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Abstract
Biofuel production from the tropical plant *Jatropha* curcas L. has recently attracted a great deal of attention. Some anticipate substantial social and environmental benefits from its cultivation, while at the same time expecting sound profitability for investors. Others are more doubtful, envisaging large trade-offs between the pursuit of social, environmental and economic objectives. The paper explores these issues in Tanzania, a forerunner in the cultivation of *Jatropha* in Africa. We trace how isolated Jatropha biofuel experiments in the country developed since their inception in early 2005 towards a fully fledged sectoral production and innovation system; and investigate to what extent that system has been capable of developing ánd maintaining sustainable practices and producing sustainable outcomes. The application of evolutionary economic theory allows us to view the ongoing development processes in the sector as a result of evolutionary variation and selection on the one hand, and revolutionary contestation between different coalitions of stakeholders on the other. Both these processes constitute significant engines of change in the sector. While variation and selection is driven predominantly by localised learning, the conflict-driven dynamics are highly globalised. The sector is found to have moved some way towards a full sectoral innovation and production system, but it is impossible to predict whether a viable sector with a strong "triple bottom line" orientation will ultimate emerge, since many issues surrounding the social, environmental and financial sustainability still remain unresolved.

Key words: biofuels, Jatropha, evolutionary theory, sustainability, stakeholder conflict, learning, Tanzania

1. Introduction

Biofuel production from the tropical plant *Jatropha* curcas L. has recently attracted a great deal of attention. Tanzania is one of the African countries that has attracted many initiatives in this line of business. A survey of the emerging Jatropha biofuels sector conducted in March-June 2005 uncovered a number of recently-started Jatropha experiments (van Eijck, 2007; van Eijck and Romijn, 2008, Caniëls and Romijn, 2008). A second survey with identical aims and methodology was carried out in Sept-Dec 2008 (Roks and van Vlimmeren, 2009). That study revealed a veritable explosion of activities, organised in a variety of business models.

The aims of this paper are twofold: (1) to explore how the Jatropha biofuel experiments in Tanzania developed since their inception in early 2005 towards a fully fledged sectoral production and innovation system; and (2) to investigate to what extent that system has been capable of developing ánd maintaining sustainable practices and producing sustainable outcomes. In this paper sustainability will be conceived of as encompassing three main dimensions: the human/social, the environmental/ecological, and the financial/economic (commonly referred to as "People, Planet, Profit" – PPP).

The methodology adopted for the analysis is grounded in evolutionary innovation theory, and combines two different types of evolutionary analysis. The first type of analysis concerns the question of how technologies and associated organisational forms and business practices arose and evolved over time as a process of evolutionary variation and selection. This process is essentially driven by learning from successes and failures. The second type of analysis is a study of how different local and non-local stakeholders involved in the sector have attempted to safeguard their interests in a conflictuous process of debate, coalition formation and power play. We have observed that this highly globalised process of contestation is a key driver of sectoral development alongside more locally-based evolutionary variation and selection in the Jatropha biofuels sector. Stakeholder interests and agendas differ predominantly in terms of the importance they attach to the three dimensions of sustainability, and their actions reflect these fundamentally different stands. The overriding profit concern of some commercial entities does not rub at all well with the goals of environmental NGOs and concerns of vulnerable social groups such as smallholders and traditional users of common property resources, or even with more societally responsible investors. Thus, in a sector such as this one, where so many contentious issues are at play, it is clear that the sustainability performance and outcomes of the sector as whole arise from the co-evolution of technology and organisation through gradual learning on the one hand, and opposing societal forces on the other.

The paper is organised as follows: In section 2 and 3 we outline the theoretical framework in detail. Section 4 has information about the gathering of field data for the study. In section 5 we apply the framework to the Jatropha case in Tanzania. We use our own two surveys as the main sources for this, and supplement these with secondary sources such as press reports, NGO studies, company reports, fieldwork reports from other research groups, and so on. Section 5 comes into four parts, which trace sequentially how the sector evolved from the incipient situation outlined in the first snapshot survey in 2005, to its more developed but also much more controversial state in 2008-9. Section 6 teases out the key developmental stumbling blocks and unresolved sustainability issues in the sector that arise from the analysis in section 4, and it reflects on the merits and possible drawbacks of our methodology.

2. Conceptual starting point: Systems of innovation

A logical point of departure for addressing our objectives is the literature on systems of innovation (e.g., Edquist, 1997; Lundvall, 1992). One major advantage of this perspective for

the purpose of analysing sectoral evolution is that explicit attention is given to the fact that innovation is a collective process driven by learning, which involves a wide variety of interacting agents. The systems perspective also points us towards the importance of sectoral structures and institutions, and how they impact on learning and innovation processes. It allows for a holistic interpretation of economic development as driven by co-evolving technologies and societal factors (Malerba, 2004).

A limitation from our point of view is that the main orientation of this literature has been on the conceptualisation of learning and innovation in systems that already exist to some degree. The dominant approach has been one of elaborate description of characteristics of system components, attempts to trace component interactions, and identify obvious gaps that obstruct adequate system functioning and growth. Such an approach is unsuitable for our purposes for two main reasons. First, we are confronted with the birth and the early development of a radically new sector. This kind of phenomenon tends to be characterised by profound uncertainties, sudden unpredictable developments, large swings in expectations, and incipient system functions such as learning and networking. Our focus is not on the more incremental development of an already existing system entity.

Second, the system of innovation literature lacks a comprehensive treatment of sustainability issues. Achieving sustainability along its three key dimensions is crucial in the Jatropha biofuels sector, because the sector emerged and has been being widely pushed precisely because of its alleged potential to contribute to climate change mitigation, restore degraded tropical ecosystems, avoid competition with food crop production, and create reliable and easy opportunities for boosting local livelihoods, alongside promising sound economic viability. If, however, the system would turn out to fall short of expectations in some of these respects in the course of its development, these problems and their consequences for further sectoral development would remain underemphasized in a conventional system of innovation analysis. The reasons for the emergence of these problems would also remain understudied.

There are few contributions to the system of innovations literature that *are* suitable for analysing newly emerging systems, but they still fall short on the treatment of sustainability. An early noteworthy paper is Van de Ven and Garud (1989), who conceptualised the emergence of new industries as an evolutionary process involving close interactions between technology and societal institutions. Industry emergence is seen to entail the establishment of various institutional arrangements, resource endowments and proprietary functions. The establishment of these components and their interactions are traced over time. However, Van de Ven and Garud altogether lack a sustainability focus.

More recently, some systems approaches have been developed that do include a more explicit focus on the environmental sustainability aspect. They address the question how, and under what conditions, more environmentally 'friendly' innovations can emerge, develop and be broadly accepted in society to the point where they can even begin to offer superior performance characteristics over extant unsustainable practices, thus enabling a so-called socio-technical ‘transition’ to occur. One of these approaches is Strategic Niche Management (e.g., Hoogma *et al.* 2002; Kemp *et al.* 2001, 1998; Weber *et al.* 1999; Elzen *et al.* 2004; Raven, 2005). SNM posits that successful radical innovations with environmentally sustainable characteristics 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 new technologies. This occurs in a protected space called a 'niche', a specific application domain for a particular new technology. Experiments create 'proto-markets', in which early connections with market parties are made. When incubation goes well, an actual market niche will develop in which the innovation can sustain itself commercially (Hoogma *et al.* 2002,

30). These experiments take place in the context of a 'socio-technical regime'. This essentially defines the established way of doing things in a particular sector. It 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, 19). In turn, the regime is embedded in a wider contextual 'landscape' – a set of structural societal factors such as demographics, political culture, lifestyles and the economic system (Raven, 2005, 31-32). The three-level SNM framework is visualised in Figure 1.

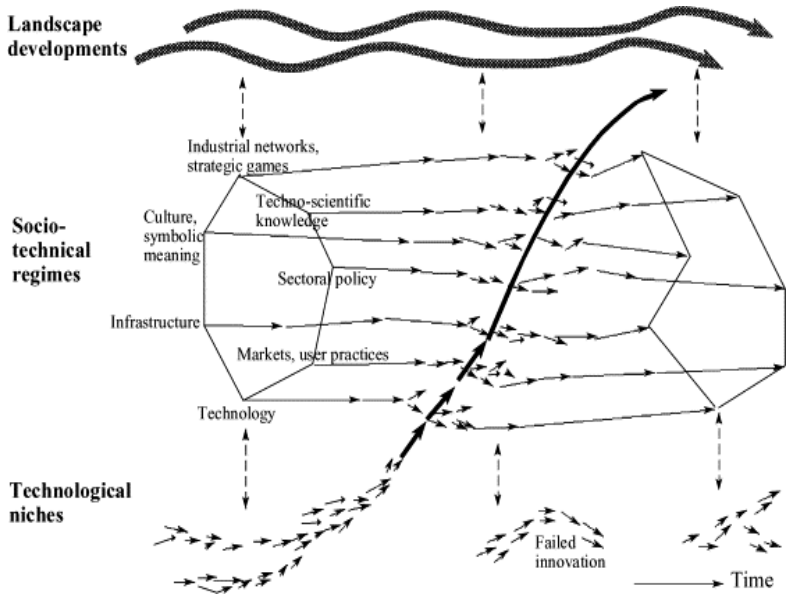

Figure 1: The approach of Strategic Niche Management (source: Geels, 2002)

Another, somewhat similar environment-focused line of research is the functions-based approach to innovation systems (e.g., Hekkert et al., 2007; Negro et al., 2008; Jacobsson and Bergek, 2004; Jacobsson and Johnson, 2000). This is reminiscent of Van de Ven's and Garud's approach in the sense that it advocates the idea that innovation systems have to be able to fulfil a variety of functions in order to support the development, adoption and wide diffusion of new sustainable technologies. The studies in this field analyse virtuous and vicious cycles that arise from the manner in which these different functions are linked to each other in the system. In this way, pivotal blockages to system performance are identified (both internal and external to the system). These are pointers for guidelines for policies geared towards alleviating the key bottlenecks through learning.

