNA approaches by Borgatti and Foster [20].
Concerning the link between networking and innovation performance (the arrow labelled ‘A’ in Figure 1), it is important to note that SNA has been used for different research goals. Borgatti and Foster [20] highlight two crucial approaches to network analysis: the connectionist and the structuralist view. According to the first approach, the network is seen as a set of connections through which resources, such as information and knowledge, can flow (Lin [21]; Snijders [22]). In this view, networks with a relatively dense contact network are expected to display better innovative performance than those with fewer contacts, since dense networks circulate information and knowledge more easily. The connections are like pipes through which information and knowledge flow between actors. In contrast, the structuralist approach focuses on the topology of the social relations (Coleman [23]; Burt [24]; Granovetter [25, 26]). According to so-called structural capital studies, the structure of a network of social relations influences its performance (Athanassiou and Nigh [27]). Granovetter argues that relatively loose, open networks with many connections to parties outside the network, tend to generate more new ideas than small, tight, closely knit networks with many redundant ties.

SNA has developed standard software (Borgatti et al. [28]) to analyse the flow- and structural characteristics of networks in a quantitative manner, using a number of indicators describing different network attributes such as density, the existence of sub-groups, degree of clustering, and distance between actors. In the next section we will use several of these indicators to analyse the network characteristics of our case study.

In addition to network connections and/or structures influencing innovation performance directly, SNA literature also elaborates indirect links between these. These indirect links run through the other two niche processes of SNM, namely learning processes and the formation and evolution of people’s expectations.

The link between networking and learning (arrow ‘B’ in Figure 1) is indicated in different streams of literature. Burt [24] states that inter-firm network structures affect learning. This is exemplified by Powell et al. [29], who suggest that collaboration among biotechnology firms cause inter-organisational learning cycles (p. 119). R&D collaborations provide firms with access to more diverse sources of information which is present at various places in the network. Other illustrations of a link between networking and learning processes in SNA comes from the 'communities of practice' literature, which posits that new practices and ideas emerge from interactions of people engaged in a common activity (Brown and Duguid [30]; Lave and Wenger [31]; Tyre and Von Hippel [32]). A third contribution in this line comes from Cross et al. [33], who argue that interaction with similar others will facilitate the
transmission of tacit knowledge (p. 229). Some social geographers and economists have referred to this phenomenon as relational or cognitive proximity, and they note its importance for successful innovation (Gertler [34]; Nooteboom [35]). Parties only add value to each other’s knowledge based when their knowledge is sufficiently different from one another, while at the same time needing some degree of affinity and absorptive capacity to be able to communicate effectively. Yet another stream of literature in this line emphasizes the spread of ideas, practices or objects through contagion arising from interpersonal contact. The importance of durable interpersonal relations such as friendship ties is highlighted (Davis [36]; Sanders and Hoekstra [37]; Harrison and Carroll [38]). Networks also influence innovation performance through the formation and convergence of expectations (arrow ‘C’ in Figure 1). For example, in the 'communities of practice' approach, homogeneity of beliefs, practices and attitudes emerge as outcomes (Borgatti and Foster [20]). A similar idea is present in literature focusing on group processes from a classical social psychology perspective. The basic idea is that individuals influence each other, in this way evolving homogeneous beliefs (Friedkin and Johnsen [39, 40]; Carley [41]). The earlier-mentioned contagion research line has evolved a similar idea, by trying to explain shared attitudes, culture and practice through interaction and sharing of information and knowledge.

4. Emerging biofuel production in Africa: Landscape and regime analysis with SNM

Currently there is a lot of interest in biofuel production driven by increasing awareness of the need to reduce CO₂ emissions and incentives to achieve this as formulated in the Kyoto Protocol. African countries in particular are seen to have a lot of potential for growing biofuels in view of abundant land resources and favourable climatic conditions. Several western companies are currently exploring the possibilities of starting biofuel production in different parts of Africa. A plant that has attracted particular interest for producing biodiesel is Jatropha curcas. At this stage, a lot of uncertainties still exist, for example about the ways of cultivating the crop, efficient oil pressing techniques, and the utilization of the oil in engines. Thus, it is clear that the development of a viable biofuel sector based on Jatropha will require considerable innovation efforts on the part of the actors concerned, along the entire supply chain.

We start with some basic facts about Jatropha and its cultivation. Then we examine the prospects and difficulties faced by local actors in this newly emerging sector in Tanzania. We first explore important contextual landscape and regime factors using SNM analysis. Then we delve into the three niche processes that impinge on innovation in the sector. We first analyse these with SNM, and then we bring in SNA and its analytical tool kit, and show how this helps to improve understanding of the functioning and characteristics of the local social network and the ways in which this affects innovation outcomes.

