

Prospects for Jatropha Biofuels in Developing Countries: An analysis for Tanzania with Strategic Niche Management

Janske van Eijck
Project Leader Biofuels, Diligent Tanzania

and

Henny Romijn
Eindhoven Centre for Innovation Studies



ABSTRACT

The paper reports on recent research in Tanzania about the scope for developing biofuels from an oil-seed bearing plant called *Jatropha Curcas Linnaeus*. The plant is widely seen to have potential to help combat the greenhouse effect, help to stop local soil erosion, create additional income for the rural poor, and provide a major source of energy both locally and internationally. The oil can be used in diesel engines, oil lamps and cooking stoves, and as a basic component in soap-making. The seedcake can be used for biogas production and as fertiliser. Our principal analytic tool is Strategic Niche Management (SNM), a recently developed approach rooted in evolutionary innovation theory. We analyse how the scope for an energy transition is influenced by factors at three societal levels distinguished in SNM, namely: the overarching 'landscape'; the sectoral setting or 'regime'; and the 'niche' level where the innovation develops and diffuses. Valuable niche processes were found in a few areas, especially in cultivation, but there are still many obstacles in Tanzania's prevailing energy regime. The development of *Jatropha* biofuels is still in an early phase. The SNM analysis yields several policy recommendations. Methodological issues arising from the use of SNM are discussed as well.

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1. Introduction

Global energy supply is currently mainly based on fossil fuels, which have many disadvantages. It is now widely agreed that more sustainable alternative energy sources will need to be developed in the not so distant future. One potentially promising option consists of biofuels, since these are derived from biomass, have a closed carbon-cycle and do not contribute to the greenhouse effect. The biomass necessary for the production of biofuels can be derived from several sources. Oil-producing crops are prominent among these.

Due to relatively faster crop growth in the tropics, as well as the substantial land requirements for large-scale production, developing countries could potentially play a substantial role in the cultivation of such crops. Moreover, they could yield major potential economic and environmental benefits for these countries. Notably, they could help to combat soil erosion, create additional income for the rural poor, and alleviate countries' balance of payments constraints by lessening oil import dependency or even by yielding export revenue. A gradual transition of the dominant energy regime in these countries from fossil fuels towards biofuels could thus have many advantages.

Researchers at Eindhoven University of Technology in the Netherlands recently have been exploring the potential of biofuels in Tanzania. Current initial activities have been directed towards the use of *Jatropha curcas Linnaeus* (henceforth abbreviated as *Jatropha*), an indigenous plant which requires little water and few nutrients and has a relatively high oil yield. *Jatropha* grows wild throughout Africa. Many developing countries in Asia and Latin America are known to have similar oil crops (e.g., *Pongamia* in India). The research being undertaken for Tanzania thus promises to generate important lessons for other developing countries as well.

This paper reports on some important recent results from the *Jatropha* research in Tanzania. The main questions addressed in the paper are: To what extent does Tanzania have potential to embark successfully on a transition towards a *Jatropha*-based energy regime, what has been its progress in that direction so far, and what are the major obstacles encountered on the path?

In addition, the paper aims to make a methodological contribution. The big potential for generating sustainable biofuels in developing countries has begun to attract attention from policy-makers and researchers only very recently. Hence, there is still a dearth of suitable robust research instruments for studying the issues involved. By applying an experimental methodology in the Tanzanian research, we are able to generate some lessons and suggestions on how energy transition processes could be studied in developing countries more generally.

Our approach, Strategic Niche Management (SNM), is rooted in evolutionary economics.¹ SNM has been designed specifically to study the introduction of radically new sustainable technologies in society.² Essentially, the SNM approach posits that a successful transition process based on more sustainable technologies encompasses a co-evolution of technology and societal factors such as culture, institutions, consumption patterns and preferences, economic regulation, and political governance systems. SNM comes with a set of concepts with which one can systematically document the initial activities and processes that should eventually lead to the adoption and broad diffusion of sustainable new

¹ Important SNM publications are: Kemp et al. (1998), Kemp et al. (2001), Elzen et al. (2004), Weber et al. (1999), Hoogma et al. (2002), and Raven (2005).

² We follow the concept of sustainability used in the SNM literature, which is derived from the Brundtland Commission Report of 1987, namely: development that meets the needs of the present without compromising the ability of future generations to meet their needs.

technologies in society, and with which one takes stock of important stimulating and constraining factors in that process.

Our use of SNM is somewhat experimental in the sense that the method was developed for the study of transitions in technologically advanced high-income countries. To our knowledge, ours is the first study to apply the method in an economically and technologically less-developed setting. Thus, our research serves as a first test of the suitability of SNM in a developing-country context.

The research on which this paper is based involved substantial fieldwork in different parts of Tanzania during March-June 2005.³ Field data about all the key concepts used in SNM were gathered through interviews with all important actors involved in *Jatropha*-related activities. Existing literature was used as a secondary source of information.

The SNM approach is outlined in section 2. A brief introduction to *Jatropha* and its applications is given in section 3. The analysis is contained in section 4, and section 5 contains the conclusions and some methodological reflections.