Both SNM and the functions-based approach focus on newly emerging innovation systems that generate innovations with environmentally promising characteristics. They try to analyse the socio-economic and environmental learning trajectories involving the incubation and commercialisation of these innovations, and the outcomes that these processes give rise to. There has been recognition of major differences between stakeholder priorities and agendas, and how these can influence these processes and outcomes. However, within the confines of the frameworks, these problems are solely explained in terms of tensions between progressive innovation-promoting (niche) actors and conservative actors in the established regime or technological-system context, who try to oppose promising novelties to safeguard their vested interests (see, e.g., Smith, 2007). While this 'niche-regime translation' view of actor contestation is probably an accurate representation of reality in many cases, it was found to be too restricted for our purposes. Stakeholders with opposing (or aligned, or complementary) interests can pop up anywhere – not only in the regime context, but also

within the emerging niche or new technological system itself, or anywhere else in society for that matter. In contentious new sectors such as biofuels, the potentially social and environmental consequences are expected to be so dramatic that many groups and individuals from all walks of life are exercised by recent developments and want to engage in the debate about where the sector should go (if anywhere).

Thus, what we require for a comprehensive analysis of the evolution of the Jatropha sector is an analytical tool that is capable of integrating a focus on gradual variation and selection in a newly emerging innovation system, with an explicit analysis of human stakeholder interests, controversies and actions around PPP issues as a dominant driver of change. Such a framework should be able to help us understand how the presence of different stakeholders from different backgrounds and representing a variety of societal interests affect the socio-technological trajectory of new system development. In particular, the framework should be able to deal with the fact that stakeholders generally have different agendas that reflect their diverging priorities concerning the weight of the three PPP dimensions of sustainability. Furthermore, it should be able to capture how these inter-stakeholder differences give rise to coalition formation and power struggles, and how these in turn drive the direction in which the system, its components and its outcomes will develop. Antagonistic processes thus have to be endogenised comprehensively within our framework itself. Only then can we understand how evolutionary variation and selection on the one hand, and conflictuous inter-stakeholder dynamics on the other influence each other over time, and how certain sustainability-related outcomes are co-produced by these two different motors of change.

3. Sectoral evolution & sustainability: A systems framework

Our starting point for developing a model that is capable of explaining how stakeholder values, interests and actions concerning different dimensions of sustainability drive the emergence and dynamics of a new sector is a paper by Van de Ven and Poole (1995). They conceptualise evolutionary change and development in organisations by defining four ideal-type process theories, which are distinguished from each other by two criteria. The first is the unit of analysis: single entity versus multiple entities. The second distinguishing element is the mode of change: prescribed versus constructed. A 'prescribed' mode of change channels the development of an entity (or entities) in a pre-specified direction, in accordance with a pre-established programme or action routine. This is typical of incremental, adaptive change processes. The 'constructive' mode generates radical change, producing new action routines that may, or may not create an original (re)formulation of the entity (or entities) (Van de Ven and Poole, 1995: 522). However, according to the authors, very few change processes can be typified accurately by just one of these four ideal-types. More commonly, a combination of two or more types of change processes would be at work. For example, the evolution of an industry over time would entail change within individual organisational entities that make up the sector, as well as simultaneous change in the larger sectoral entity itself, due to its changing composition of the multiple entities that constitute the industry. Similarly, the prescribed and constructive modes are not mutually exclusive. For instance, change cycles of a closed-loop nature, for example 'plan-do-check-act', can at the same time form part of a larger open-ended process of change. Van de Ven and Poole discuss several examples of studies that have applied such composite change theories.

One of these composite approaches makes a particularly relevant starting point for our analysis, namely Greiner's (1972) model of organisational development. The essence of Greiner's model is the interspersing of periods of incremental learning and adaptation with upheaval and turbulence, in his case in one organisational entity. The model consists of five stages, each of which represents a different developmental form of the entity under

consideration.[1] During each stage, gradual incremental change and adaptation processes are at work. However, there comes a time when the entity cannot progress further in such relatively smooth incremental fashion. People working in the entity begin to encounter fundamental misalignments between the requirements of good organisational functioning and existing organisational routines. As Greiner puts it: "Traditional management practices that were appropriate for a smaller size and earlier time no longer work and are brought under scrutiny by frustrated top-level managers and disillusioned lower-level managers. During such periods of crisis, a number of companies fall short. Those that are unable to abandon past practices and effect major organizational changes are likely either to fold or to level off in their growth rates." (p 401).

A combination of two ideal-types outlined by Van de Ven and Poole can be seen to underlie the dynamics in Greiner's model. One is a 'prescribed' evolutionary model based on cycles of variation, selection and retention, and the other is a 'constructive' dialectic model driven by the emergence of opposition against a dominant way of doing things or 'thesis' in the entity, and resolution of the resulting conflict. Conflict resolution yields in due time the dominant thesis for the next conflictuous cycle.[2] From the point of view of the objectives of our paper, Greiner's explanation of the essence of his model is worth quoting: "… variation, selection … explains the form of the stages, while the dialectics explain the underlying dynamics of movement [from one form to the next]. … I put the crises in the model because I could not find data showing the stages as naturally and automatically evolving one after the other. This is not a model where a future life or end stage is assured. … there is no envisioned end state that pulls the process – for me it is the current dynamics within the organisation that are driving it forward – convergence around the thesis of each stage and then running into resistance (antithesis) and requiring re-orientation for the conflict to be resolved. The model in fact has no ending and concludes with a question mark." (Greiner, as quoted by Van de Ven and Poole, 1995: 530)

It is this type of open-ended developmental model that we require in order to analyse the emergence and early development stages of the Jatropha biofuel sector in Tanzania. A brief period of incremental development during its early emergence, in which highly positive expectations – if not hype – were widely shared, was quickly followed by more turbulence and contestation as reflective learning processes about potentially large social and environmental consequences began. Seen from the perspective of the sector as a whole, the development of the industry is thus intimately bound up with a continuous search for technologies, practices and business models that can deliver a workable balance between economic, social and environmental concerns. Different stakeholders push and pull in different directions to gain influence over that process. The extent to which particular parties are successful in achieving their aims will thus be reflected in the future development path of the sector in terms of chosen technologies and practices, business models, and the institutions and structures that govern these. In view of large trade-offs between the three sustainability dimensions, one cannot explain the evolution of the sector without analysing dialectic stakeholder relations and how these shape sectoral development.

In comparison with Greiner's treatment of conflict in his early organisational model, our scope is much broader. Greiner's model was designed in a period when social and environmental sustainability issues were still primarily subservient to the pursuit of profit for commercial gain. Back then, the key contentious issue concerned the different ways in which economic efficiency could be increased and competitive advantage ensured, while the primacy of those aims themselves was not questioned except by a fringe minority in society.

[1] The five stages are: creativity, direction, delegation, coordination, and collaboration.

[2] Another well-known example of a 'constructive' conflictuous model of change is Sabatier's advocacy coalition framework (1988).

The challenges raised in relation to biofuels today are more fundamental as societal moral values have evolved to reflect broader environmental and equity concerns under influence of debates about global warming, social impacts of globalisation and so on. These concerns are reflected in different stakeholder experiences, interests, and perceptions with respect to the profound environmental and social sustainability implications that the sector may give rise to in the course of its pursuit to become economically viable.

The second way in which we need to adapt Greiner's model relates to the unit of analysis. Unlike Greiner, who designed his model to understand and explain the dynamics of one organisational entity, we are concerned with the developmental dynamics of an entire sector composed of multiple actors. Thus we require a suitable sectoral equivalent to substitute for Greiner's stages of the development of single business organisations. The obvious choice is a simple industry life-cycle model consisting of introduction, growth, maturity and decline (Abernathy and Utterback, 1978) A finer sub-division of the first stage in 'embryonic / proto' and 'introduction' is often made, and we will also adopt this distinction in this paper.

We introduce Greiner's adapted model into a multi-level dynamic innovation systems perspective, as used in Strategic Niche Management (see section 2). This approach constitutes a convenient way to express and order the dynamics of a newly emerging innovation system. A multilevel perspective is needed here, because we want to explain the *emergence* of a *new* sector. This cannot be done without studying the contextual forces in the 'landscape' and the 'regime' that give rise to its birth. The more conventional innovation systems frameworks such as those developed by Malerba, Edquist, Lundvall, etc., do not transcend their scope of analysis beyond system boundaries; hence they are less suitable for this purpose.

The second reason for using a dynamic innovation systems perspective lies in the systematic way in which the evolutionary variation and selection mechanisms in the developing innovation system are analysed. In SNM, three interrelated and mutually reinforcing processes have been emphasized (Raven, 2005, p. 43):

(1) Voicing and shaping of people's expectations concerning the new technology (ies). This is necessary in order 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. In the course of time, people's expectations will become more aligned with one another, and they will become more specific and consistent under the influence of experience.

(2) Experimentation-based learning about the possibilities and constraints of the innovation, specific application domains, its acceptability, suitable policies to regulate or promote it, and so on.

(3) The constitution of a co-operating actor network, especially to enable early feedback from users and for the actors to develop a common core view about where they are going with each other and with the technology ('alignment').

The effect of integrating Greiner's sustainability-augmented model of conflictuous change into an SNM perspective is a more distinctive phasing of the system's innovation development trajectory. Evolutionary processes of variation and selection driven by the three SNM niche processes outlined above, become interspersed with tumultuous changes caused by stakeholder disagreements – whether with outsiders to the innovation system, or with actors from within the system – concerning the importance of certain sustainability outcomes. The essential difference with a 'classical' SNM framework is that in our model, at certain points in time gradual variation and selection processes become insufficient vehicles for solving certain emerging problems and contradictions in the sector. Conflict then becomes a *necessary condition* for sectoral development to proceed further. Conversely, the SNM (and functions-based) approach to transition predicts the fastest progress in the *absence* of conflict, because of easy alignment of expectations and efficient collaborative learning.