The research on which the case study is based involved substantial fieldwork in different parts of Tanzania during March-June 2005. Field data were gathered through interviews with all important actors involved in Jatropha-related activities. Existing literature was used as a secondary source of information.

We tried to identify all significant socio-technical experiments and network actors in relation to Jatropha in Tanzania by talking to key informants. In total, 17 experiments were found, of which 16 were visited and one contacted through e-mail. In addition, seven organisations (of which three were actively executing projects), two commercial companies, and two individuals were visited. The total number of interviews was 28. Each interview

1 The SNM analysis of the Jatropha case draws substantially on Van Eijck and Romijn [58].
covered information about the three key niche-formation processes: actor networking activities, people’s learning processes, and the dynamics of their expectations. Considering the complexity of the processes and the experimental nature of the research, we confined ourselves to gathering qualitative information about these processes.

4.1 Basic facts about Jatropha

The Jatropha plant is easy to establish and drought resistant. It can grow up to 8 metres high, and is not browsed by animals. Therefore it has been traditionally used in African countries as a hedge, and for producing soap and lamp oil on a small scale for local use. Recent experiments have also been initiated with the oil for use in cooking stoves. The plant can live up to 50 years and can produce seeds up to three times per annum (Chachage [42]; Openshaw [43]).

Figure 2 shows that a commercial Jatropha supply chain would need to comprise three main stages, from seed to end product, i.e. biodiesel. Under the cultivation stage come the activities pertaining to the growing of the Jatropha plant and the harvesting of the seeds. In Tanzania, the geographical focus of this case study, Jatropha is grown in nurseries from seeds by some women’s groups. But villagers also take use cuttings and plant them. Direct seeding on location is also practised. Cuttings take less time to establish, but the seed-grown Jatropha plants are stronger because they develop a tap-root. The seed yields reported for different countries and regions vary widely, ranging from 0.1 to 15 t/ha/y (Heller [44]; Jones and Miller [45]). Apparently the yield depends on a range of factors such as water, soil conditions, altitude, sunlight and temperature, but no systematic research seems to have been conducted yet to determine the influence of these factors and their interactions. People knowledgeable about the Tanzanian situation say that the crop can yield up to 10 t/ha/y in good locations. Seeds are harvested during the dry season, normally a quiet period for agricultural labour. They contain about 35% oil. The oil contains a toxic substance, curcasin, which is a strong purgative (Chachage [42]). Seed storage is important for continuous processing, since the availability of the Jatropha seeds is seasonal. Two options are bulk storage and bag-storage. Only bag-storage is currently practised in Tanzania. Storehouses should be well ventilated in order to prevent self-ignition. Location plays an important role, since it has a considerable impact on transport and storage costs (UNIDO [46]).

The production (or processing) stage involves pressing of seeds to expel the oil, leaving seedcake. In Tanzania, oil is currently extracted with small manual ram-presses and power-operated screw-presses. The extraction rate of the ram-press is quite low; the left-over seedcake still contains a lot of oil. About 5 kg of seed is needed for 1 litre of oil (Henning [47]). The capacity is about 1.5 litres per hour. The ram-press is only suitable for the processing of small quantities, e.g. for lamp oil for local village use, or for small-scale soap-making. The extraction rate of power-operated screw-presses is higher, and the cake residue is dryer. The Sayari oil expeller, of German design, has a capacity of about 20 l/hour (60 kg/hour) and can extract 1 litre of oil from 3 kg of seeds. It is manufactured in Tanzania itself by a non-governmental organisation (NGO) in Morogoro. A Chinese screw-press capable of processing 150 kg seed per hour was installed by another NGO in 2005.

At the distribution and usage stage, the oil and the seedcake are consumed or further processed to generate final products. The product of interest is biodiesel (or straight use of the vegetable oil in engines). Since the viscosity of Jatropha oil is much higher than that of conventional diesel fuel, using it pure in engines causes problems, despite claims that it is possible in many engine types (Heller [44]). Problems encountered include premature wear of parts and clogging, and inability to start, especially in cool weather. Search for adequate
solutions is ongoing. Options include adaptation of the oil through transesterification, i.e. mixing the oil with methanol and caustic soda (Research Group IP [48]); fitting vehicles with dual fuel tank systems; performing engine adaptations; and blending pure unmodified Jatropha with conventional mineral diesel, which reportedly works well up to a proportion of 40-50% per cent Jatropha (Pramanik [49]).

The seedcake is also potentially valuable. It can be used to produce biogas for cooking, as fertiliser, or - in briquette form - as cooking fuel (Openshaw [43]). Chachage [42] identifies the current activities in Tanzania based on Jatropha oil as soap-making on a limited scale, and use in oil lamps. Transesterification of Jatropha oil generates glycerine as a by-product, which can be used for soap production, skin creams and lubrication.

