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Abstract

The extant supply chain literature devotes remarkably little attention to possible strategies and instruments of supply chain design associated with the development of radically new innovations. The main argument put forward in this paper is that an analytical framework derived from evolutionary innovation studies, Strategic Niche Management, is helpful for this purpose. The framework offers a set of concepts with which one can shed light on three key dynamic processes that have to form an integral part of the setting up of a new supply chain, namely networking, learning and the management of actor expectations. It also helps to understand how these processes are embedded into a wider societal context, which forms the setting within which supply chain design decisions have to be made. We illustrate these points with a case study about the setting up of a new supply chain in the biofuels sector in East Africa. Some implications for strategic managerial decision making are also addressed.

1. Introduction

Competitiveness and growth are increasingly seen to be driven by effective organisation and co-ordination of entire supply chains, rather than by strategies and processes of individual firms (e.g.: Vonderembse *et al.*, 2006; Bechtel and Jayaram, 1997; Tan, 2001; Cooper *et al.*, 1997; Martínez-Olvera and Shunk, 2006). Recent years have witnessed the emergence of a wealth of studies aiming to contribute to effective supply chain design, organisation and management. These include many contributions from logistics, operations research and engineering. Writers in this line emphasise supply chain design and management techniques such as supply chain mapping and simulation modelling, with which the functioning of the supplier system can be predicted, controlled, and optimised.

However, as noted by Choi *et al.* (2001), in today's dynamic and complex environment the practical value of these approaches is limited. They cite a manager of a leading automobile maker who complains that "… as soon as we came up with a strategy for management the chain, the chain changed on us -- we got new suppliers and new relationship configurations. It took a lot of effort to map one supply chain, and we could not possible map it every time something changed" (Choi *et al.*, 2001, p. 352). This quote illustrates that continuous change driven by, and involving the development of new products, processes and improved production organisation is part and parcel of today's competitive environment. It is also clear that, especially in its more radical forms, innovation is not merely a matter of developing new products or improved processes within the boundaries of one single firm, but involves reorganisation and adjustment of entire chains. In some cases, completely new chains may even need to come into existence. Yet, in the supply chain literature remarkably little attention has been devoted to possible strategies and instruments of supply chain design associated with the development of radically new innovations. It is particularly unclear what is involved in setting up new supply chains for radically new products. Extant approaches are too static and deterministic to be useful for tackling these issues effectively.[1]

This paper aims to shed light on new supply chain development by drawing on insights from Strategic Niche Management, an analytical approach rooted in evolutionary innovation economics which has been used for studying radical product innovations. SNM comes with a set of concepts with which one can systematically document the initial activities and processes that should lead to the eventual adoption and broad diffusion of new technologies in society, and with which can one take stock of important stimulating and constraining factors in that process (Hoogma *et al.*, 2002; Kemp *et al.*, 2001, 1998; Weber *et al.* 1999; Elzen *et al.*, 2004; Raven, 2004 and 2005).

SNM posits that successful radical innovations emanate from socio-technical experiments in which various stakeholders collaborate and exchange information, knowledge and experience, thus embarking on an interactive learning process that will facilitate the incubation of the new technology. This occurs in a protected space called a 'niche', a specific application domain 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 which the innovation can sustain itself commercially (Hoogma *et al.*, 2002, p. 30). These 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.*, 2002, 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, 2005, p. 31-32).

When viewed from a supply chain perspective, SNM experiments actually involve the establishment of a new chain of co-ordinated actors who together will bring a new product to market. Therefore, it is possible to derive insights from SNM studies about the supply chain development process and what this involves. In particular, SNM authors have emphasised that three key processes need to proceed well for experiments with new technologies to be successful: network formation; learning; and stabilisation and convergence of expectations. High-quality processes are characterised by the development of a wide and interconnected actor network, by extensive and experimentation and broad learning, and by expectations that become more specific and better aligned among the actors.