4. Fieldwork methodology

In the two surveys in early 2005 and late 2008, we tried to identify all significant socio-technical SNM-experiments with Jatropha in Tanzania by talking to local people who were knowledgeable about the budding sector, primarily officials from the Ministries of Agriculture and Minerals and the National Biofuels Taskforce (started in 2006), NGO representatives, academics and private entrepreneurs. For identifying these key informants we relied on the snowball method, starting with a few known experts, and identifying others through these people. An "experiment" in this context should be understood as an activity undertaken by an individual or a group aimed at growing Jatropha, seed pressing, or developing one or more end-use applications for the oil or the seedcake. Most of the experiments took the form of development projects led by local NGOs and governmental agencies, but there were also a few for-profit ventures run by commercial companies. Some had foreign connections involving financial support or knowledge transfer, while others were purely local affairs. In the first survey, 17 experiments were found, and the second survey uncovered close to 40. The great majority of these were visited and a few were contacted by e-mail. Most early experiments were situated in the Arusha and Kilimanjaro regions in the northeast. Others were situated in Morogoro, Dar es Salaam, Kilwa and in Tunduru in the south. Later experiments were also found in western Tanzania. In addition, government representatives were interviewed. The free-flowing interviews predominantly focused on contextual information about Tanzania's energy bottlenecks and strategy, and the government's views on the role of biofuels. Participants located outside Tanzania (such as international donors and car manufacturers) were not interviewed.

The interviews with the representatives of the Jatropha experiments were held face to face, with the help of a detailed standard checklist of open-ended questions. Each interview covered information about the goal, history and nature of the Jatropha-activities undertaken. The respondents were requested to provide considerable details about the development trajectory of their Jatropha activities over time, in order to get a sense of the evolution of the sector. The three key SNM niche-formation processes were covered: actor network activities, people's learning processes, and the dynamics of their expectations. Considering the complexity of the processes, the experimental nature of the research, and the low level of literacy and capacity for abstract thinking present among some respondents, we confined ourselves to gathering mostly qualitative information through informal discussions, loosely guided by our checklist. We did not ask respondents to rate issues on qualitative scales. We did, however, try to collect quantitative estimates from them about the costs and benefits of each major Jatropha-based activity.

5. The jatropha biofuels sector during 2005-9: Emergence, evolution and conflict

5.1 The proto stage: landscape & regime dynamics and niche emergence in 2005

The broad global '*landscape*'-canvas against which the Tanzanian Jatropha sector emerged in 2004-5 was one of increasing concerns about global warming due to the greenhouse effect, combined with increasing awareness of the finiteness of fossil fuels, fast rising energy demand from emerging Asian economies, and structural unreliability of middle eastern oil supplies due to political problems. High and rising prices of fossil fuels were one important manifestation of these rising concerns. Meanwhile, potential investors in biofuels began to perceive the attractiveness of vast areas of uncultivated land in Africa that could possibly be exploited for biofuel cultivation (Mercer, 2003).

Tanzania began to attract attention in this connection in an early stage for several reasons that have to do with its national 'landscape'-characteristics. Foreign investors generally find it an attractive country because of its political stability, democracy, relatively low violent crime, treaties to protect foreign investment and recent economic liberalisation. Foreign investment is actively promoted and facilitated by the Tanzanian Investment Center. There is also a large workforce which is relatively highly trained due to prioritization of education during the past decades. Likewise, many aid organisations find Tanzania a good place to execute projects and programmes.

However, there are also unfavourable national landscape factors: Tanzania suffers from all kinds of problems associated with poverty. Its policymaking and implementation capacity is limited, its degree of industrialization is low, and infrastructure network is inadequate. Road transport is time-consuming, difficult and costly.

At the level of the '*regime*', Tanzania has a high import-dependence on fossil fuels, and a particularly underdeveloped modern energy supply system. The electricity grid reaches just 11 % of the total population (EWURA, 2007). Rural electricity coverage is estimated to be no more than 4% at best. Essentially, electricity reaches only densily populated areas, and even there frequent blackouts and power drops occur. Traditional sources of biomass fuel are becoming increasingly scarce and expensive, especially charcoal and firewood. There is increasing deforestation due to land clearing for fuel and for agriculture for an expanding population. Among different biofuels, Jatropha is seen to be particularly promising, because early publications noted that it has potential for land regeneration and erosion prevention alongside energy provision (Openshaw, 2000). On the other hand, the introduction of new energy sources may face opposition because Tanzania's government budget is highly dependent on import duties from fossil fuels. Also, there is no renewable energy policy that could stimulate, facilitate and assist orderly market development of biofuels.

In addition to the energy regime, there are other regimes that influence the prospects for the development of a viable biofuel niche. The most important among these is Tanzania's agricultural sector which is dominated by vast numbers of traditional smallholders. These are poor marginal farmers, who have been suffering from structurally low prices of staples such as maize and cassava. They might be interested in switching over to a new cash crop such as Jatropha. Cash crop agriculture is already well established in Tanzania. However, no policy support for smallholders exists to make this happen. There are no micro credit programmes, or well-running extension services through which peasants can learn to cultivate new crops. Moreover, local farmers tend to have low faith in becoming outgrowers with new crops. Past experiences such as with the Moringe tree – promoted by the government some years ago – have been disappointing (Roks and van Vlimmeren, 2009).

Another regime that is relevant to the establishment of a biofuel niche is oil pressing. Basic technological knowledge exists in Tanzania due to widespread use of vegetable oil presses for crops such as sunflower and castor; however there is no advanced knowledge about efficient high-capacity presses in the country. The fourth regime that needs to be discussed here is the land regime. Government policy prohibits land ownership by foreigners, although land can be leased by them for up to 99 years. Acquisition of land is difficult and time-consuming. Furthermore, many Tanzanian citizens and local and international NGOs oppose land acquisition by foreing investors. This opposition is mainly based on negative experiences in the past with different crops and resources. It goes back a long way to colonial times. Some valuable resources, e.g. Tanzanite and gold, have been exploited by foreigners while Tanzanians have hardly benefited. There is considerable public fear that the same will happen when large patches of land will be exploited for biofuels by foreign investors.

It is against this landscape and regime background that the first activities towards the development of a Jatropha *niche* in Tanzania began to take shape. In 2005, the innovation

system had only just begun to emerge and basically consisted of a few loosely connected single experiments involving no more than around 30 different actors in total (see Figure 2). Network density is low. The government is notably absent from the network. There is no regulation, and no stimulation (van Eijck, 2007: 87).

There are just two key players, one NGO, Kakute, and one subsidiary of a small Dutch TNC, Diligent Energy Systems. Their business models are not yet clearly articulated. Kakute was first on the scene. It was pursuing an informal outgrower model, collecting seeds from farmers on an irregular basis (including seeds from wild Jatropha plants already growing in the region). These are pressed manually with a ram press. The oil is used as lamp oil and as the key ingredient in medicinal Jatropha soap. Production takes place on a small scale. Diligent had just begun operations in Tanzania, trying to contract small farmers to supply its prospective oil pressing facility in Arusha with seeds from small plants that the company supplies, and that the farmers plant around their small plots as hedges. No large plantation cultivation was noted in 2005.

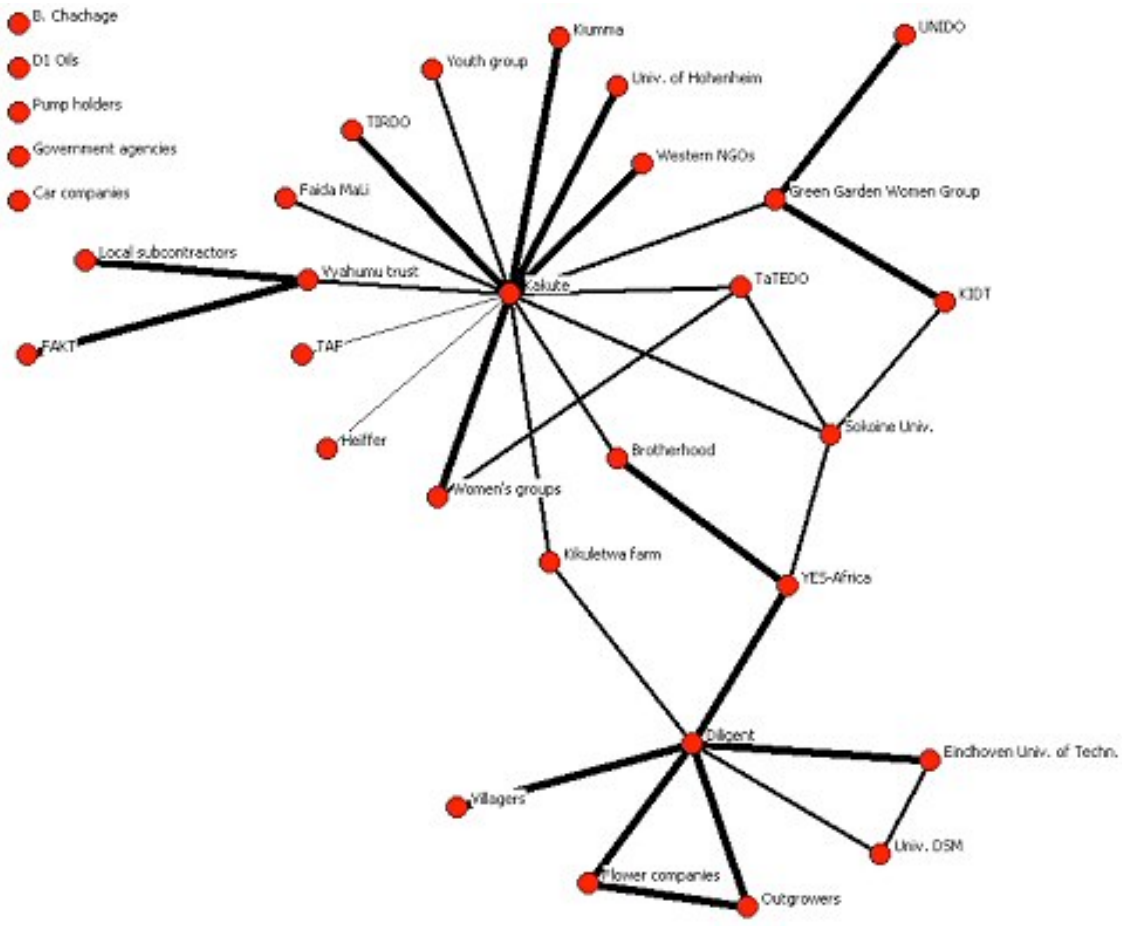

Figure 2: The Jatropha biofuels network in early 2005 (Source: van Eijck, 2007)

We see more differentiation when we look in more detail at the niche processes in 2005. There is already a good diversity of actors involved in the cultivation stage, but less so in the oil pressing stage and only less than a handful in the end-use stage. This makes sense, since a full value chain can only be built up once sufficient oilseeds are available, and it takes 3-4

years for new plants to start bearing fruit. In the cultivation stage, the *actor network* was also found to be expanding quickly and becoming more diverse, with research institutes beginning to be involved. Several agronomic *learning processes* had already occured, for example concerning ways of propagation of seed, irrigation, and planting distances. For example, propagation could be done through (1) growing little plants from seeds in nurseries and then transplanting; (2) taking cuttings from existing plants; and (3) direct seeding on location. However, these learning processes had not yet been synthesized or shared among all the relevant actors. Also we notice that this part of the network was dominated by just the two parties already mentioned above. People's *expectations* about Jatropha's viability are highly variable between actors, but many are highly positive. On hindsight (from the perspective of late 2009) people's yield estimates of 5 to 10 t/ha/yr have proved to be completely unrealistic, a clear sign of the underdevelopment of the sector in 2005.