2. The Strategic Niche Management Approach

Central to SNM is the notion that the introduction of radical innovations that are socially, economically and environmentally sustainable is a complex and protracted process with a high likelihood of failure even if the new technologies appear to be promising. This is explained by the fact that technologies are always part of a much broader system – a *socio-technological regime*. This is defined as "... the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures" (Hoogma et al., 2002, p. 19). The regime is thus the dominant or 'normal' way of doing things.

In turn, the regime is embedded in a wider context – the *landscape*, which consists of material and immaterial societal factors. Most of these, for example, demographics, political culture, lifestyles and the economic system can change only slowly over time, (Raven, 2005, pp. 31-2). However, sudden or unexpected (often 'global') events also emanate from the landscape level. Examples are wars, nuclear disasters like Chernobyl, and the oil crisis of 1973.

Mature, well-established technologies form an integral part of the dominant regime and fit into the overarching landscape. This is a result of a long process of mutual adjustment and adaptation of technological and societal factors, in which they gradually get attuned to one another. Innovations with radically new features, especially those that aim to improve environmental and social equity-related sustainability, do not rub well with extant socio-technical regime characteristics that reinforce the importance of short-term economic benefit alone.

Simultaneous adaptations in all major parameters of the regime are thus required for such technologies to be successfully developed, introduced to the market and adopted widely. However, there is a limit to the adaptability of the regime itself. Regime change is conditioned by landscape factors. This can result in powerful inertia that can prevent new sustainable technologies from gaining ground, let alone from unseating incumbent ones.

In order to address these problems, the SNM approach advocates the creation of *niches*: temporarily protected spaces in which new technologies can incubate and become viable by means of gradual experimentation and learning by networks of actors. Important parties in these networks include manufacturers,

³ See: van Eijck (2006) for a comprehensive report on the research.

users, researchers, civil society organisations, governmental organisations and possibly others, depending on the specific circumstances.

This multi-level perspective – landscape, regime, and niche – is adopted in SNM to analyse the potential of emerging transition processes and their dynamics. By identifying the major characteristics and developments at each level and tracing their effects to the other levels, one gains insight into the constellation of major forces that push for, and hold back, the development of new viable sustainable technologies through niche formation:

- Developments at the landscape level are external to the regime (and thus also to underlying niches), but they do influence them, especially through their effect on regime stability. Scope for change in a regime may occur when important landscape conditions change over time, and when the effects of these changes begin to manifest themselves and start to have an impact on people's lives. Think, for example, of developments like rising energy prices due to political instabilities and structural increases in energy demand from big countries like China and India; and mounting concerns over rising global temperatures and increasing instabilities in weather patterns.
- Such changes feed uncertainty, and tensions begin to appear between the main components of the extant regime. People also begin to perceive that problems are no longer solvable within the current regime itself.
- The extent to which upstart technologies are able to capitalise on the possibilities offered by this kind of situation is determined by three processes at niche level, where the experiments with the new technologies take place. These are: 'network formation', 'learning' and 'stabilisation and convergence of expectations'. High-quality niche processes are characterised by a wide and interconnected actor network, by extensive experimentation and learning on several subjects – not merely about the new technology itself, but also about user acceptance, economic aspects, required infrastructure, etc., and by expectations that are gradually stabilizing and becoming more specific.
- In the initial stage of niche formation, experiments with a new technology tend to be confined to a few isolated activities, and the principal aim of the learning is to arrive at a technically promising design. Once this has been achieved, a 'technological niche' is said to have been created.
- When the niche processes continue to function well beyond this point, experiments begin to be joined up, learning becomes more widely shared, and its scope expands to include major societal factors. Gaining social and cultural acceptance, institutionalisation, and achieving economic viability are of key importance in the context of a regime that will still be rather unfavourable for emerging alternatives to its incumbent technologies. These broader societal adaptation and learning processes in turn induce and guide further improvement of the technology itself, which enhances its societal fitness. When this stage is completed successfully, a 'market niche' will have been created. This is the starting point for successful wider commercialisation and diffusion processes that may ultimately culminate in a change of the regime itself (i.e., a transition).

With this framework, we proceed to analyze the major recent developments with respect to *Jatropha* in Tanzania. After a brief introduction in section 3 to *Jatropha* and its possible uses, we explore the landscape, regime and niche dynamics in section 4. The information in section 3 and the landscape and regime analysis in section 4 are largely based on secondary sources supplemented by

information from some key informants. The analysis of the niche dynamics is based on systematic interviews with all the major network actors.

3. Jatropha and its Applications

The Jatropha plant is easy to establish and drought resistant. It can grow up to 8 metres high, and is not browsed by animals. Therefore it has been traditionally used as a hedge. It can live up to 50 years and can produce seeds up to three times per annum (Chachage, 2003). Figure 1 shows the main stages in the Jatropha production chain, from seed to end product. There are many possible uses for Jatropha. The figure only shows those applications that were actually in use or under active exploration in Tanzania at the time of our research in mid 2005.