Figure 2: Jatropha-biodiesel supply chain
4.2 The impact of the landscape on the prospects of the Jatropha sector

A number of major aspects of the landscape influence the scope for viable investment in Jatropha-related activities. The global oil price has been a major factor. It has increased sharply during the last years and is expected to remain high or to rise even further in the near future. In 2003 the benchmark Brent crude was under US$ 25 per barrel, rising to over US$ 60 in 2005 and US$ 63 in 2006. Dependence on countries in the (unstable) Middle East is also increasingly considered to be a risk. This is strengthening demand for biofuels, and stimulates new investments in the sector. Although unconventional renewables accounted for only 2% of global primary energy in 2004, the biodiesel-sector grew by 25% per annum between 2000 and 2004 (Renewable Energy Policy Network [50]).

However, there are severe constraints to foreign investors in Tanzania, emanating from the country's poor infrastructure. This is a major factor to be reckoned with, especially by investors interested in exporting the oil to western markets. Most roads are hardly sufficient for lorry transport. Government support for investment in the sector is also lacking. Local cultivation of Jatropha and production of biofuels could significantly improve the country's balance of payments situation by substituting imported conventional fuels, but policies to promote and regulate the production and use of biofuels are still in their infancy. Tanzania is totally dependent on imports for its diesel fuel requirements, which constitutes a heavy burden on the country's balance of payments. Yet, the country’s current National Energy Policy (in 2005) merely affirms the desirability of promoting “development and utilisation of appropriate new and renewable sources of energy”, without specifically mentioning biofuels.

The first specific biofuel-related government initiative started only in 2006 with the formation of a National Biofuel Taskforce that brings together several ministries and major stakeholders such as NGOs and private investors. The taskforce has been charged with developing guidelines for the development and regulation of biofuel activities, which should be ready by the end of 2007. The adoption of official guidelines should hopefully deal with the lack of a clear and fair biofuel tax regime. Local actors pinpointed this problem as the main current bottleneck to their business. Standards of political governance also need to improve for directives and institutions to work effectively. Large Jatropha plantation farmers that were interviewed for this research reported major bureaucratic problems in their dealings with the government. One respondent in our fieldwork noted that it is crucial to work with someone who knows his way around at the government level.

4.3 Regime dynamics

There are three different regimes that influence the potential success of commercial Jatropha activities, namely the energy regime (which affects the end product), the agricultural regime (which affects the cultivation of the crop), and the vegetable oil regime (which affects oil processing conditions).

Instability in the fossil fuel-based energy regime is growing under the influence of the landscape factors discussed above. This is generating significant scope for demand growth for biofuels as well as for other renewable energy sources in the near to medium-term future, both in foreign and domestic markets. Biofuels like Jatropha seem to have certain advantages over solar and wind power. Initial investment requirements could be quite low, since many Jatropha activities can be started on a small scale. Another advantage is versatility. In

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principle, Jatropha oil can be used for all the main purposes for which energy is needed, i.e. for transport, electricity generation, direct lighting, and cooking.

However, the world's current transport regime is still entirely based on fossil fuels. A change-over to Jatropha biofuel would need to involve some adaptations, either to the oil, or to vehicle engines. One company in Tanzania is currently experimenting with its own vehicle which has been modified to run on both conventional diesel and Jatropha oil. However, it is clear by now that the additional cost to vehicle owners associated with conversion to a dual fuel tank system would engender considerable resistance, especially in low-income countries like Tanzania. Local technical knowledge required for these modifications is not widespread either. Even in high-income markets a transition is unlikely to be smooth and quick. For example, evidence from the UK indicates that the use of E85, a blend with 85% bioethanol, is limited to special biofuel-enabled cars like the Ford Focus flex-fuel or the Saab Biopower (Madslien [51]). When Jatropha oil is converted into biodiesel, vehicles require almost no modification (only the fuel hose needs to be resistant to biodiesel), but this requires chemical conversion, which is also not easy to manage locally. Experiences from India indicate that cost-effective transesterification requires a medium to large scale operation, capable of processing 30,000 tonnes per annum. This greatly exceeds current demand. Jatropha oil could also be blended with normal diesel fuel and sold at petrol stations. People would not even know they were driving on biodiesel. Hence, consumer resistance for this option could be expected to be low. Pump holders at petrol stations, however, might less co-operative. Most service stations are operated by the fossil oil industry which is "pathologically opposed to going down the biofuel route" (Madslien [51]). With the benefit of a few years of experience, companies in Tanzania now say that blending seems to be the best option for the near future, but even developing this option - and a corresponding supply chain organisation - will need considerable effort and persuasion. In the remainder of this article, our focus will therefore be confined to biodiesel blending.