In oil pressing, we see a small but diverse *actor network*, mostly linked through Kakute. Early technical *learning* by Diligent and Kakute was based on basic mechanized Sayari oil expellers made in Tanzania by an German aid-supported NGO in Morogoro, and on manual ram presses suitable for pressing small quantities only. There were no lessons about profitability of different press techniques yet, although some actors observed that the ram press is definitely unwieldy for larger quantities. There were no ideas either about what press capacity would ultimately be used, because of complete lack of information about market acceptability and suitability of the oil. There were also no lessons yet about the infrastructure and storage requirements of seeds and oil, although this aspect was expected to be important due to the fact that the seeds and the oil are natural products which should be able to be conserved adequately. People's *expectations* about viable business models varied widely: some mentioned small pressing units in several rural places, from where the oil could be collected and distributed further. Others envisaged one pressing unit in a central place, with the seeds being collected from various places. Transport difficulties due to poor roads, and unreliability and inefficiency of equipment are seen as barriers to the development of the industry.

At the usage-stage of the production chain, the *network* is embryonic because a commercial market for Jatropha oil and its by-products does not yet exist, while there is also no developed seed and oil supply system. However, actors had by then identified several different possible uses for Jatropha and were just beginning to engage in *learning*. First, actors had identified Jatropha oil as a potentially good diesel substitute in remote locations within Tanzania, or for export. Diligent was also planning to explore the behaviour of the pure plant oil (PPO) in car engines by converting one car engine to enable it to run on pure Jatropha oil. Diligent's experiments were to some extent supported by research at Eindhoven University of Technology (TUE), the Netherlands, where an MSc project had started about the behaviour or Jatropha oil in diesel engines (Rabé, 2004). However, since Jatropha had never been used as a diesel substitute, lessons on acceptance by users and car manufacturers were still lacking.

A second set of applications that was beginning to be investigated was the use of Jatropha seedcake for biogas production, as fertilizer, and as stove briquettes. Kakute had already conducted an experiment with a small biogas plant, which yielded mixed results because of unreliable gas pressure. There were no experiences with Jatropha as fertilizer or briquettes. Clearly, much technical (and societal) learning was still required here. The research in 2005 concluded that seed cake applications had been explored only very marginally. This was identified as a major weakness for the development of the Jatropha innovation system, because productive use of the seedcake (which still contains about 50% of the oil) is crucial for making Jatropha biofuels profitable.

The third possible application concerned the use of the PPO in oil lamps and cooking stoves. Kerosene lamps are widely used in the villages, but using Jatropha oil is expensive because a separate lamp with a thicker wick is required than what is normally used. Kakute has a small Jatropha-oil lamp factory, but no widespread market for this new lamp was found. Kakute has also experimented with a cooking stove prototype, but there has been no sharing of lessons and no continuous learning due to shortage of Jatropha oil. The stove prototype was not yet functioning properly and there were many complaints about fumes.

Finally, Jatropha can give rise to some non energy-related by-products, notably medicinal soap, which is made by Kakute on a small-scale basis. The soap commands a small niche market due to its high price. Users are happy but there is no clear strategy for upscaling and more systematic marketing.

In sum, people's *expectations* about possible end-uses varied widely in the absence of developed end-markets. There is no communication with potentially interested users who could provide useful information about their preferences and needs. This state of affairs is reflected in all the different potential Jatropha applications. For instance, some actors thought Jatropha as a diesel substitute could best be exported in order to gain scarce foreign exchange for Tanzania, whereas others opined that the oil can best be used domestically for example for local rural electrification projects, or as an ingredient in bio-diesel blends that could be sold in the major urban centres. Expectations about the seedcake are also very mixed. Some farmers would gladly welcome the high quality fertilizer, whereas others worried about its possible toxicity when applied to their foodcrops. Yet others worry about toxicity of emissions when using the oil or briquettes in cooking stoves. It is clear that the end-use part of the production chains is still in its earliest development stage, driven by beliefs and expectations rather than facts and experiences.

To conclude, we spell out the findings from the above review of the 2005 situation for the two evolutionary transition drivers discussed in the previous section. At this very early stage in the development of the sector, it is evident that *evolutionary variation* is the dominant mode of progress. In particular we see variation emerging in the technologies used, e.g., three different agronomic practices for propagating Jatropha in the cultivation stage. Another example of variation is oil use, where participants had identified many different possibilities of using Jatropha or its by-products. We also see the early beginnings of what were later to become two distinct business models: Diligent's commercial outgrower model, which combines highly decentralised small-scale contract farming with centralised pressing with the aim to develop a national or even an international supply line. Kakute is pursuing something similar but more on a local/regional scale and less commercially oriented, with prime emphasis on Jatropha exploitation for local rural development and empowerment of women through local income generation and local use of the Jatropha products. However, the differences between these business models were not yet clearly articulated at this early stage.

Neither did we witness any *evolutionary selection* processes. There is no selection in terms of cultivation and pressing technologies, business practices, and business models. The absence of selection is due to the simple fact that learning has still been insufficient for lessons and experiences to accumulate to the point where people can make informed decisions. This stage is characterised by what Kempf (2007) has called 'limited first order learning' which is basically just technical learning about the key technical processes in the value chain. There are no wider lessons yet about the impact of the processes: about user acceptance, logistics, or possible toxicity. There are also no lessons yet about economic viability of Jatropha, although this is receiving everyone's attention and is subject to much speculation. We can say that the process of niche development as a whole is pulled mainly by highly optimistic yield expectations at this stage.

Meanwhile, major social or environmental sustainability issues are not yet in view. In SNM terminology, there has been no reflexive societal learning in this stage of sector development. The second motor of change that we identified in our analytical framework, the *socio-political conflict-driven process of change*, is not yet operating. We still see a reasonably harmonious process led by few individual actors with plenty of space in this vast country to pursue their own interests without having major effects on each other. At this embryonic stage there is no large influx of big investors whose activities could potentially have major effects on the rural ecological and social-economic scene. The public at large – both within Tanzania and abroad – is still hardly aware of Jatropha's emergence. To the extent that people are aware of it, there is just a vague sense, mostly based on heresay, that social and environmental impacts will be positive: 'Jatropha, the wonder crop' is expected to restore degraded lands, contribute greenhouse gas emission reduction, will not compete with food production, yield incomes for poor farmers through intercropping with food crops or hedge plantings, boost national energy-self-sufficiency, help empower women, and foster rural economic development.

5.2 Introduction: increasing landscape pressures and evolutionary variation in 2006-7

The favourable expectations generated in the early years of Jatropha niche development in Tanzania - as well as in many other tropical countries - began to foster an international climate of great optimism regarding investment possibilities in these countries. This was simultaneously being stimulated by developments in the *landscape*: the IPCC published a report stating that it is 90% certain that the increase of CO_2 in the atmosphere over time is induced by human activity. It also stated that if the combustion of fossil fuels would not be reduced significantly within the next decades, a temperature increase of over 2 degrees Celsius will cause climate change with catastrophic consequences (IPCC, 2007). The film 'An Inconvenient Truth' produced by Al Gore also did much to enhance public awareness of the dangers of human-induced climate change.

The positive expectations attached to Jatropha were accompanied by a growing interest in western developed countries to utilise biofuels to combat climate change and enhance energy security. In the EU, for example, this gave rise to Directive 2003/30, in which the EU set indicative targets for biofuel consumption as road transport fuel of 5.75% by 2010, and 10% by 2020. In the US, a target was set of 7.5 billion gallons by 2012. According to the OECD, the annual support given by the US, EU and Canada to stimulate the supply and use of biofuels had risen to US$ 11 billion in 2006 and was expected to rise further to approximately US$ 25 billion by 2015 (Hauwermeiren, 2008).

The combined occurrence of these trends heralded the second major phase in the industry's development. It began to cause a major influx by western transnational corporations (TNCs) into a range of tropical countries in Asia, Africa and Latin America. These companies have been intent on the large-scale commercial cultivation of Jatropha predominantly for western markets of transport fuel and electricity-generation feedstocks (e.g., ABN, 2007; Beattie, 2008; Knaup, 2008; FAO, 2008; GEXSI, 2008; Mackenzie, 2008). Within just a few years, the stream of these investments had grown to such an extent that it began to attract considerable attention in the press in developed and developing countries alike. One CNN report estimated that more than 720.000 ha had been planted by spring 2008, which was expected to rise rapidly to over 21 million ha in 2014 (Whiteman, 2008), out of an achievable total potential of around 30 million ha (Wille, 2008).