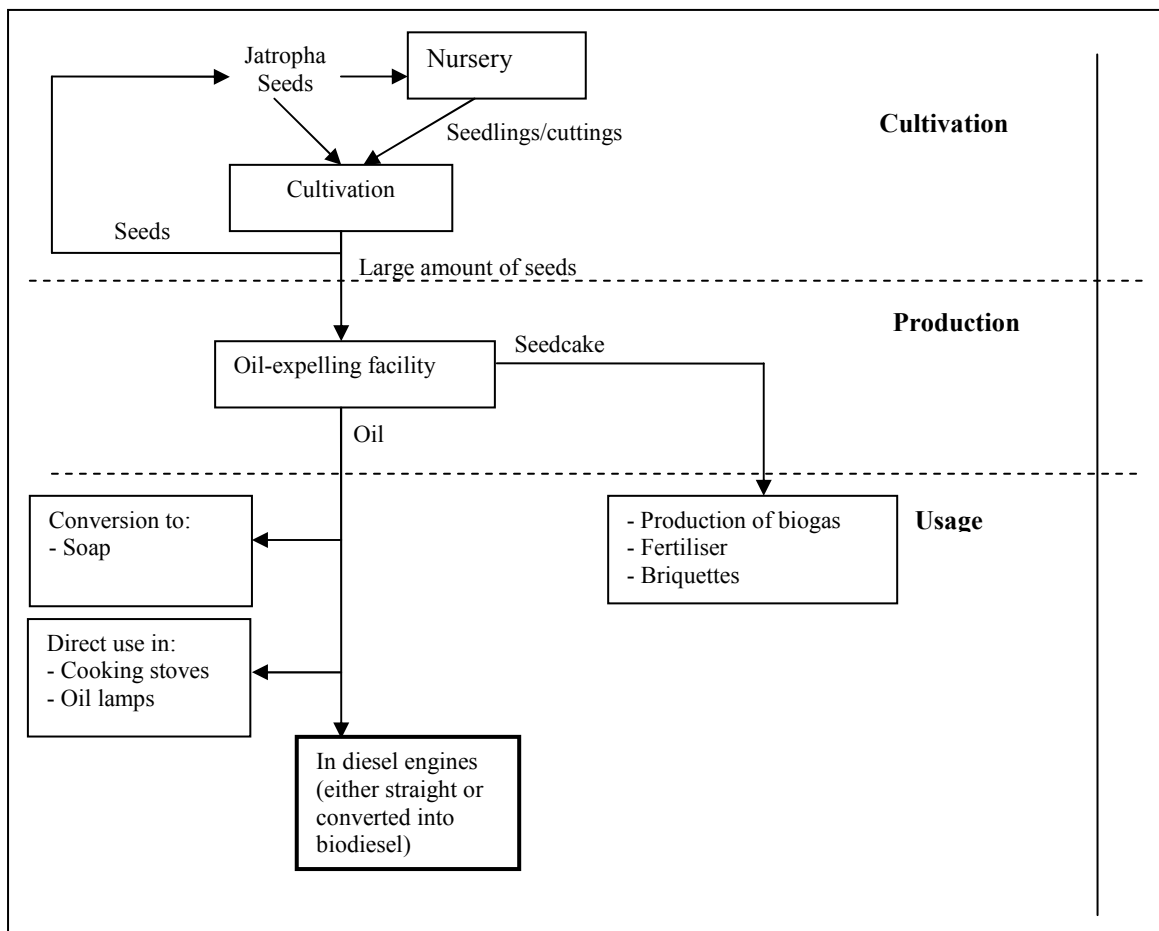


Figure 1: Jatropha production chain

Under *cultivation* come the activities pertaining to the growing of the Jatropha plant and the harvesting of the seeds. Jatropha is grown in nurseries from seeds. In Tanzania this is done by some women’s groups. But villagers also take cuttings and plant them. The cuttings take less time to establish, but the seed-grown Jatropha bushes are stronger because they develop a tap root.

The seed yields reported for different countries and regions range from 0.1 to 15 t/ha/y (Heller, 1996; Jones and Miller, 1993). Apparently the yield depends on a range of factors such as water, soil conditions, altitude, sun and temperature.

No systematic research seems to have been conducted yet to determine the influence of these factors and their interactions. People knowledgeable about the Tanzanian situation expect that the crop can yield even up to 25 t/ha/y in good locations.

Harvesting of the seeds takes place during the dry season, normally a quiet period for agricultural labour. The seeds contain about 30% oil. The oil contains a toxic substance, curcasin, which is a strong purgative (Chachage, 2003). The seedcake which is left after pressing is relatively rich in nitrogen.

The *production* (or processing) stage involves pressing of seeds to expel the oil, leaving seedcake. In Tanzania, oil extraction is done by means of small manual ram-presses and power-operated screw-presses. The extraction rate of the ram-press is quite low; the left-over seedcake still contains some oil. About 5 kg of seed is needed for 1 litre of oil (Henning, 2004). The capacity is about 1.5 litres per hour. The ram-press is only suitable for the processing of small quantities, e.g. for lamp oil for local village use, or for small-scale soap making.