Another major problem is that with the current price constellation, even the blending option is not yet financially attractive in areas where fossil diesel is widely and easily available. For example, the diesel pump price in Dar es Salaam was TZS 1,100 per litre in July 2005, compared with TZS 2,000 per litre of Jatropha oil. This price differential will take time to diminish. In the meantime, only a small minority of environmentally aware consumers might be willing and able to pay, say, 30 to 50% more for Jatropha-blended diesel than for conventional diesel. One company also explored western export markets, but also found these to be unviable at current prices. Hence, it started to explore up-country markets in the East African region, for example, Uganda, where fossil diesel prices are higher due to the large distance to sea harbours. However, that effort has not been very successful either, because of logistical transport issues. This clearly implies that Jatropha investors have to look for ways to achieve cost reduction in order to achieve competitiveness, both in local and in export markets. Early indications are that this has significant consequences for the way in which investors should organise their Jatropha supply chain. One company initially emphasised that it wanted to rely substantially on external outgrowers. However, in order to be viable, it has learnt that it must also have its own large-scale plantations and centralised processing plant. In 2006 it announced that it had leased 7000 hectares wasteland from the Kilimanjaro International Airport authority, which it has planted with Jatropha (van Kollenburg [52]). Another company that has recently started in neighbouring Kenya reported that large scale centralised cultivation makes it possible to introduce drip irrigation and mechanised harvesting, technologies which further improve cost-competitiveness. Irrigation allows a tight control over (seasonal) harvest times, which in turn enables mechanised harvesting (Strydom [53]). The Tanzanian company is now also looking into possibilities for mechanised harvesting (van Kollenburg [52]).
Moreover, it has become evident that the viability of starting a Jatropha-based biofuel business also depends on finding a lucrative use of the by-product, the seedcake, since this constitutes between 65 and 70% of the physical output from the oil processing. Considering its weight in relation to its potential value, most likely this should be found in the local market. In the dominant energy regime in Tanzania, fuelwood is the dominant cooking fuel of choice, since it can be collected free (even if it takes significant time and effort to do so). This is becoming ever harder to obtain due to significant overuse of forest resources. For the same reason, the price of charcoal, a much used cooking fuel in urban areas, has been rising drastically. One bag now costs between TZS 15,000 and 17,000, up from TZS 10,000 a few years previously (Kasumuni [54]). A local NGO has been providing several women's groups with a biogas cooking system that uses Jatropha seedcake. However, this experiment illustrates that the development of alternative cooking systems is not quick and easy. The women were unhappy with this system, complaining about longer cooking times, lack of gas pressure and possibly poisonous smoke. Another major factor is the extra cost of having to acquire a Jatropha biogas cooker, which costs TZS 10,000. In conclusion, the dominant cooking regime is quite strong, and alternative systems have not been able to meet people’s demands and priorities well enough. A potentially more promising use for the seedcake is as fertiliser, since it has a high nitrogen content, but this still remains to be explored. We revert to this issue in the analysis about the niche dynamics.

The Tanzanian agricultural regime is relevant in so far as it affects the financial attractiveness of Jatropha cultivation by independent farmers, which in turn affects the possibilities for, and constraints on, building relations with local farmers as sourcing agents. These farmers might become regular suppliers to foreign Jatropha investors who wish to supplement their own plantations with supply from independent outgrowers as a secondary production feedstock. Using external suppliers is also important for a company's corporate social responsibility image, because it can generate a significant number of local jobs (Strydom [53]). One firm says that it works with almost 100 farmers who earn a decent income from supplying Jatropha nuts to it (van Kollenburg [52]). For this sourcing strategy to work, the company had to become aware that farmers' decisions to enter into Jatropha outgrowing contracts are greatly influenced by the prices of other crops that they could also choose to cultivate. In this connection it proved to be important to collect information about prices of existing crops. We found that Jatropha cultivation is expected to yield two to nine times as much per hectare as conventional crops such as maize, wheat, sweet potato, cassava, cashew nuts, bananas and sisal, suggesting that cultivating Jatropha as a cash crop could be very profitable for farmers. There is, however, a major difference between cultivating Jatropha and other crops. Jatropha is a multi-year crop which starts yielding seeds only one to two years after planting. This can be a major problem for poor farmers in a country like Tanzania. Intercropping of Jatropha with other crops could help alleviate this problem, but introducing this successfully will require experimentation, on-site training and demonstration. Most farmers in poor developing countries are conservative and risk averse, and can also not be expected to have high literacy and ready access to relevant documentation. The company learnt that establishing successful sourcing relationships with such local partners must be actively nurtured, so that a relationship based on trust can develop.