In Tanzania, the combination of the various global landscape pressures and positive expectations gave rise to a virtual deluge of foreign direct investments into the fledging Jatropha sector. A survey undertaken in the spring of 2008 identified a whole range of

different initiatives and scales of production, varying from very small-scale production activities to extremely large plantations (or sets of plantations) exceeding 50,000 ha. In another survey later that year, these initiatives were found to be linked to foreign investors or aid donors without any exception (Roks and van Vlimmeren, 2009).

It is at this stage that we can also begin to differentiate between more or less distinct business models with their own distinctive technologies (Martin et al., 2009). On the smallest size of the spectrum, we see the establishment of local Jatropha-energy projects in poor rural areas, motivated by the potential for improving livelihoods through collective utilisation of local resources (Appropriate Technology, 2007). Two so-called 'Local Multifunctional Platforms' (LMPs) were established in the remote Maasai villages of Engaruka and Leguruki. Designed to promote local economic development through self-sufficiency, LMPs consist of a set of three basic machines placed behind one another: a small oil expeller, a generator set, and a maize mill. The idea behind this concept is that local farmers will cultivate the plant as hedges round their fields and/or as part of intercropping regimes. After a few years of start up, sufficient Jatropha seeds should be generated for the local community to enable the oil expeller to be utilised to full capacity, and the generator set to run for several hours per day. This could in turn stimulate food processing activities such as maize milling, as well as home lighting, radio services and mobile phone charging. Furthermore, the electricity supply would in due course be sufficient to substitute for fossil diesel-generated electricity as the power source for the oil expeller (Wijgerse, 2007). The LMP business model is copied from projects in Mali, where it was reportedly considered to be a highly promising model (Togola, 2008).

The large plantation (LP) side of the spectrum consists of a number of western investors, mostly from EU countries, attracted by the Tanzanian government's welcoming attitude to large scale agrofuel initiatives. In addition to Jatropha investors, which dominate numerically, we also see entry of some sugar cane (for ethanol) and palm oil projects (ABN, 2007). Since these projects are required to go through lengthy land acquisition procedures, they were still in their infancy during this stage, but their plans were certainly grandiose. In one case, a company wanted to lease 80,000 ha of village land for conversion into 200 ha estate plots of Jatropha monoculture. It planned to remove existing vegetation using heavy duty imported machinery. It was also planning to conduct systematic agronomic experiments in collaboration with local and foreign universities to optimise Jatropha yields by means of pruning, mulching, and introducing pest and disease controls, and it wanted to use mechanical harvesting, never tried before with Jatropha (Romijn, 2008).

Many of these plantation schemes were being established in Tanzania's coastal zone, in view of their ambitions to cultivate the export market (Martin et al., 2009), in many cases through shipping out the raw agricultural product (Romijn, 2008). In 2007 the African Biodiversity Network (ABN, an international NGO) noted that "... the Tanzanian government is evidently committed to fast-tracking agrofuel initiatives, and switching over vast areas of land to sugar cane, palm oil and Jatropha. The most fertile lands, with best access to water are being targeted, even though these lands are already used for food production by small-scale farmers. Any talk of biofuel production for local energy consumption is undermined by the obvious intent of international investors to target foreign markets ... Also, there are no plans to invest in infrastructure in Tanzania to process agrofuels for local use" (p. 12).

The middle range in the business model spectrum is occupied by some schemes that try to use a model centred on decentralised production of Jatropha seeds by small-scale outgrower farmers, combined with centralised oil pressing. These projects do not depend on own land (Sulle and Nelson, 2009). This outgrower model (OM) thus affords a more gradual growth trajectory, enabling firms to start experimenting with oil pressing on a small scale, growing gradually by extending their contract farmer network over time. They can also utilise well-established Jatropha plants that are already growing wild in some areas, such as Shinyanga

and Singida. These companies were not established with a definite plan where there main market should be. Exports as well as domestic and even local sales (for instance, to a soap producer and to local eco-safari companies) are being considered, depending on the economic viability. In any case they plan to utilise the Jatropha by-products (hulls and seedcake) locally, so their market strategy is more mixed than that of the LMPs and the LPs (Roks and van Vlimmeren, 2009).

Summing up the main developments during 2006-7, we see a continuation of the *evolutionary variation* motor of change at work in the sector. Compared with the earlier period, the learning is broadening from purely technical aspects of cultivation and production. It is beginning to encompass different ways of setting up complete business models and how to organise and coordinate these. While three distinct business models begin to cristallyze out, we cannot yet identify any *evolutionary selection* in the sense of failing alternatives falling by the wayside, or any of the three emerging models being clearly preferred over the other(s).

As far as *antagonistic processes* go, we cannot yet see full-blown conflict, but we can discern the seeds of these in early publications by NGOs such as the African Biodiversity Network.

5.3 Frustrated early growth: Landscape instability and seeds of conflict during the 1st half of 2008

The first half of 2008 is marked by major instabilities in the *global and local Tanzanian landscape*, which have had dramatic effects on the development of the Tanzanian biofuels innovation system. These developments coincided with the accumulation of experiences from the cultivation of Jatropha as a managed agricultural crop. Since Jatropha takes about 3 years to start yielding seeds, the earliest Jatropha projects in Tanzania and in other countries such as India were beginning to get their first results around this time. From these results, it was becoming increasingly clear that although Jatropha is indeed able to survive under hostile environmental conditions, its seed and oil yields are much higher in conditions where the plant has adequate access to soil nutrients and water (FAO, 2008; Achten et al., 2007, 2008, *The Guardian*, 2009).

At around the same time, global food prices began to climb to an all time high. The FAO's annual review of food and agriculture in 2008 stated that food prices had been rising to the highest levels since the 1970s (in real terms), and gave warning about serious implications for food security among poor populations around the world. It forecasted global food-import expenditures to reach US$1035 billion dollars in 2008, 26 percent higher than the previous peak in 2007. It also pointed out that the bulk of the anticipated growth in the world food import bill would come from higher expenditures on rice (77 percent), wheat (60 percent) and vegetable oils (60 percent) (FAO, 2008, p. 107). These emerging facts intensified and expanded a debate, which had so far been limited to the USA and Brazil, about competition between food and fuels (Rathmann, et al., 2009). The World Bank (Mitchell, 2008a) and the OECD (2008) came out with reports claiming that biofuel production, spurred by attractive subsidies, minimum blending requirements, and skyrocketing fossil oil prices in an overheating global economy, had been one of the main reasons for the increasing food prices.

This, coinciding with a drought in Eastern Africa, caused great concern in the region, where periodic food shortages have been an issue for a long time (The Citizen, 23 July 2008). It began to spur major controversies over the large scale biofuel plantations that had recently been established in the country. While the plantation investors often tended to claim land abundance, others began to point out that land that might seem unused at first sight can yet be valuable for its provision of durable ecosystem services, as a resource of forest products such as fuel wood, building materials, medicinal plants, mushrooms, bush meat and honey, as

religious places, and as places where nomadic people and cattle can freely roam around. One Tanzanian NGO cites a World Bank report which had estimated that local informal uses of local forests account for US$ 35-50 in generally unaccounted-for per capita income in Tanzania (Sulle and Nelson, 2009, p. 4). Also, the argument is surfacing that future land requirements for food crop cultivation restrict its availability for biofuel production, for example in traditional rotational agricultural schemes that are still widely practiced in Tanzania.

Another major global *landscape factor* that began to come into play was the official coming into force of the Kyoto Protocol on 16 Feb 2008. The Kyoto agreement bound the 183 signatory countries, among which Tanzania, to reduce their collective emissions of greenhouse gases by 5.2 % by 2012, compared to the 1990 value. Under the agreement, rich developed countries could fulfill their own reduction requirements by buying CDM (Clean Development Mechanism) credits from projects in developing countries that reduce emissions. This served to focus the global community on the greenhouse gas saving potential of biofuel investments. Several bodies began to raise questions whether biofuels were really as GHG-friendly or -neutral as they were initially claimed to be. In January 2008, two articles in *Science* caused a worldwide stir, pointing out that biofuel energy life cycle studies so far had neglected an important dimension of greenhouse gas emissions due to conversion of lands which is needed to start cultivating them (Fargione et al., 2008). Fargione's study introduced the concept of 'carbon debt', showing that palm oil plantations established on former tropical forest lands in Malaysia and Indonesia would need to run for over 300 years for the initial carbon debt to be repaid. Only switchgrass crops planted on US prairies (already in degraded condition) were shown to have negligible carbon debt periods.

Although Jatropha was not yet included in these initially studies, they raised worldwide doubts about the desirability to promote biofuel investments of any sort. It did not take long for these concerns to be reinforced by other scientific publications. Achten et al.'s (2008) worldwide Jatropha survey asserts that "the removal of (semi-) natural forest for the introduction of JCL [...] is expected to have a significant negative effect on the GHG balance of the whole life cycle. The caused emission due to removal of (semi-) natural forest is a heavy burden on the initial GHG investment, which will take a significant time span before it is paid back with the GHG emission reduction of the use of the bio-diesel." A survey of environmental life cycle studies of Jatropha biofuels concluded that all of them were deficient in their treatment of land use change. Its own preliminary estimations of GHG emissions associated with the conversion of Miombo Woodland – the dominant Sub-Saharan African ecosystem – into Jatropha plantations confirm Achten's qualitative conclusions (Romijn, 2009).

Several countries, regional groupings, and organisational networks step up efforts to institute committees to develop social and environmental sustainability criteria that biofuels must meet to ensure responsible practices (Lerner, 2008). The best-known national initiatives include: the RTFO (UK), the Cramer initiative (The Netherlands), the Social Biodiesel Schemes and Programme for Certification of Biofuels (Brazil) and the South African biofuel standard. Three international institutional initiatives were also started: The GBEP (G8+5, UN agencies), the BEFS and BIAS (FAO), and the EU Biofuels Directive. In addition there is an international voluntary initiative, the Roundtable on Sustainable Biofuels (RSB), which initiated a specific working group devoted to standard setting for sustainable Jatropha in mid 2009.