In the paper we conceptualise new supply chain development with reference to these three processes. We also illustrate what these processes involve, and how they contribute to successful supply chain establishment, with case study evidence from biofuel production in Africa. In this way we show that new supply chains do not result from purposeful attempts at optimal ('blueprint') design, but rather emerge and evolve in iterative fashion in the course of a complex interplay of various actors, whose activities are shaped by a dynamic and uncertain environment. At this stage, trial and error, search, learning and networking are the central activities of the concerned parties. Based on these insights, we derive tentative suggestions for suitable supply chain-development strategies for companies.

In Section 2 the SNM approach is elaborated, and its relevance for supply chain design is made clear. This is followed by an application of the SNM framework to our empirical case in Section 3. We illustrate how supply chains develop through the three niche processes that are central to the SNM approach, in the context of an incumbent regime. The biodiesel case is based on own fieldwork supplemented by secondary material. Section 4 summarises the emerging insights, and offers tentative guidelines for supply chain design.

2. Literature review

The SNM approach posits that radically new technologies may fail to get fully developed, or to catch on in the market, even though they promise superior performance compared to incumbent technologies. It employs a multi-level perspective to study this phenomenon of inertia. Technologies develop at the niche level, which is embedded in a broader complex regime. The regime itself is in turn part of a wider contextual landscape consisting of material and immaterial societal factors that can change only slowly over time. 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.

For this reason SNM advocates the purposive creation of socio-technical experiments that are in one way or another shielded from commercial market conditions. Protection is a broad concept. It can take the form of protective government policies such as regulations, tax exemptions and grants, but it can also take place as a result of private firms committing substantial R&D budgets to the development of particular innovations, or prospective adopters' willingness to participate in trials on an unpaid basis. Protection can give rise to a sheltered space (niche), in which various individuals and groups can become engaged as participants in the innovation process. 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. Experimentation and learning thus involves technological functioning and performance characteristics of the innovation, as well as social-cultural, economic, institutional and political aspects of the environment in which the innovation is to be introduced (Kemp *et al.*, 1998). Iterative interaction between these two main elements, the new artefact and the societal context, helps to deal with teething problems and gives people experience with the innovation, which is of great value in subsequent successful market implementation. It is meant to match the promises held out by the innovation and the stakeholders' expectations about it, with the needs in society that the innovation is meant to satisfy (Kemp *et al.*, 1998, p. 190). Kemp *et al.* say that "experiments are a way to stimulate articulation processes that are necessary for the new technology to become socially embedded" (p. 190).

In addition to experimentation and learning, SNM authors have pointed up the importance of two other niche processes that determine success of radical innovations, namely network formation and convergence, and alignment of actors' expectations. Together, these three processes are seen to interrelate closely, and be mutually reinforcing (Raven, 2005, p. 43). Niche creation is widely seen to require a broad and diverse co-operating actor network. According to Hoogma, it will be conducive to success when actors' motivations to participate are not centred on short-term financial gains (2000, p. 84). Furthermore, the composition of the network is important (Kemp *et al.*, 1998, p. 191). Following Von Hippel (1986), 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.*, 1999, p. 68; Hoogma and Schot, 2001). Sometimes, an already existing social network that evolved for some unrelated purpose can serve as a useful basis for designing a new experiment. However, this may not always work well, especially when it means that stakeholders that are important to the development of the new technology are left out (Raven, 2005, 40-1, citing Hoogma, 2000, p. 353).

The third niche process, convergence and alignment of expectations, 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, 2000, p.85-86).