Another major aspect of the agricultural regime pertains to the selling of seeds. Currently there is no well-established commercial market for Jatropha seeds because cultivating the plant as a cash crop is still too recent. An NGO started to buy seeds from villagers on a small scale in the Arusha and Engaruka regions (in Northern Tanzania) in 2000. Their system of local collection points and buying at weekly markets is comparable to the current system of private business persons buying small quantities of agricultural produce from small farmers. However, collecting the seeds in this way is becoming unwieldy as the supply of Jatropha
seeds increases, especially in view of the poor roads and inadequate transport facilities. This points once again towards the requirement of larger-scale centrally located plantations, at least in addition to independent outgrowers as a sound basis for a viable supply chain.

The vegetable oil regime proved not to be an overriding constraint on the development of a Jatropha supply chain. Tanzania already produces and processes substantial quantities of oil-seeds for edible purposes and for industrial use. Edible oil-seeds are generated from groundnuts, cashew and sunflower. An example of an industrial oil-seed is castor. Oil presses used for these crops are in principle also suitable for Jatropha pressing, and local capabilities for press manufacturing and maintenance exist. The only problem that needs to be confronted in this regime emanates from the fact that Jatropha is poisonous. Existing oil millers are thus unwilling to use the same equipment to press edible seeds and a poisonous seed. Separate new oil-expelling facilities need to be set up that are specifically dedicated to pressing Jatropha seeds.

In conclusion, many different regime characteristics and trends affect the way in which a Jatropha-based biofuel supply chain has to be set up. Our research indicates that a lot of these factors only began to manifest themselves after local actors actually began investing in Jatropha-related business activities. The sector is evolving through continuous learning-by-doing by the actors. More detailed insights into this can be obtained by looking at the activities going on at the niche level.

5. Biofuel niche dynamics: SNM analysis and SNA insights

We start the niche analysis with reference to Figure 2. The activities depicted in this figure are linked to each other in different ways. Some are so strongly complementary that one activity cannot be expected to get off the ground without a simultaneous development of another. This is so for cultivation and processing, and again for processing and any significant type of end-use. This may seem obvious, but from an SNM perspective it means that simultaneous initiation of experiments at each of the three stages in the chain would therefore seem to be vital for the emergence of a viable Jatropha-based production chain as a whole. Broadly speaking, then, an effective initial constellation of experiments that could pave the way for the establishment of viable biofuel supply chains based on Jatropha would need to exhibit networking, experimentation and learning within and across these different production stages. We therefore analyse the niche dynamics for each of the three production stages.

5.1 Jatropha niche analysis according to SNM

The actor network is expanding quite rapidly at the cultivation stage. More and more farmers are starting to plant Jatropha, expecting to make a considerable profit. This is happening mainly because they have been able to sell their seeds to a oil processing and distribution company, Diligent Tanzania Ltd., since 2005. Diligent pays a guaranteed fixed price for several years, reducing the risk of a price fall. Declining and low prices for existing crops acted as an additional push factor.

The actor network is quite diverse. There is participation by NGOs, private farmers, farmer groups, individual larger farmers, and private companies. Only research organisations had not been involved, but one was beginning to undertake research at the time of our fieldwork.

The oil pressing stage of the Jatropha chain shows a more mixed performance from an SNM point of view. With the involvement of a variety of actors, including NGOs, women’s groups (press users), equipment producers and subcontractors, and even a foreign university, a diverse and dynamic network has emerged. One drawback is that most of the contacts run through one particular NGO, Kakute, which has a reputation of being rather selective in the
information it wants to share. There are few lateral links in this part of the network. The emergence of Diligent is perceived to be a threat to the NGO's own Jatropha-activities (such as small-scale soap making). The two organisations compete for seed suppliers and do not collaborate smoothly.

The distribution stage of the network is least developed. There is no distribution system for biodiesel to speak of. All the oil that has been pressed so far has been used in vehicles owned by the processing companies themselves, and by a nearby NGO for the purpose of soap making. The different potential options for oil use still remain to be explored. The actor network is quite limited, and shows no signs of expansion. Just three actors – one commercial firm (Diligent again), the University of Dar es Salaam, and a development project – are pushing this application in Tanzania. Perhaps more actors will get moving when the University's planned engine tests yield positive results. As far as the utilization of the seed cake is concerned, network formation is hardly observable. As reported earlier, one NGO has tried to experiment with a biogas installation for cooking purposes, but the women users were dissatisfied with its performance, although they also noted that Jatropha biogas burns well and that the seedcake generates a lot of gas.

There are many learning processes in the cultivation part of the chain, mostly with regard to how Jatropha should be grown and managed (e.g. with respect to watering, intercropping, and pests) but also regarding user acceptance. There are also higher-order learning processes: some farmers have started to conduct systematic experiments for gathering specific bits of knowledge. These individuals are beginning to build learning routines (‘learning to learn’). Much knowledge is still lacking, but it is becoming clearer where the gaps are, and how to fill them. Still, there is a long way to go, since many of the lessons are not yet shared among the actors. The remaining barriers to the growing of Jatropha as a cash crop mainly have to do with lack of information by local villagers on specific aspects of the cultivation regime and their attitude towards risk. However, all these barriers seem to be surmountable through training and demonstrations.