Due to all these cumulative pressures, the Tanzanian Jatropha *niche* is forced to prove the environmental and social sustainability of all the stages in the production chain. Issues include previous use of the land, CO_2 balances, water use, food security effects, effects on local ecosystems, and socio-economic effects on local populations. Understandably, the pressure

comes down mainly on those projects connected to large international investors who aim to satisfy western energy demands. Different actors begin to put the thumbscrews on. Global, Pan-African and local NGOs are among the first to become restive. The African Biodiversity Network flags potential threats to land, livelihoods, food security, biodiversity and water, and notes that the government of Tanzania has already surveyed many fertile regions with the best access to water, which also happen to be the regions where farmers are already growing food. It warns that Tanzania's main rice areas could be given over to biofuels production and that production of maize, wheat, beans and cassava may also be affected. The NGO accuses the government of having few qualms about evicting smallholders from their land. Perhaps worst of all, it predicts increased conflicts over already problematic water access when this resource will be diverted for biofuel irrigation (ABN, 2007).

The biofuel sector in Tanzania had grown so large (from 2 key actors in 2005 to approximately 38 leading companies and projects in early 2008) that the situation even began to draw the attention of the international press. In May 2008, the *Financial Times* reported that the food versus fuel debate and associated turmoil had begun to put so much pressure on the Tanzanian government that it was in disarray about how to proceed, "blowing hot and cold" depending on who's asking, and dithering over the introduction of effective regulation. A national biofuels policy was called for by concerned donors and investors who dearly desire more clarity about future prospects and land acquisition procedures, but so far divided politicians and the 'creaky government machinery' had not made much progress (Beattie, 2008). The *East African* regional newspaper quickly picks up on this news and adds further inflammatory details about one 8000 ha plantation scheme close to Dar es Salaam implemented by Sun Biofuels, a large UK investor, especially about its lack of local prior consultation with local affected villagers, the low daily wages on the plantation ($3), the long land lease (99 years), and the danger that Tanzania might soon be overrun by similar investments, which would cause a major threat to its already precarious food security situation (Redfern, 2008).

Just a few weeks later, the *East African* again carries a report about biofuels, this time honing in on a highly critical new report by Oxfam International (2008). The Oxfam report estimates that the EU biofuel target could actually increase carbon emissions by 70 times by 2020, because of the required changes in land use in exporting developing countries like Tanzania (Oxfam International, 2008). The same newspaper article also reports on a Tanzanian Member of Parliament (MP) cum environmentalist who takes the government to task over its rush to embrace biofuels without proper consideration. In reply, the Prime Minister announces that the Ministry of Energy and Minerals and the Ministry of Agriculture, Food and Cooperatives have been tasked to come up with policy regulation, but that investments that are already underway in the country cannot be halted (Afandi, 22 July 2008). Just two days later, a local Dar es Salaam-based paper adds to the heat with an editorial stating that another concerned MP spoke in parliament about a Dutch investor acquiring long leases over very large tracts of fertile land directly from villagers in the Kilwa area, which it is not allowed to get without prior government permission under the 1999 Village land Act. The journalist laments that the government has remained silent, in spite of more and more reports and statements from local watchdogs, NGOs, university researchers and MPs expressing great concerns over the large-scale allocation of fertile land (estimated by the Land Research and Resources Institute to amount to 641,170 ha by then) and the uncertainties hanging over the supposed benefits of biofuels like Jatropha. It is urged to act immediately to put regulatory and legislative mechanisms in place (*The Citizen*, 24 July 2008).

An interesting example of academic voices in the debate is a presentation given in a biofuels conference in Tanzania, which reported on survey findings from a study group of engineers, lawyers, economists, land experts, commerce/trade exports, and

agriculture/forestry/livestock experts from Tanzania's three best known universities. In surveying the investment locations, the group noticed that the country's coastal regions top the list because of port facilities, a factor indicating that the biofuel business is mainly for export. This, they say, raises concern about benefit sharing for improved local livelihoods. Long term attractiveness of the current crops is also no certainty – due to intensive ongoing research for more efficient biofuel crops, plantations that are now being erected might be abandoned sooner rather than later. Will the costs of the loss in biodiversity and land degradation caused by these developments not outweigh short term financial gains? And finally, they draw attention to the need to build better national capabilities and research and transport infrastructure. In the absence of these assets, foreign investors will be induced to keep relying on foreign partners for key services and collaborations, thus contributing to exclusion of national parties and lost knowledge accumulation and local development opportunities (Mwamila, 2008).

In retrospect, we can say that this brief period was a particularly tumultuous one in the biofuel development trajectory, both in the world at large and in poor developing countries like Tanzania. Most of the tumultuousness emanated from developments in the *landscape* and in the *niche.* However, the *energy regime* also contributed through unprecedented fossil oil prices that averaged US $ 120 per barrel during the 2nd quarter of 2008 (Bloomberg, 2008). This boosted renewable energy investments by fuelling widespread expectations of structurally high energy prices.

As far as the global *landscape influences* were concerned, these culminated in enormous spikes in food prices, leading to social unrest in many countries. Whether or not biofuel investments indeed played a truly dominant role in these food price rises has remained a matter of some debate because there were also other factors at play, especially droughts, high demand, financial speculation and high transport and processing prices associated with the oil price hike. However, a more important lesson that sunk in during this episode was that some of the major drivers of the food price hike constitute major structural developments – especially the steadily rising purchasing power in large emerging economies in Asia. Hence, the world can ill afford to devote vast tracts of arable land to the cultivation of biofuels.

This lesson began to sink in just as the first results of significant progress in learning in the emerging global *Jatropha biofuel niche* began to circulate. First of all, in addition to ongoing *evolutionary variation processes* we now begin to perceive *evolutionary selection* in Jatropha cultivation. The vital agronomic lesson that is emerging at this stage is that Jatropha is in fact no different from any other wild hardy crop, in that it can survive in drought-prone conditions and poor soil, but it cannot possibly be expected to be a financially attractive and reliable oil crop under hostile environmental circumstances. This caused increasing pressures on investors to scout for cultivable land, inflaming the food versus fuel debate in Tanzania. This dawning reality therefore also marks the start of what SNM theorists have called broad 'reflexive learning', i.e. learning about sustainability impacts. The accumulation of problematic experiences with large plantation investments was beginning to cause disillusionments about the much hyped developmental benefits of the crop for poor developing countries like Tanzania. For many, this effectively punctured the overblown expectations that had been built up around it.

In all this upheaval and contestation, it is hard to find evidence of additional *evolutionary variation processes* such as oil pressing and user applications, which along with agronomic learning had been the dominant drivers of progress in the sector in the earlier years. Undoubtedly these processes went on as before, but they became largely invisible because many parties concerned with the development of Jatropha (and other) biofuels became preoccupied by major unresolved issues relating to environmental and social sustainability.

Seen through the lense of Greiner's conflict-driven framework, this is a period in which it is discovered that major parameters governing the future operation of the sector need to be reset for further progress to be able to take place. We also see different parties mobilising to make this happen, by doing research, writing reports, begin work on regulatory institutions, forming stakeholder forums, and striking up informal alliances (e.g., by supporting each other on blogsites and in the local press). We begin to discern the first *selection* results from these power struggles in late 2008/early 2009, to which we now turn.

5.4 Interrupted early growth: landscape & regime instability and niche conflict from mid 2008 onwards

The start of the final period in the development of the Jatropha sector so far is marked by the global financial crisis causing major *energy regime instability*. The recession begins to bite worldwide in the form of dramatically plunging oil prices and falling oil demand. The oil price plunged by US$ 115 from its peak of US$ 147 at the end of July 2008 to its lowest point of US$ 32 in December of the same year, the most precipitous fall the world had ever seen (*The Economist*, 23 May 2009, p. 69). Although long-term oil price projections point upwards, the large swing caused major problems for renewable energy projects and programmes worldwide, including those based on Jatropha bio-oil. In the preceding years, major investments had been made in EU biodiesel factories, which suddenly experienced dramatic overcapacity. By early 2009, only 60% of the German biodiesel production capacity was still in use, and several factories had closed down (MVO Magazine, May 2009). Producers of Jatropha feedstocks – particularly large export-oriented firms – had to revise their expectations about the market prospects in this market.

Meanwhile, the severe food shortages and high food prices that are also experienced in this period begin to fuel major concerns about the backwardness of Tanzanian domestic agricultural sector and its inability to provide food security. This is an effect of international landscape factors putting pressure on Tanzania's *agricultural regime*. One finds increasingly vociferous criticisms by actors such as NGOs, academics and journalists in the press and on blogs, about the neglect of these issues by the government (Godoy, 2009; Kamata, 2009). One journalist criticises the wishy-washiness of a recent FAO report about the consequences of the large scale acquisition of African land by foreign investors. The FAO report emphasises the potential for macro-economic developmental benefits arising from this development, while underplaying the regulatory and legal requirements that need to be in place and to be enforced in order to guarantee the safeguarding of local Tanzanian interests. The journalist points out that African countries precisely lack the required governance capacity. In these circumstances, the foreign investor can strike deals with corrupt representatives of the host state or local elites to get its way, while displaced smallholders do not have the wherewithal to negotiate fair deals, nor are they able to enforce agreements when the foreign party fails to deliver promised services such as employment or public services (Godoy, 2009).

Another piece suggestively titled "Imperial Projects and the Food Crisis in the Periphery" reports on a seminar held at the University of Dar es Salaam by concerned academics. It draws attention to the long historical neglect of Tanzania's agricultural smallholder sector and its colonial history, when rulers gave preference to cash crops for export, or to the modern food sector (such as groundnuts, and rice and wheat to feed the British army stationed in Tanzania). The biofuel wave is feared to be a mere continuation of these past policies and colonialist relations (Kamata, 2009). Similar sentiments are expressed in international publications as well (e.g., Dauvergne and Neville, 2009). Another local academic study details the impacts of advancing Jatropha cultivation on Maasailand, and questions for whose benefits the crop is actually being promoted. It describes many unfavourable effects for

Maasai pastoralists, including loss of grazing lands and spiritually significant places. It also cautions NGOs that try to coax Maasai to get involved in cultivation of Jatropha themselves. Many Maasai apparently experience it as upsetting their traditional ways of life and culture and are not interested in these kinds of projects, though they might not say so openly (Laltaika, 2008).