The extraction rate of power-operated screw-presses is higher, and the cake residue is much dryer. The Sayari oil expeller, of German design, has a capacity of about 20 l/hour (60 kg/hour) and can extract 1 litre of oil from 3 kg of seeds. It is manufactured in Tanzania itself by an NGO in Morogoro. A Chinese screw-press capable of processing 150 kg seed per hour was installed by another NGO in 2005.

Storage of the seeds is important for continuous press operation, since the availability of the *Jatropha* seeds is seasonal. Two options are bulk storage and bag-storage. Only bag-storage is practiced in Tanzania currently. Storehouses should be well ventilated in order to prevent self-ignition. The location plays an important role, since it has a considerable impact on transport and storage costs (UNIDO, 1983).

At the stage of *usage*, the oil and the seedcake are consumed or further processed to generate final products. A major end-use from the point of view of an emergent energy transition is fuel for diesel-powered vehicles and electric generators. Since the viscosity of *Jatropha* oil is much higher than that of conventional diesel fuel, there are problems with using pure *Jatropha* oil in engines, despite claims that it is possible for many engine types (Heller, 1996). Problems encountered include premature wear of parts and clogging, and inability to start, especially in cool weather.⁴ Search for adequate solutions is ongoing. Options include adaptation of the oil by mixing with methanol and caustic soda (Research Group IP, 2002); fitting vehicles with dual fuel tank systems; performing engine adaptations; and blending *Jatropha* with conventional diesel, which reportedly works well up to a proportion of 40-50 per cent *Jatropha* (Pramanik, 2002).

The seedcake is also potentially valuable. It can be used to produce biogas for cooking, as fertiliser, or - in briquette form - as cooking fuel. There are other applications for the oil as well, including *Jatropha*-based soap, use in oil lamps, and use in cooking stoves. Chachage (2003) identifies the current activities in Tanzania based on *Jatropha* oil as soap-making on a limited scale and use in oil lamps. The other applications listed in Figure 1 have been started only within the past few years.

Not all the *Jatropha* applications are directly energy-related (notably soap and fertiliser). Nevertheless, niche processes within those application areas could also aid a *Jatropha*-based energy transition process by broadening and widening the

⁴ For example, as shown by research done by TIRDO in Dar es Salaam.

networking and learning processes and by capturing production complementarities.

The various activities in Figure 1 are linked to each other in different ways. Some are so strongly complementary that one activity can barely be expected to come off the ground without a simultaneous development of another. This is so for cultivation and processing, and again for processing and any significant type of end-use. The simultaneous initiation of experiments at each of the three stages in the chain would therefore seem to be vital for the emergence of a viable *Jatropha* chain as a whole.

Relations of a more competitive nature are likely to prevail between some of the end-uses. For example, if utilization of the oil in diesel engines takes off, it may well begin to compete with the already existing utilisation of the oil for small-scale soap production by poor women.

Broadly speaking, then, an effective initial constellation of experiments that could pave the way for a broad transition based on *Jatropha* would need to exhibit the following features:

- Strong experimentation in each of the three stages in the production chain, and growing interconnections between the activities and actors in these stages;
- Transport-related experiments that play at least some part in the end-use stage; it is simply impossible to conceive how a *Jatropha*-based energy regime can come about without the transport sector being weaned of its fossil fuel dependency.
- Substantial experiments in cooking and lighting, the essential domestic energy services.
- Some experiments with the seedcake.
- Finally, in view of the equity dimension of sustainability, this configuration should not cause employment loss for the poor, but rather generate new opportunities for remunerative employment for them.

The above considerations broadly determine the relative emphasis that will be devoted to the different *Jatropha*-related experiments discussed below.

4. Towards a *Jatropha*-based Energy Transition? An Assessment with Strategic Niche Management

Landscape influences

A number of major trends at landscape level influence the scope for developing a *Jatropha*-based energy supply system. Worldwide trends as well as major Tanzania-specific factors play a role.

Among the *worldwide trends*, the oil price has been a major factor. It has increased sharply during the last years and is expected to remain high or to rise even further in the near future. In 2003 the benchmark Brent crude was under USD 25 per barrel, rising to over USD 60 per barrel in 2005. It is expected to average USD 64 per barrel in 2006.⁵ Closely related to this point, dependence on countries in the (unstable) Middle East is increasingly considered to be a risk. This is strengthening the movement towards development of sustainable energy sources.

⁵ <http://www.eia.doe.gov/emeu/steo/pub/contents.html>, accessed March 2006.

Then there is the issue of increased environmental awareness due to mounting evidence of global warming. Policies to promote renewables have mushroomed worldwide over the past few years. At least 43 countries, including 10 developing ones, now have some type of renewable energy promotion policy (Renewable Energy Policy Network, 2005). Just after this research was completed, Tanzania set up a national commission to develop a renewables policy.

Although unconventional renewables accounted for only 2% of global primary energy in 2004 (Renewable Energy Policy Network, 2005), more and more attention is being directed towards them. Worldwide production of biofuels exceeded 31 billion litres of bio-ethanol and 2.2 billions litres biodiesel in 2004. This was 3% of the worldwide gasoline consumption of 1,200 billion litres. About 900,000 people are active in this sector worldwide. The biodiesel-sector grew by 25% per annum between 2000 and 2004 (Renewable Energy Policy Network, 2005). Many other sources of renewable energy are also being stimulated.