The learning processes in oil pressing part of the chain have been limited to a few technical lessons about the operation of the presses and the quality of the seeds, and regarding user acceptance. There have been no broader learning processes in relation to infrastructure yet, about how best to set up a pressing facility or, for example, how best to store the seeds. Also, a lot more experimentation needs to be done to optimise pressing techniques. The oil content of the press cake is still too high, and there is too much debris in the pressed oil, so that extensive filtering is needed. As soon as oil production capacity will be ramped up beyond a couple of 100 litres per week, the slowness of the filtering process will begin to pose a bottleneck. Frequent clogging and need to replace filters is also problematic.

This brings us to the learning dynamics at the distribution and usage stage. There are no learning processes on the user side yet. The only technical learning processes so far have been some experiments carried out by Diligent in its home base in the Netherlands. World-wide, of course, many more experiments are being carried out on the properties of Jatropha oil; these seem to point in an encouraging direction, especially about the possibilities for converted oil and emissions (Rabé [55]). However, some technical uncertainties remain, for example about long-term effects on engines. Opposition against use of biofuels in the existing fuel distribution network is also a major issue to be tackled. At the moment, 5 % blends are deemed acceptable, but anything higher than that is still greeted with considerable scepticism. There is also still a problem over car companies' unwillingness to honour their warranties. This will only be solved when the performance of the biofuel is deemed acceptable by car manufacturers (Nevin [56]).

Much more experimentation and learning about technical properties of the seed cake will be needed for this technology to take off. Using seedcake as fertiliser could be more
promising because of its favourable nutritional qualities. This possibility was mentioned by several respondents in our field research, but it remains untested as yet. There are no local learning processes yet, although expectations are slightly positive. Potential actors in this domain – aside from Diligent – are farmers who want to use the cake as fertiliser. It would appear to be highly important for this niche to develop, because the formation of a commercially viable Jatropha supply chain as a whole stands to benefit from it (Venkataraman [57]).

The expectations of actors involved in cultivation are predominantly high and positive, and in some cases rising further, in response to yields that turned out to be higher than expected. However, the experience with the crop is still too brief for expectations to stabilise, or to allow very specific conclusions. The positive expectations are based on forecasts of a large market for biofuels. If this market turns out to be smaller, or less profitable than anticipated, farmer prices will drop.

The participants’ expectations in the pressing stage vary widely. It is not clear in which direction the Jatropha chain will evolve. Although Diligent is moving to centralised processing, some others still think that it might be best to install smaller expelling units in different locations, perhaps operated by farmer collectives, with the oil then being transported to a central collection point. This will also affect the choice of pressing technology, especially the capacity of presses. Related aspects, such as transport needs, are still to be addressed. With respect to the use of Jatropha oil in diesel engines, there are mainly just positive expectations, but hardly any actual lessons from experiments.

5.2 Jatropha network analysis according to SNA

When we bring an SNA type of analysis to bear on the Jatropha niche processes, we obtain a number of additional insights. Figure 3 depicts the network actors and their relationships in the sector as a whole. Three different types of relationships can be distinguished. The first, strongest type of link, depicted by a bold black line, is an ongoing relationship in which there is cooperation in terms of knowledge building. The second type, shown as a non-bold, regular line, represents incidental contact between the actors concerned. The third type of link is depicted by a thin line. This represents a mere financial (donor) relationship, whose value for knowledge transmission purposes can be presumed to be limited.

Figure 3: The Jatropha network, all ties
Initially we focus solely on the presence or absence of ties among the actors in the network, without taking note of the intensity of the links. Two sub-networks are clearly distinguishable in Figure 3. One revolves around the NGO Kakute, while a second, smaller sub-network centres around Diligent Tanzania Ltd. Kakute in particular has many direct links with other actors. It is thus immediately apparent that these two actors play key roles in the sector, while the others seem to function in a more subsidiary capacity. There seem to be very few lateral links. One quantitative indicator that is used in SNA to describe this aspect of networking is called 'density'. This indicator considers the ratio of the total number of actual ties to the total number of possible ties. Density is thus a measure of cohesiveness in networks. The underlying assumption is that if a network consists of actors that are well interconnected, this implies that knowledge flows rapidly among them. The indicator lies on a scale ranging from 0 (no ties at all) to 1 (all actors are connected to all others). The value of the density indicator in our Jatropha network is 0.0665 (st. dev. 0.2492), which should be considered very low. This suggests that the overall network processes are still very weak. This conclusion could not be drawn on the basis of the SNM niche analysis.