The main developments in the Tanzanian Jatropha niche at this stage are detailed in a comprehensive survey in sept-nov 2008 (Roks and van Vlimmeren, 2009). When we compare Figure 3, depicting the *network situation* at the end of 2008 with the incipient network of early 2005 (Figure 2), it is clear that the sector has expanded exponentially. In addition to the two original lead players (Kakute and Diligent Tanzania Ltd) we see a raft of major new players, many of them large plantation investors. Roks and van Vlimmeren obtained estimates of the numbers of ha planted by all these players during the few years prior to their survey. They estimate that when these Jatropha plantings start yielding seeds in approximately 3 years from the time of survey, the amount of oil produced would soon exceed 5 % of current imported fossil oil in Tanzania (p. 61), although the majority would probably be destined for the export market.

The different stakeholders were found to execute a number of increasingly differentiated roles, including: cultivation; processing; knowledge and consultancy; financing; purchasing of end products; special interest group promotion and lobbying; regulation; machinery supply and new equipment development (Roks and van Vlimmeren, 2009, pp 47-49). There is also some progress in terms of institutional development. In mid 2009, a number of private biofuel producers got together to form an association for the purpose of collaboration on research and lobbying for coherent and transparent policies (ProBEC, 2009). The sector is thus developing considerable specialisation and gaining more depth in its functions, as well as growing fast in terms of sheer size.

The stellar growth, combined with the adverse landscape constellation and the absence of government regulation, conspire to feed the worries by local and non-local actors about the current and future impacts of the sector. Several leading NGOs start investigating. One highly critical study investigating potential and actual social and ecological impacts is undertaken by the WWF Tanzania chapter with support from WWF Sweden in 2008. It contains damning findings regarding the location decisions, investment procedures and operations of some of the foreign plantation investors (WWF-Tanzania Programme Office, 2009). Another study is done jointly by the Tanzania National Research Forum's Forestry Working Group and the International Institute for Environment and Development, carried out from Oct 2008 to March 2009. It estimates that a total of 640,000 ha had been allocated for biofuel investments by then, with approximately 4 million ha being requested by investors. It also estimates that between 5000 and 10000 local people have been affected so far, leading to the alienation of their rights over customary lands (Sulle, 2009). We will come across more examples of critiques in the analysis of the *learning processes* in the Jatropha niche further below.

Looking at the actual developments on the ground in this period, we can say that the future outlook is more mixed than the recent fast growth suggests. Despite increasing international landscape pressures favouring renewables for environmental reasons, local user preferences in Tanzania are primarily based on price because of the poverty. Hence, the crash of the fossil fuel price in the fall and winter of 2008 was, on the whole, a bad thing for the development of an economically viable local Jatropha sector that would cater to local needs. This is especially true for the national regime-competitive applications, such as Jatropha fuel for transportation or lighting. However, since the quantities of Jatropha oil that are actually reaching these markets are still minimal in any case, there was not much short-term negative impact there.

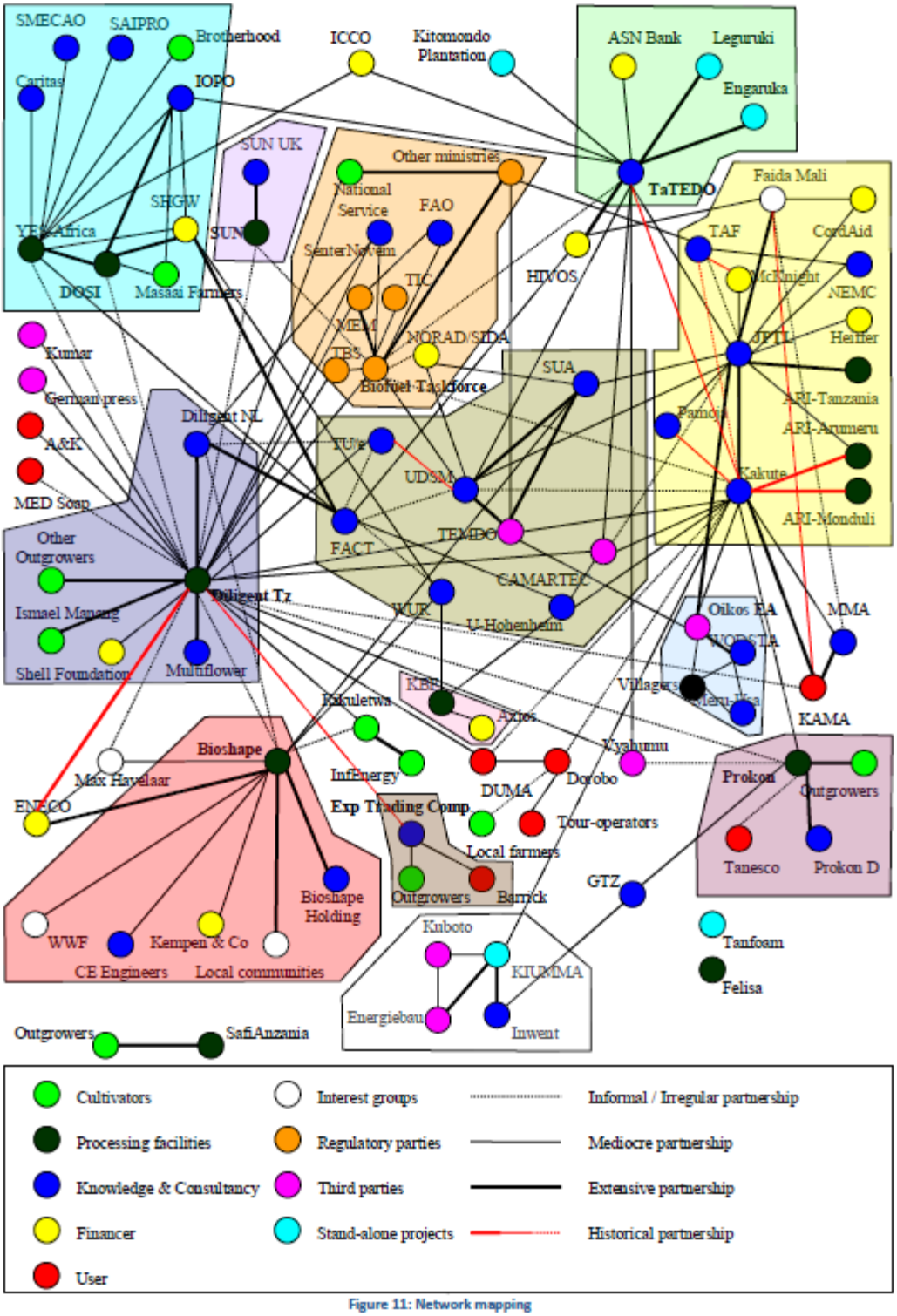

Figure 11: Network mapping

Figure 3: The Jatropha network in Nov. 2008 (source: Roks and van Vlimmeren, 2009)

The outlook is better for local Jatropha applications do not aim for substitution of an existing energy regime, but rather at complementation. For example, some projects aim for rural electrification or expansion of modern energy sources in places where the existing fossil regime is not yet present or rudimentary. Here Jatropha does not have to compete with an established fossil fuel regime, and can meet user needs. Prospects in these local sheltered spaces continue to appear to be somewhat promising, also because the desirability of local applications for Jatropha – as opposed to export to western markets – is increasingly being emphasized in international publications (Tilman, 2009, Vilt, 2009). It has become easy for NGOs to acquire donor finance for such applications. A local technology development organisation, TADEDO, announced that it had received funding from Dutch parties to implement 100 additional rural MFPs along the lines of the two experimental ones installed earlier, even though these were not yet functioning adequately. Some worry about the longer-term economic viability of these schemes. The NGOs introducing the crop may not require viability themselves, but unless Jatropha is introduced on a commercially sound basis and accompanied by strong local capacity building for project management and maintenance, it will not be sustainable after the donors pull out (Trondsen, 2009; Wijgerse, 2007).

The *learning* in the niche is still mostly supplier-driven (about costs, technical performance, etc). User involvement is still limited. At the same time, learning mechanisms have expanded over time, from trial and error in 2005 to systematic search, use of test plots, use of literature, internet use, participation in international conferences, etc. in 2008/9. As a result, enough lessons have accumulated for local actors to agree that the technology functions well enough. Further learning is geared towards overcoming problems in other dimensions, e.g., to improve alignment in preferences between users and suppliers, or to minimize ecological impact. Technological learning is also still ongoing, e.g. experiments with biodiesel through transesterification and blending yield new facts and possible practical lessons around this new product. Also, in order to extract more value from the Jatropha seeds, actors continue to search for, and experiment with ways of using the seed cake. Stimulated by user preferences and possible future regulation, some actors also investigate properties of the Jatropha oil. One company installed its own laboratory facilities to do this. This company also assists the government with the drawing up of national technical standards, since the government's own facilities and capabilities are insufficient for this purpose (Romijn, 2008). Actors also continue to learn about the agronomical properties of Jatropha and conditions affecting its growth such as soil composition, fertilizing, how and when to prune and irrigate, weed, etc. A new experience concerns bottlenecks with seed supply logistics. These begin to be seen as a barrier for the further development of the Jatropha technology particularly by the OM companies. One project is setting up an efficient supply chain for large scale decentralized production involving thousands of outgrowers, based on regional collection centres that are also hubs for training and extension work (Roks and van Vlimmeren, 2009).

Early learning on the user-side gets under way at last. There are different experiments related to different end uses, so here we see a new instance of *evolutionary variation* occurring. So far, distribution has been done with barrels delivered to special user categories, including eco-safari companies, a local soap producer and Boeing (15,000 litre in 15 barrels exported by air) which used the oil for a highly successful test flight in a Air New Zealand plane in December 2008. We also begin to see the first instances of *selection*. One possibility being pursued was the use of PVO in the Siemens Protos cooking stove. However, an experiment with local users failed because of fast clogging of the pipes, high oil use and high costs. Usage in older vintage stationary diesel engines – as designed for the rural MFPs, is still in the planning stage. A more promising end use is biodiesel for clients like Boeing and eco-safari companies. Different applications for the seed cake, already mentioned as

possibilities in the 2005 survey, are now being tried out. Many projects have not settled on the main type of end-use that they will go for, but socio-political pressures against large-scale export for western markets are mounting.