Finally, after a prolonged period of neglect, there is renewed interest in agriculture on the part of the World Bank and other major development organisations. Agricultural development is now being viewed as crucial for achieving the Millennium Development Goals, especially for developing or low-income countries (World Bank, 2006).

Among the *Tanzania-specific landscape factors* Tanzania's low level of development is a prominent one. Tanzania's GDP per capita was a mere USD 700 in 2004. Of the country's 35.5 million people,⁶ 36% live below the poverty line.⁷ Agriculture provides about half of GDP and employs over 80% of Tanzania's workforce.⁸ Over 77% of the population live in rural areas,⁹ where adequate energy services are lacking. Nationally, 97% of energy consumption derives from biomass, mainly fuelwood. This creates serious problems, including soil erosion, deforestation and respiratory ailments.

Another poverty-related aspect is the scarcity of foreign exchange. Tanzania imports all its diesel fuel. The import of over 465 million litres of diesel in 2002 had a value of over TZS 465 billion (USD 423 million) at a pump price of TZS 1000 (USD 0.90). This was 4.7% of Tanzania's GDP for that year, a heavy burden on the balance of payments. Growing *Jatropha* could alleviate this problem substantially, while at the same time boosting growth. In order to produce 465 million litres of *Jatropha* oil, the country would need 69,750 to 139,500 ha of land (with an assumed *Jatropha* yield of 10-20 tonnes/ha). The country's total surface area is about 90 million hectares, of which 85 million ha is not arable or under permanent crops. This leaves 5 million ha for *Jatropha* cultivation, which would be ample for self-sufficiency.

Tanzania's poor infrastructure can also work to the advantage of a *Jatropha*-based energy regime. Its roads are hardly sufficient for lorry transport, especially in very remote areas. Electricity infrastructure is also very poor. Most electricity is generated in the south (through hydro power), and the power lines are not particularly reliable. This results in regular power shutdowns. *Jatropha* biofuel can be produced in a dispersed manner including in remote areas, creating a decentralised energy source which is independent of the current infrastructure.¹⁰

Despite these advantages, one factor limits the emergence of *Jatropha*-based energy system, namely the Tanzanian government. The country's current

⁶ July 2005 est. World Fact Book, <http://www.cia.gov/cia/publications/factbook/geos/tz.html>

⁷ 2002 est. World Fact Book, <http://www.cia.gov/cia/publications/factbook/geos/tz.html>

⁸ 2002 est. World Fact Book, <http://www.cia.gov/cia/publications/factbook/geos/tz.html>

⁹ Data from October 2004, Tanzania National Profile Data in Brief, National Bureau of Statistics.

¹⁰ On the other hand, if *Jatropha* seed or biofuel were also to be exported to other countries, road infrastructure and port facilities would be important.

National Energy Policy (at the time of the research, in 2005) merely affirms the desirability “to promote development and utilisation of appropriate new and renewable sources of energy”,¹¹ without specifically mentioning biofuels. Activities to promote biofuels are still in their infancy. In 2005, the government began to set up a Rural Energy Agency (REA) that will serve as the responsible institution for rural energy development. REA will facilitate development of projects that will ultimately be owned and implemented by the private sector, NGOs and community-based organisations. A Rural Energy Fund (REF) will also be established, to provide capital subsidies in order to reduce the risk to project developers. These are positive developments in principle, but standards of governance will also need to improve for these new institutions to work. Large *Jatropha* plantation farmers interviewed for this research reported major corruption problems in their dealings with the government. One noted that it is crucial to work with someone who knows his way around at the government level.

Regime dynamics

From the perspective of SNM, the focus of this section should be on Tanzania’s prevailing energy regime because this affects the possibilities for using *Jatropha* as an energy source, and we are ultimately interested in uncovering the potential for a shift in this particular regime. However, there are other regimes whose features also influence the potential for a *Jatropha*-based transition in the country. In particular, *Jatropha* cultivation is influenced by the agricultural regime, oil production is affected by the vegetable oil regime, and investment possibilities in *Jatropha*-related activities are influenced by the financial regime. We first discuss the energy regime, and then go on to highlight key characteristics of the other three regimes insofar as they are relevant to our investigation.

Some aspects of Tanzania’s extant energy regime have already been introduced. Of the total energy consumption in the country, 97% is derived from biomass,¹² mainly fuelwood and charcoal. A smaller percentage is derived from agricultural and forestry waste and dung. Fewer than 8% of households in Tanzania are connected to the electricity grid.

Table 1 shows the projected consumption of various fuels in Tanzania up to 2020. The demand for energy is expected to rise markedly, so the potential for biofuels like *Jatropha* is quite high.