A somewhat more complex density indicator is the 'overall clustering coefficient', which is the average of clustering coefficients of all individual actors in the network. The individual cluster coefficients are calculated as the density of the neighbourhood, i.e. the number of actors directly linked to the respective actor. In the Jatropha network, the overall clustering coefficient 0.397. In other words, each actor in the network has a direct link with just 0.4 other actors on average. This is far below 1, a very low figure by any means.

Another SNA indicator called 'distance' gives insight into the efficiency of knowledge diffusion within the network. If all actors would be directly connected to one another, the average distance would be 1 and knowledge diffusion is expected to be fast. This is thus the minimum value for this indicator. The average distance in the Jatropha network is 2.726, which tells us that many actors do not have direct contact with each other. There is at least one intermediary, on whose functioning the others depend. This is illustrated well by Kakute's sub-network in Figure 3, whose many partners are only linked to each other through this organisation. Just two of Kakute's partners have a direct link to each other (TaTEDO and local women's groups), and a few others are indirectly linked through a third actor. On the whole, Kakute is the dominant actor in this part of the network. For the purpose of knowledge exchange and diffusion in the network as a whole, much thus depends on the functioning of this organisation. This insight lends more importance to the earlier SNM-based observation that Kakute is not very keen on sharing information. The SNA analysis brings out that this fact signals serious obstacles to knowledge flow in the network as a whole.

More detailed insight into the knowledge diffusion properties of the network can be obtained with an indicator called 'degree centrality'. This is the number of direct ties of an actor within the network. Within SNA it is posited that actors that have many direct relationships have also more opportunities to access diverse types of knowledge. In our network very few actors - mainly Kakute and Diligent - have a good range of direct ties. Kakute has the top score with 15 direct ties, and Diligent follows with seven. The next best is Sokoine University, the only actor with four direct ties. There are as many as twelve actors with just one direct tie, while another five actors have no ties at all. That means that the network is highly vulnerable to the good performance, networking skills and willingness to share information of just a couple of dominant actors. Kakute has 23% of all ties in the network, Diligent 11% and Sokoine 6%. Together, the top three possess 50% of all network ties. This insight is much more specific than the information derived from the SNM analysis.

Another network characteristic often used in SNA is represented by an indicator called 'lambda'. This classifies each of the ties in the network according to their importance for innovation in the network as a whole. A relation is considered important when a great
quantity of the flow among the actors in the network goes through it. Such relations are critical in the network because their disconnection would result in the interruption of the knowledge flow among all actors. Only two actors in the Jatropha network, Sokoine University and Kakute get the highest possible value (4) in this classification. These actors are crucial for the flow of information between the almost separate sub-networks of Diligent and Kakute. YES Africa and TaTEDO received a value of 3. If these nodes would also become dysfunctional, the network would more or less disintegrate. This reinforces the observations about the vulnerability of the network as a whole. It might rather easily degenerate into two small sub-networks. These observations could not be made on the basis of SNM analysis alone.

We now move on to take account of the intensity of the links depicted in Figure 3. It has to be said that most of the indicators used in SNA are not suited to this kind of sophisticated analysis. We have to make do with just a few statistics and Figures 3 and 4. First we calculate a 'valued density' indicator, which corresponds to the unvalued (binary) density indicator given above. Its value is 0.1613 (st. dev. 0.62390). This is a little higher than the binary indicator, which signals the existence of some high-intensity ties in the network. Although the cohesiveness of the network is low, some of the ties that do exist are of high value. There is also a valued version of the 'overall clustering coefficient'. Its value is 1.018, which is higher than the unvalued 0.397 statistic, thus pointing in the same direction as the above density statistic.

Figure 4: The Jatropha network, high-value ties only
The pictorial representation of the network in Figures 3 and 4 provides additional insights. As we can see clearly, truly substantial network ties exist only among a limited number of actors. If the secondary and tertiary ties were to be removed, the network as a whole disintegrates, leaving the actors with meaningful and ongoing interactions for knowledge building and exchange to function in four unconnected sub-groups. In one of these, we recognise Kakute as the central actor. In the second one, Diligent constitutes the main node. The third and fourth consist of quite small sub-groups of three actors each. The overall impression from the valued SNA analysis is one of a very weak network, that could easily degenerate and unravel.

6. Conclusions

The Strategic Niche Management approach is a powerful instrument for analysing the importance of networks of social actors for successful niche experimentation, which determines the successful development of sustainable technologies. However, the approach has shortcomings where it comes to analysing in detail how the incubation of new technologies relates to different characteristics of the structure and functioning of networks. In this paper we enriched SNM in this respect by bringing in insights from Social Network Analysis. We showed that this body of literature is broadly compatible with the SNM framework because it recognises the same three niche processes and points up their importance for the successful incubation of new technologies. Our case study of an emerging biofuels network in Tanzania illustrated the value added of using SNA techniques.