From the perspective of the objective of this paper, the three niche processes can be visualised as being intimately intertwined with new supply chain formation. An important element of the learning and experimentation process consists of bringing together unconnected parties in a new supply network. Each of these parties is learning about its own new contribution to the chain as a whole, and how to attune its activities to those performed by others in the network. Inevitably this constitutes an iterative trial and error process, in which new knowledge and accumulating experiences are exchanged up and down the chain, inducing gradual alignment of expectations and views. One can conceptualise this as a supply chain incubation process, in which actors build connections and together orchestrate the emergence of a co-ordinated production and knowledge network. If it goes well, the innovation around which the network was formed will be improved and perfected to the point where a viable market niche develops. By then, the innovation can sustain itself commercially in a specific market segment and the key processes and actors in the supply chain are more or less defined. At this point in the process, conventional supply chain design methods and techniques (such as those mentioned in the Introduction to this paper) become useful for further optimisation. SNM provides an analytical structure for viewing and handling the chaotic processes that precede this stabilisation phase, for which conventional supply chain building techniques are of little value.

3. Initiating biofuel production: an illustration of supply chain development

Currently there is a lot of interest in biofuel production driven by increasing awareness of the need to reduce CO_2 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.*
This section starts with some basic facts that are already known about Jatropha and its cultivation. Then, using the Strategic Niche Management framework, we examine the prospects and difficulties faced by a Dutch company, Diligent, that has recently started to develop a new supply chain utilising this crop in Tanzania. We first explore important landscape and regime factors that form the context for the company's operations and its prospects, and then delve into the three niche processes that directly impinge on the building of its supply chain.

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, 2003; Openshaw, 2000).

Figure 1 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, 1996; Jones and Miller, 1993). Apparently the yield depends on a range of factors such as water, soil conditions, altitude, sunlight and temperature. 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 expect that the crop can yields up to 10 t/ha/y in good locations (van Eijck and Romijn, 2006). 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, 2003). 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 practiced in Tanzania currently. 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, 1983).

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 (van Eijck and Romijn, 2006). The extraction rate of the ram-press is quite low; the left-over seedcake still contains some oil. About 5 kg of seed is needed for 1 litre of oil (Henning, 2004). 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 (van Eijck and Romijn, 2006).

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, 1996). 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. by mixing with methanol and caustic soda (Research Group IP, 2002); 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, 2002).

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, 2000). Chachage (2003) 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.

Since 2005, Diligent Tanzania Ltd, a subsidiary of the Dutch company Diligent Energy Systems, has begun to establish a supply chain for Jatropha-based biofuels in Tanzania (URL: http://www.diligent.nl/index.php?id=29). Below, we detail the lessons learned at the landscape, regime and niche level since the company's establishment, and we explore how this has affected the design of its supply chain.

The impact of the landscape on investment prospects for Jatropha

A number of major aspects of the landscape influence the scope for viable investment in a commercial Jatropha-based biofuel supply chain by energy companies like Diligent. World-wide issues as well as major Tanzania-specific factors play a role. Among the world-wide trends, the 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.[2] 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, 2005).

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. The import of over 465 million litres of diesel in 2002 had a value of over US$ 423 million. This was 4.7% of Tanzania's GDP for that year, a heavy burden on the 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 NGO's and private investors. Diligent is also one of the participants. 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. The Diligent staff, as well as other Jatropha-investors in Tanzania, 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, including Diligent, 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.

Regime dynamics and lessons for supply chain organisation

From the perspective of SNM, the focus of this section should be on the prevailing energy regime because this affects the possibilities for using Jatropha as an energy source. However, experience with the initial attempts to set up a supply chain indicates that there are two additional regimes whose features also influence the potential success of commercial Jatropha activities and the best way of organising the supply chain. In particular, it has become apparent that Jatropha cultivation, the first step in the supply chain, is influenced by the agricultural regime; while oil production, the second stage in the supply chain, is affected by the vegetable oil regime.

We first discuss the experiences with the energy regime, and then go on to highlight key characteristics of the other two regimes insofar as they proved to be relevant to the setting up of the supply chain by Diligent.