Fuel Type	1990	2000	2010	2020
Oil products	729.4	1,028.3	1,655.7	2,707.5
Coal	82.3	134.0	206.0	317.0
Wood fuel*	9,000.0	11,862.0	16,420.0	22,729.6
Natural gas**	0.0	153.0	226.4	226.4

Table 1: Projected consumption of various fuels in Tanzania, in '000 MT

Notes:

* Units in tonnes of oil equivalent

** Units in millions of cubic metres

Source: Meena and Mwandosya (1996)

¹¹ Justina P. Uisso, ‘Government Policy on Rural Energy Development’, Ministry of Energy and Minerals, n.d., mimeo.

¹² Data from October 2004, ‘Tanzania National Profile Data in Brief’, National Bureau of Statistics.

Several renewable energy technologies that avoid the problems related to the use of traditional energy sources are available to help meet this demand. The main projects being promoted are biogas production for cooking, improved cooking stoves and kilns, solar thermal applications for water heating and cooking, and solar and wind technologies. However, few serious attempts have been made to utilise wind and solar energy. Schemes implemented to date have suffered from a number of problems, including poor payment records; low awareness of, and lack of confidence in these technologies; high investment requirements in relation to low purchasing power of target groups; weak institutional framework and infrastructure for effective promotion and support; and lack of appropriate credit mechanisms.¹³

While some of these problems could also be expected to manifest themselves in programmes aiming at utilisation of biofuels like Jatropha, these fuels seem to have certain advantages over solar and wind power. Initial investment requirements could be quite low, since many Jatropha activities can be started on a small scale. This reduces the need for substantial loans. Another advantage is versatility. In principle, Jatropha oil can be used for all the main purposes for which energy is needed, i.e. for transport, electricity generation, direct lighting, and cooking.

Tanzania's current transport regime is entirely based on imported fossil fuels. A change-over to Jatropha would involve some adaptations. If the pure oil were to be used, diesel engines would have to be modified (for example, by installing a two-tank system or changing fuel nozzles). The additional cost for vehicle owners would create considerable resistance. The technical knowledge required for the modifications is not widespread either.

When Jatropha oil is converted into biodiesel, vehicles require almost no modification (only the fuel hose needs to be resistant to biodiesel). The University of Dar es Salaam and Eindhoven University of Technology have begun research on the effects of biodiesel on vehicle engines, but this is still in its infancy. Jatropha oil could also be blended with normal diesel fuel and sold at gasoline stations. People would not even know they were driving on biodiesel, so resistance would be low. Blending seems to be the best option in the near future.

Still, with the current price constellation, even this option is not attractive in areas where fossil diesel is widely and easily available. The diesel pump price in Dar es Salaam in July 2005 was TZS 1,100 per litre, compared with TZS 2000 per litre of Jatropha oil. Only a small minority of consumers with high awareness of environmental problems might be willing and able to pay, say, 30 to 50% more for Jatropha-blended diesel than for conventional diesel. Fossil fuel prices would have to rise much more for the biofuel alternative to become attractive for the majority of diesel users in a city like Dar es Salaam. However, the situation would be different in more remote areas, where the diesel price is higher because of transportation costs.

The electricity sub-sector contributes only about 0.6% of the country's total energy consumption.¹⁴ Petroleum, hydropower and coal are the major commercial energy sources in Tanzania. Two-thirds of the installed capacity is hydro powered. Rural areas often have no electricity. Even in the larger cities, power shutdowns are very frequent and factories and households have to use diesel generators as a backup source. The room for Jatropha-based niches in this field is quite large in remote areas, where the diesel price is high. However, the maintenance of the generating equipment does require some technical skills, while working out an

¹³ <http://www.ared.org/country/tanzania/tanzania.pdf>, accessed February 2006.

¹⁴ <http://www.ared.org/country/tanzania/tanzania.pdf> (Tanzania Country Assessment 2001) accessed February 2006.

equitable system of sharing in the costs and benefits of electrification can also be problematic in local communities.

Kerosene is the light source of choice for more than 90% of Tanzania's low-income households; in rural areas, the figure is almost 100%.¹⁵ Kerosene is imported by private oil companies and sold at gasoline stations. This facilitates its use by low-income urban and rural households.¹⁶ Kerosene imports keep rising. In 1998, Tanzania imported 122,535,993 litres; in 2002 this had risen to 154,702,808 litres. The price also keeps rising, from TZS 426 per litre in 2002 to TZS 505 in 2003¹⁷ and TZS 850-980 in 2005.¹⁸ However, at TZS 2000 per litre the Jatropha-based alternative is still far too expensive. Moreover, Jatropha needs an oil lamp that is specially made for it. These oil lamps, made from Africafé tincans, cost TZS 1,700 apiece.

The dominant energy source for cooking is fuelwood. In 2000, households in sub-Saharan Africa consumed nearly 470 million tonnes of wood and charcoal. This is far more than on any other continent. Wood or crop residues are the primary source of energy for 94% of rural households and 41% of urban households in the region (Renewable Energy Policy Network, 2005).