Summarising the application from a conventional SNM analysis to the case, we find that the three niche processes - networking, learning and convergence of expectations - seem to be quite positive for the cultivation part of the chain, reasonable in the oil pressing part, and essentially undeveloped in the oil distribution stage. In the cultivation part there are many actors who are paying attention to the emerging challenges, and actively conducting experiments. The network in the processing part contains a number of actors, but needs to develop more lateral relations for more effective learning to take place. Significant technological efforts still need to be invested in improving the reliability and efficiency of the equipment and its maintenance. For processing companies, the choice for centralised versus decentralised oil pressing remains a major unsolved issue. Expelling technologies designed for different scales of production need to be identified, tried out and possibly further adapted to improve their local suitability, and their economic viability under a range of different market scenarios needs to be explored. Considerable collaboration with seed suppliers will be needed in order to pull this off. At the downstream part of the Jatropha supply chain, there are only positive but vague expectations due to lack of learning, and only three network actors could be identified. The main challenge for parties is to set up a oil distribution network, invest in further learning about the properties of Jatropha biodiesel in compression ignition engines, and experiment with the seed cake. Network building will be essential to achieve this. As noted by researchers at the University of Dar es Salaam: "What we need is to mobilise stakeholders for embarking on this kind of project commercially" (Kasumuni [54]).

In comparison to SNM, our SNA analysis of the case gives a much better overview of the functioning of the Jatropha network as a whole, and how its properties affect its performance. This, in turn, has a major impact on the functioning of the parts of the network that are organised around a specific stage of production. The analysis demonstrated that the Jatropha network as a whole is very weak, and lacks cohesion. Although there are a considerable number of actors in the network, there seems to be an unhealthy domination by two major parties. In the SNM analysis the conclusion about network weakness only emerged in the
third (end-use) stage of the network, while the functioning of the network in the first and - to a lesser extent - the second production stages appeared to be quite positive. The outcomes on the basis of the SNA analysis, however, point to an underlying risk of network disintegration emanating from a basic weakness of the system as a whole. This exposes the vulnerability of all the network parts, including the cultivation part which currently exhibits a lot of dynamism in terms of networking, learning, and formation and stabilisation of expectations.

The SNA analysis also allows a good insight into the morphology of the network and its importance for innovation. It points up dominant actors which function as information and knowledge bridges between other unconnected actors, and which are therefore crucial for learning and knowledge diffusion in the network as a whole. In the case of the Jatropha network, it emerged that Sokoine University plays such a role, something that remained hidden in the SNM analysis. SNA also allows a clear insight into the existence of, and roles played by sub-groups within the overall network. These insights are not easily derived from a qualitative SNM analysis. Having this information allows one to concentrate on the innovation-related behaviour and performance of the specific actors that matter most for the functioning of the network as a whole, and on their relationships. SNA thus leads to a much more focused analysis of the three niche processes that form the core of the SNM framework.

In doing so, the application of SNA can also enhance the value of SNM analysis for policy making purposes. By pointing up the crucial actors and nodes in innovation networks, it can guide policy makers to design interventions that target specific actors and links that are crucial for the functioning of the learning network as a whole, thereby increasing its success in developing successful technological innovations. For example, in the Jatropha case, the analysis pointed towards the need to strengthen the relationships between different sub-networks across the different stages of the production chain. It also signalled problems with respect to lack of information dissemination by certain central authors, which could be addressed by establishing new organisations that would take up that role. Weak parts of the network can also be strengthened by network-building activities such as workshops and demonstrations, specifically targeting key actors such as – in our case – Sokoine University. The role of such actors in the network can be boosted by, for example, subsidising networking activities and research undertaken by this actor.

The case analysis further demonstrated the value of incorporating insights from the two different main types of SNA thought, namely structuralism and connectionism. Yet, the two perspectives have different uses. The usefulness of the connectionist perspectives lies primarily in the theoretical underpinning of the interconnections between networking, learning, and formation and convergence of expectations. In this sense, the connectionist stream of SNA furnishes a welcome enhancement of the SNM framework. At the same time, when it comes to an empirical application of the connectionist SNA approach, the possibilities are limited. There are few network indicators for a systematic analysis of a network of valued ties, and we had to resort to an interpretation of basic pictorial representations to be able to draw significant conclusions. In comparison, the structuralist SNA perspective allows a more elaborate empirical analysis of the structural network properties. However, this perspective yields little in the way of theoretically relevant insights with which one could increase one's understandings about the interactions between the three SNM niche processes.

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<th>Year</th>
<th>Paper ID</th>
<th>Title</th>
</tr>
</thead>
<tbody>
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<td>Year</td>
<td>Issue</td>
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<td>Ge 07-01</td>
<td>Caniels, Van Eijck en Romijn: Development of new supply chains: Insights from Strategic Niche Management</td>
</tr>
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