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 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. Diligent 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 specially biofuel enabled cars like the Ford Focus flex-fuel or the Saab Biopower (Madslien, 2006). 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. Moreover, the process generates 250 kg of glycerine for every 1,000 transesterified oil. Even in a country as large as India, this is already leading to huge surplusses that cannot be sold locally. Meanwhile, capacity creation for biodiesel in the Western world already poses a glycerine disposal problem (Venkataraman, 2005). 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, 2006). With the benefit of a few years of experience, Diligent now says that blending seems to be the best option for the near future, but even developing this option - and corresponding supply chain organisation - will need considerable effort and persuasion. In the remainder of the 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, in Tanzania itself, the diesel pump price in Dar es Salaam in July 2005 was TZS 1,100 per litre, compared with TZS 2,000 per for litre of Jatropha oil. This will take time to change. 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. Diligent also explored western export markets, but also found these to be unviable at current prices. Hence, Diligent 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 harbours. However, that effort has not been very successful either, because of logistical transport issues. This clearly implies that Jatropha investors such as Diligent 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. Initially, Diligent 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 Diligent announced that it had leased 7000 hectares wasteland from the Kilimanjaro International Airport authority, which it has planted with Jatropha (van Kollenburg, 2006). Another company that has recently started in neighbouring Kenya reported that large scale centralised cultivation also makes it possible to introduce drip irrigation and mechanised harvesting, which further improve cost-competitiveness. The former allows a tight control over (seasonal) harvest times, which in turn enables mechanised harvesting (Strydom, 2006). Diligent is now also looking into possibilities for mechanised harvesting (van Kollenburg, 2006).

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, 2006). 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 such as Diligent, who wish to supplement their own plantations with supply from independent outgrowers as a secondary production feedstock. Using external suppliers is important for a company's corporate social responsibility image, because it can generate a significant number of local jobs (Strydom, 2006). Diligent says that it works with almost 100 farmers who earn a decent income from supplying Jatropha nuts to it (van Kollenburg, 2006). For this sourcing strategy to work, Diligent 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. It turned out 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 (van Eijck and Romijn, 2006), suggesting that cultivating Jatropha as a cash crop could be very profitable for farmers. The main difference between cultivating Jatropha and other crops is that 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. Diligent learnt that establishing successful sourcing relationships with such local partners must be actively nurtured.

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 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. When Diligent started operations, it adopted the same practice. 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. In fact, 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. It turned out to be necessary for Diligent to develop its own new oil-expelling facilities 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. The case of Diligent indicates that a lot of these factors only manifested themselves after the company actually began operations, and started to try out ways of organising its activities and explore market prospects. It is still in the process of gravitating towards a viable and efficient supply chain design, by flexibly adapting its strategies and operations in response to accumulating experience. At some point, efforts were undertaken to calculate optimal logistics for sourcing, processing and oil export to the Netherlands, using conventional supply chain management techniques, but this turned out to be rather in vain in the face of manifold uncertainties and unknowns in the company's business environment. The company's supply chain organisation is evolving through continuous learning-by-doing. More detailed insights into these processes can be obtained by looking at the activities going on at the niche level.

Niche dynamics and its effects on Jatropha supply chain development

In this subsection we explore the recent Jatropha-activities at the niche level. We also assess what would be required in terms of niche experimentation for a viable supply chain to develop, and we pinpoint deficiencies and weaknesses that still need to be addressed by the company in collaboration with other supply chain actors.

We start the analysis with reference to Figure 1. 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 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 the following features:

- Strong experimentation in each of the three stages in the production chain, and growing interconnections between the activities and actors in these stages;
- Engine-related experiments that play at least some part in the end-use stage; it is simply impossible to conceive how a Jatropha-based energy regime can come about without the transport sector and the fuel distribution network being weaned of their fossil fuel dependency and attachment.
- Substantial experiments with the seedcake, because the viability of the chain is determined in a major way on finding profitable uses for this by-product.

These considerations broadly guide the discussion of the different Jatropha-related experiments discussed below.