Several NGOs are actively spreading more efficient cooking stoves, some of them for use with Jatropha. TaTEDO, for example, has provided several households with improved stoves. Kakute, another NGO, has been providing several groups with a biogas system that uses Jatropha seedcake. This indicates that some alternative energy sources are available for cooking purposes. However, our field observations indicate that they are not popular. The biogas system was found to be used only when conventional sources were unavailable (e.g., during the rainy season). Women interviewed for this research indicated that the biogas system increases cooking time, and they also expressed misgivings about possibly poisonous fumes. They do not attach much value to the positive health effects of decreased indoor smoke; only the NGOs recognise that as important. Another major factor is cost. A Jatropha cooking stove costs TZS 12,000-20,000¹⁹ and a biogas cooker costs TZS 10,000.²⁰ Fuelwood remains the cooking fuel of choice since it can be collected free. In conclusion, the dominant cooking regime is quite strong. Alternative systems have not been able to meet people's demands and priorities well enough.

In addition to analysing the conditions governing the attractiveness of different Jatropha uses, we also need to determine how attractive it would be for people to grow Jatropha, and to press the seeds. From our interviews with villagers it appears that cultivating Jatropha is not radically different from current practices in the agricultural regime. People are already used to planting a fence around their land to protect their crops from wild animals. Many households are also used to selling crops on the market: 59% of rural households in Tanzania sell food crops for onward processing (National Bureau of Statistics, 2000).

Farmers are also actively looking for new crops because of recent low prices of most existing crops. Table 2 compares the yield and income from some of Tanzania's main food crops and cash crops with those from Jatropha.

¹⁵ <http://www.hedon.info/goto.php/TanzaniaCountrySynthesis>, accessed July 2005.

¹⁶ Ibid.

¹⁷ <http://www.tanzania.go.tz/economicsurveyf.html>, accessed July 2005.

¹⁸ Price in Dar es Salaam on 28-7-2005 (at different petrol stations).

¹⁹ Information obtained from Green Garden Women's Group, KIDT.

²⁰ Information obtained from Monduli Women's Group.

Crop	Average yield (kg/hectare)	Average price (TZS)	Average revenue for one hectare (TZS)
Maize (region Arusha)	1220 ('94/'01)	136.70 (TZS/kg) (July'98-June'99)	166,774 (≈ €119)*
Wheat	1344 ('94/'01)	220 (TZS/kg) ('98)	295,680 (≈ € 211)
Sweet potatoes (Arusha region)	2085 ('94/'01)	100 TZS/kg ('97/'98)	208,500 (≈ € 150)
Bananas	2585 ('94-'01)	300 TZS/kg ('97/'98)	775,500 (≈ € 554)
Cassava	2219 (2431 for all regions, 94-01)	125 TZS/kg ('97/'98)	277,375 (≈ € 198)
Cashew nuts	Total production '01-'02: 122*1000 tonnes	375 TZS/kg ('93/'00)	
Sisal	Total production: 23.5 *1000 tonnes for '01-'02.		
Jatropha (seeds)**	10,000-20,000	80 TZS/kg	800,000- 1,600,000 (≈€571 - € 1,143)

Table 2: Yields, prices and revenues for selected crops in Tanzania

Notes:

* TZS 1400 = € 1 (May 2005)

**Assumptions: Jatropha yield between 4-8 kg/plant/year with about 2500 plants per hectare, and a sales price of TZS 80/kg seeds. Most Jatropha fields were in the Arusha region; the prices and yields for other crops are listed for that region only where data was available.

Sources:

Basic data, agricultural sector, Tanzania Ministry of Agriculture and Food Security.

<http://www.agriculture.go.tz/MAFS-Services/Statistics.htm> (chapters 1 and 2) and

http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/004/w9479e/w9479e00.htm

Table 2 indicates that cultivating Jatropha as a cash crop could be very profitable compared with growing traditional crops.

The main difference between cultivating Jatropha and other crops is that Jatropha is a multi-year crop that can be harvested only one to two years after planting. This requires more long-term thinking, unlike for crops that need to be replanted each season. Intercropping of Jatropha with other crops could help alleviate this problem. Moreover, Jatropha can also be grown on infertile uncultivated land, which means that it does not necessarily need to compete with food crops.

Currently there is no well-established market for Jatropha seeds. Only one NGO and one newly established commercial company buy seeds from villagers on a small scale in the Arusha and Engaruka regions. Their system of local collection points and buying at weekly markets is comparable to the current system of private business persons buying agricultural produce from farmers. However, collecting the seeds in this way will become unwieldy as the supply of Jatropha seeds increases, especially in view of poor roads and inadequate transport facilities. Large-scale commercial Jatropha oil production will most likely have to rely on more centrally located plantations, at least in addition to independent outgrowers.

The vegetable oil regime also is not an overriding constraint on the development of a Jatropha sector. Tanzania produces substantial quantities of oil-seeds for edible purposes and for industrial use. Edible oil-seeds are generated

from groundnuts, cashew and sunflower. An example of an industrial oil-seed is castor. It is not unusual in Tanzania for an oil facility to be owned by a local co-operative. Farmers take their seeds there and have them pressed for a fee. So, current practice is not very different from what would be required for the production of Jatropha oil. The only problem that needs to be confronted in this regime emanates from the fact that Jatropha is poisonous. Processing firms thus are unwilling to use the same equipment to press edible seeds and a poisonous seed. It might be necessary to develop new oil-expelling facilities that are specifically dedicated to pressing Jatropha seeds.