Despite the mounting pressures, no experiments are set up for the sole purpose of reflexive social and ecological sustainability-related learning. Ecological sustainability learning occurs through literature search, limited data collection, and tests performed in the projects, e.g., about poisonous qualities, effects of Jatropha on soil quality, and the effect of Jatropha on nitrogen depletion and how to prevent this through intercropping with leguminous plants or feeding back the seed cake. Regarding the impact on global warming, some lessons are being learnt through monitoring in ongoing projects. One investor is measuring carbon sequestration in its growing Jatropha plants.

It becomes increasingly evident that the environmentally sustainability effects differ markedly in the different business models. Some plantations are found to be located in ecologically rich areas (such as in Tanzania's coastal forest belt) and these are thought to have invasive effects on flora and fauna. They projects are not necessarily favourable in terms of GHG emission reductions either, because they cause carbon emissions from clearing vegetation and disturbing soils that have never been tilled before. The OM and LMP models are emerging as the ecologically soundest options, because Jatropha is not planted on uncultivated land and it also does not compete much with food production. On the social dimension, the three business models are more competitive. Large plantations offer much short term wage employment, but longer term employment is uncertain, and plantations use a lot of village land. Longer term implications for local food security are also still questionable. The OM and LMP models offer much less employment, and only limited supplementary income to poor smallholder farmers (Loos, 2008; Mitchell, 2008b). On the other hand, their impact on food security is expected to be minimal, and investors do not acquire land. The LMP schemes are expected to have the best potential social results, because they are designed to combine benefits for local growers with benefits for local energy users.

The overall balance of all the emerging pro's and con's associated with the different business models have the effect of putting the Jatropha plantation model under a lot of pressure – and the same holds for the recently started palm oil and sugar cane plantations. The first company to succumb to the *selection pressure* is a Swedish ethanol producer from sugar cane, called SEKAB. SEKAB received a great deal of adverse publicity in the Tanzanian press and on environmental blog sites related to its water use, its adverse impacts on the valuable local ecosystem and its dubious social effects (a good example is Madoffe et al., 2009). When the news reached the Swedish parliament and the Swedish public, SEKAB found it impossible to raise the additional funds it needed to make its plantations operational. It announced its withdrawal from Tanzania in January 2009. A second victim in the making is the Dutch Kilwa-based Jatropha producer Bioshape that had set its sights on 80,000 ha of 'degraded Miombo' that turned out to include substantial sections of valuable coastal forest according to the above-mentioned investigation by the WWF (WWF-Tanzania Programme Office, 2009). One of the investors in the company got cold feet and withdrew, leaving the firm with an acute cash flow problem. This company has not withdrawn from Tanzania, but it will be forced to undergo a new start and re-orient its operations.

Another aspect of sustainability-related learning that puts special pressure on the plantation investors concerns the formation and implementation of rules, regulations and standards. Within Tanzania, this issue came to the fore after the National Biofuel Taskforce – constituted by the government in 2006, but initially not quick-acting – finally came with its first results in August 2008 in the form of a Draft National Biofuel Guideline. The task force includes a representative selection of industry stakeholders, who debated and helped to set the definition of national standards for the quality of biodiesel and bioethanol (now completed,

with the help of the one firm with a laboratory), and how the government should enforce these standards (still ongoing). A need for clear rules about taxes on Jatropha biofuels was also voiced during the consultation process. But perhaps the most important issue tackled by the Taskforce has been the formulation of guidelines on respecting biodiversity, ensuring food security and preventing exploitation of villagers, e.g. in the form of rules on how to acquire land. A revised/improved guideline was issued in November 2008 which has since been passed by parliament. However, in the fall of 2009, the guideline had still not approved by the Cabinet. This has attracted severe criticism from the local media (Mngazija, *Daily News*, 12 Oct 2009; Kandoya, *Daily News*, 4 Oct, 2009). Even villagers had become so politically aware by this time that they refused to sign a recent land lease contract with a major investor Sun Biofuels, for its expanding plantations in Kisarawe district (Lugungulo, *Daily News*, 12 October 2009).

Worse than the pressures from within the Tanzanian system are those emerging with respect to international norms and standards currently under development, such as the Dutch NEN norm (currently in the trial stage), the GBEP GHG guidelines (GBEP, 2009) and the EU sustainability directives (McGregor, 2008). For the actors targeting international markets, learning had to begin about how to adjust their practices to these new standards. The standardisation and certification efforts are clearly linked to *landscape pressures:* negotiations are underway to create a successor treaty to Kyoto, which will be enacted when Kyoto ends in 2012, leading up to a major climate summit in Copenhagen to be held in December 2009. In connection with this development, worldwide efforts to define truly sustainable biofuels are being stepped up (see, e.g.,Tilman, et al., 2009). The formation and introduction of trade standards and certification is widely been seen as a suitable and necessary instrument for market regulation and promotion of sustainable practices by investors: the idea is that they can only earn carbon credits en market access in major western markets when they are able to prove that they meet certain sustainability requirements in the social and environmental sphere.

The third niche process, *formation and alignment of stakeholder expectations*, suggests that the sector is still very much in a flux. No dominant design is being foreseen yet, although the stakeholders observe that the OM has achieved the most stable situation in respect of supply and demand. The OM model is also expected to top the list in terms of market size and surface area in future years (Roks and van Vlimmeren, 2009, p. 64). However, the logistics, extension, and certification requirements of this model will become highly complex and costly when OM companies grow large, encompassing thousands or even tens of thousands of small contract farmers. That is why some investors are beginning to consider moving to hybrid business models, comprising a core plantation supported by a sizeable outgrower system. Other ideas include hiving off all the labour-intensive training, extension, standards monitoring and seeds collection activities into a separate non-profit foundation that may qualify for carbon credit funding and can attract socially ethical investors who cannot involve themselves as co-owners in a commercial entity. This could be a way to cover the structurally high costs of working with smallholders (van Eijck, 2009; van Eck, 2009).

Another major expectation is that by-products must be used for the achievement of economic profitability; and that in addition, seed yields can and must also be increased through improved crop management, better seed varieties, etc. Actors generally expect that the financial feasibility of Jatropha projects can and should still be improved strongly for the sector to become economically sustainable in the longer term. It is this perspective that is likely to drive some convergence between the dominant LP and OM models. For the OM businesses this will involve some sacrifices in terms of social and environmental sustainability, whereas the LP companies could improve their performance on these scores to some extent.

However, it is still an open question to what extent an acceptable balance between the three PPP-sustainability elements will be achieved in this way. First, it remains to be seen if the sector will ever get the opportunity to develop this far in the first place. In October 2009, the *East African* newspaper reported that the Tanzanian government was finally giving in to the public pressure by suspending all new investments and acquisition of new lands by investors already in the country, until it had reviewed the selection criteria for each investment and drawn up clear policies and procedures. This followed a report in the same newspaper a few days earlier, in which an academic from Sokoine University of Agriculture accused the government of treating the biofuels sector as a 'bottomless pit' at the expense of local farmers after it had emerged that 5000 rice farmers were being evicted to pave the way for plantations (Mande, 5 October 2009). In this latest development, then, we recognize the question mark indicating the undefined end stage in Greiner's model.

6. Conclusions

From this review about the development of the Jatropha biofuels sector in Tanzania we can conclude that the sector has evolved from an enbryonic state in early 2005 to a sizeable sectoral system of innovation and production in late 2008/early 2009. This in itself is a remarkable achievement. Our analysis with the multilevel framework of SNM also provides good insights why the sector developed so quickly. Notably, there were a number of drivers in the landscape, such as temporary high energy prices, mandatory blending requirements, and subsidies, that gave rise to major incentives for investors.

At the same time, the fast pace of investment has its clear downsides. Most investors piled into the country in a great rush, without much regard to possible longer-term effects of an as yet unknown wild crop. This bandwagon effect is at least in part responsible for the major social and the environmental sustainability problems that soon began to emerge. Many investors did not take time to start experimenting on a small scale, so that the puncturing of the hype of Jatropha as a reliable and viable oil crop for marginal soils gave many large investors a particularly hard hit from which some may not recover. Added to this were major landscape instabilities that led to an unprecedented spike in worldwide food prices, igniting a worldwide food versus fuel debate.

As a result, the sector is still highly unstable and its future is uncertain. Whilst economic viability is still not assured, and much further experimentation and learning is required to raise yields and efficiency, the general public and many interest groups – both in Tanzania and abroad – are unlikely to have enough patience to wait for these outcomes because of their urgent concerns over food security, adverse ecological impacts and socio-economic marginalisation of vulnerable groups. In that sense, our analysis confirms Greiner's idea of an open-ended process which is driven by its own internal dynamics without being pulled by a defined end state, and which does not follow a strict sequence of prescribed evolutionary stages.

Having said this, we were unable to explore the suitability of Greiner's model to the full in our analysis, because of the very recent emergence of the industry. Our timeline covers just four years and a few stages, including only one stage of contestation and conflict, which is still intensifying and has not reached any acceptable compromise at the time of writing. Yet we are convinced that a combination of two evolutionary drivers of change, consisting of gradual evolutionary variation and selection and a more discontinuous process of conflict represents a significant advance on earlier studies on innovation systems, especially where it concerns sectors that generate radically new technologies such as biofuels and other renewables, nanotechnology applications, genetic engineering for health and agriculture, and so on. The development of these sectors raise many contentious issues that are relevant to lots

of different stakeholders, whether they live close to the implementation scene or thousands of miles away. In that sense, it is hard to separate the influencing factors that drive the sector into "local" and "global". Stakeholders near and far strike up alliances, for instance through research collaborations, financing, trade linkages, and so on, and it is impossible to determine who is influencing whom. The local-global interface is likely to be an intricate two-way process, although further field research on this issue could shed more light on the causalities and the drivers.

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