We tried to identify all significant socio-technical experiments with Jatropha ongoing in Tanzania in 2005, 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 companies (including Diligent), and two individuals were visited. The total number of interviews was 28. Each interview covered information about the three key niche-formation processes: actor network activities, people's learning processes, and the dynamics of their expectations.

In the **cultivation stage**, the actor network is expanding quite rapidly. More and more farmers are starting to plant Jatropha, expecting to make a considerable profit. This is happening mainly because they are now able to sell their seeds to Diligent which started operations in 2005. The company 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.

There are many learning processes in this 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 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 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. In sum, the niche processes all seem to be quite positive for the cultivation part of the chain. Diligent, along with other actors, are paying attention to the emerging challenges.

We may conclude that this part of Diligent's supply chain is developing well. Its network of outgrowers is increasing rapidly and a viable way of organising this part of the chain is beginning to crystallise, thanks to considerable trial and error and experimentation among all the major stakeholders.

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, which is also known to be rather selective in the information it wants to share. There are few lateral links in 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 learning processes in this part of the chain have been limited to a few technical lessons on 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 begins to pose a bottleneck. Frequent clogging and need to replace filters is also problematic.

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.

In conclusion, overall, the SNM processes in the pressing stage have not proceeded as well as in the cultivation stage. In particular, the network 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. From the point of view of supply chain design, the choice for centralised versus decentralised oil pressing remains a major unsolved issue that Diligent needs to sort out. 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. Diliget will need to collaborate with its suppliers in order to pull this off.

This brings us to the dynamics at the **distribution and usage stage**. We have already seen that Diligent does not yet have a distribution system for its biodiesel to speak of. All the oil that has been pressed so far has been used in its own vehicles, and by a nearby NGO for the purpose of soap making. With respect to the use of Jatropha oil in diesel engines, there are mainly just positive expectations, but hardly any actual lessons from experiments. 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 – Diligent itself, 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. 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, 2006). 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, 2005).

As far as the utilization of the seed cake is concerned, niche formation processes are hardly present. 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. On the positive side, they noted that Jatropha biogas burns well and that the seedcake generates a lot of gas. Much more experimentation and learning about technical properties 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, 2005).

In conclusion, the downstream part of the supply chain is essentially still undeveloped. At this stage, there are only positive but vague expectations due to lack of learning. The next main challenge for Diligent 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 also 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, 2006).

4. Conclusions

The main argument put forward in this paper has been that the use of an unconventional analytical framework derived from innovation studies can be helpful for gaining insight into the development of complex new global supply chains. The chosen framework, Strategic Niche Management, offers a set of ordered concepts with which one can shed light on three key processes that have to form an integral part of the setting up of a new supply chain, namely networking, learning and the management of actor expectations. It also points up how these processes are embedded into a wider societal context, which forms the setting within which supply chain design decisions have to be made. By directing the focus on the context within which companies and supply chains operate, vital information concerning external threats and opportunities is systematically taken into account in supply chain decision making.

Our case study about the setting up of a new supply chain in the biofuels sector in East Africa illustrates that new supply chain formation is highly dynamic, and subject to high uncertainties. A framework like SNM, which is rooted in evolutionary theory, is particularly well suited for application to this kind of organic process.

In addition to SNM being of value as an analytical instrument, meant to gain insight into the dynamics of supply chain formation, the framework is also useful as a strategic managerial tool. By focusing attention on the three key supply chain formation processes and giving guidance about what constitutes effective niche processes, shortcomings in these processes come to the fore so that they can be dealt with. Strategic management of information flows and relationship management stand out as key areas for remedial action. For example, SNM would recommend such things as experimentation incentives for employees and partner companies when learning processes are inadequate. Activities such as organisation of stakeholder workshops, demonstrations, consultation, and efforts to disseminate information would be appropriate in order to stimulate deficient networking processes. Attention to active and frequent communication with different actors in the supply chain to align people's views, perceptions and priorities is necessary in situations when expectations are unstable and diverging.

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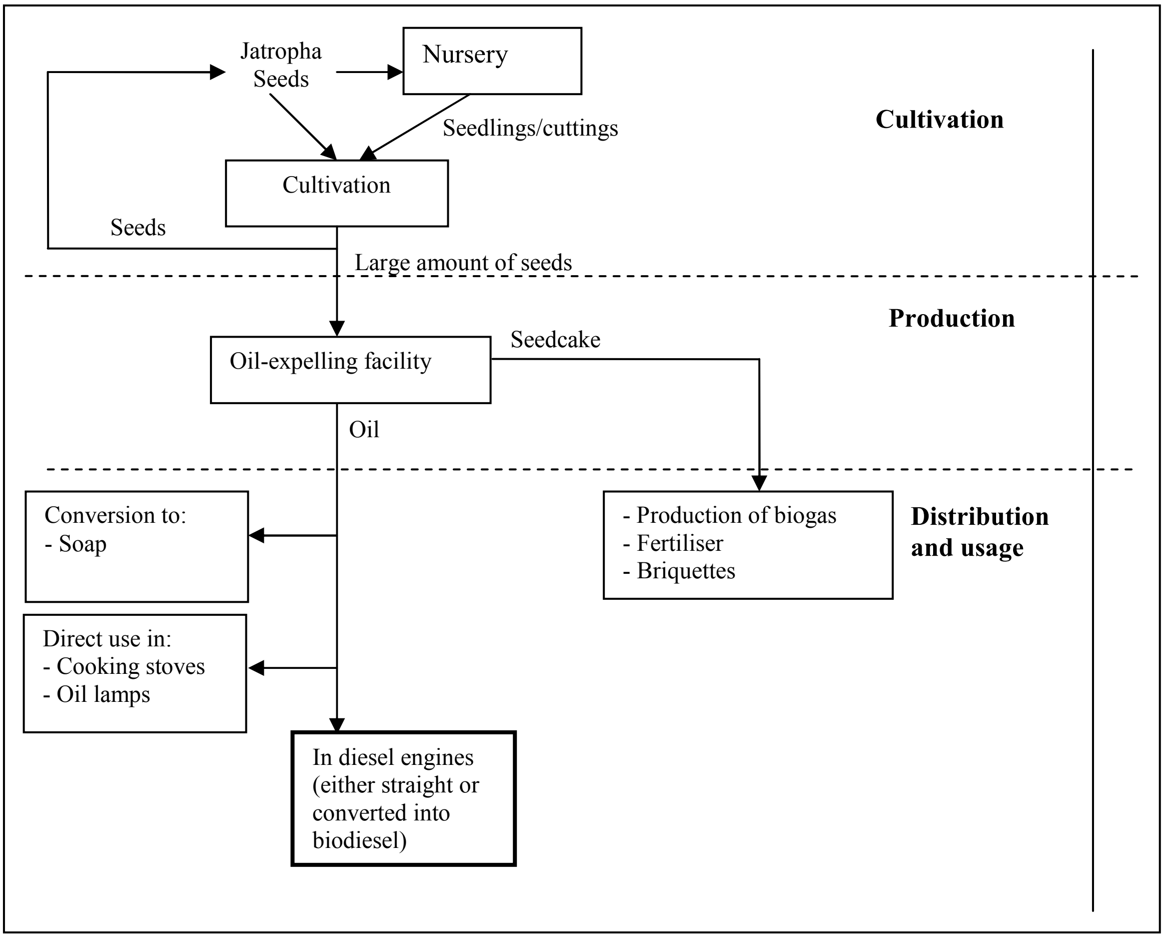
Figure 1: Jatropha-biodiesel supply chain



Notes

[1] A representative example of extant approaches in supply chain design is Schary and Skjott-Larsen (2001), p. 487.
[2] http://www.eia.doe.gov/emeu/steo/pub/contents.html, accessed March 2006.