As far as the financial regime is concerned, it has to be said that financial considerations are all-important in decision making in poor countries like Tanzania. Any extra cost, for example, for cooking fuel, will not be accepted easily. Many people are risk averse. Especially in the rural areas, interest on loans is often quite high and loans are not given easily. However, conditions are improving slowly. There are experiments with group-based savings and credit schemes by micro-credit organisations such as FINCA, which avoid high overhead costs as charged by banks. One Jatropha-NGO is linked to a micro-credit facility, which has given loans to some farmers in Engaruka to the tune of TZS 50,000 - TZS 500,000. The year 2005 was declared 'the international year of microcredit',²¹ an indication of growing awareness and increasing initiatives in this field, both worldwide and in Tanzania.

In conclusion, the current energy regime presents the dominant obstacles for an emerging energy transition towards Jatropha. In spite of many favourable developments at landscape level, it seems that there still is only limited room for development of successful alternative energy applications based on Jatropha. Cost considerations are of overriding importance. At the current price of TZS 2000/l, people are unlikely to become enthusiastic about Jatropha biofuel, with the possible exception of people in remote communities where conventional energy sources are scarce and expensive. For adoption of applications like blended biodiesel for vehicles and electric generators to occur in urban areas, major changes in the tax structure in favour of biofuels would be needed until scale- and learning economies begin to kick in.

Recent developments at the niche level

We tried to identify all significant socio-technical experiments with Jatropha in Tanzania by talking to key informants. In total, 17 experiments were found, of which 16 were visited and one contacted through e-mail. In addition, seven organisations (of which three were actively executing projects), two companies, and two individuals were visited. Most experiments were situated in the Arusha and Kilimanjaro regions in the northeast. Other actors or projects were situated in Morogoro, Dar es Salaam and in Tunduru in the south. The total number of interviews was 28.

Each interview covered information about the three key niche-formation processes: actor network activities, people's learning processes, and the dynamics of their expectations. Considering the complexity of the processes and the experimental nature of the research, we confined ourselves to gathering qualitative information about these processes, but in addition we tried to obtain quantitative estimates about the costs and benefits of each major Jatropha-based activity, since financial profitability could be expected to have a major impact on people's expectations.

The *actor network* in the **cultivation stage** is expanding quite rapidly. More and more farmers are starting to plant Jatropha, expecting to make a

²¹ <http://www.yearofmicrocredit.org/>, accessed February 2006.

considerable profit. This is happening mainly because they are now able to sell their seeds to a multinational company that started operations in 2005. The company pays a guaranteed fixed price for several years, reducing the risk of a price fall. Declining and low prices for existing crops acted as an additional push factor. The actor network is quite diverse. There is participation from NGOs, private farmers, farmer groups, individual larger farmers, and private companies. Only research organisations had not been involved, but one was beginning to undertake research at the time of our research.

There are many *learning processes* in this part of the chain, mostly with regard to how *Jatropha* should be grown and managed (e.g. with respect to watering, intercropping, and pests) but also regarding user acceptance. There are also higher-order learning processes: some farmers have started to conduct systematic experiments for gathering specific bits of knowledge. These individuals are beginning to build learning routines ('learning to learn'). Much knowledge is still lacking, but it is becoming clearer where the gaps are, and how to fill them.

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

The profitability of *Jatropha* cultivation at the prices currently paid to cultivators is evident from Table 3, which displays the result of a cost-benefit analysis for five experiments (projects) about which we were able to collect detailed information. All figures are highly positive, except for those of the Brotherhood, a religious order. The (large) differences in the profit figures for the projects emanate from a range of factors, especially scale. Kikuletwa Farm is working with 200 hectares (494 acres), Mr. Manang's farm is working with 80 acres, while the Brotherhood has planted less than three acres.

Differences in the figures are also due to the necessity or otherwise of initial investments. Establishing a plantation entails investment and costs and the plants take some time to mature. However, the Engaruka villagers, for example, do not need to invest money to grow *Jatropha*. The plant is indigenous in their region, so they can pick seeds from wild plants and grow more *Jatropha* along their fields.

Another difference lies in the way a *Jatropha* plantation is managed. Kikuletwa Farm uses intercropping, avoiding extra costs for weeding and irrigation. In contrast, the Brotherhood has hired one full-time person for the *Jatropha* field, even though the labour requirement for their small area is minimal. They also incur some transport costs to get to the area where they grow the *Jatropha*. The data thus suggest that even if the current sales prices would be unsustainable in the longer run, all except very small growers operating under sub-optimal economic conditions could still make a good profit from *Jatropha*.

Project	Kikuletwa Farm	Brotherhood of Jesus the Good Shepherd	Farmer Ismael Manang	Engaruka Village	Monduli Women's Group
Size of plantation	200 ha (494 acres)	1 acre (3 acres after 2 years)	80 acres (33 ha)	300 bags/season, 60 kg per bag (2-4 acres)	10,000 seedlings
Investment costs for first 2 years	22,000,000 (\$20,000)	1,577,500 (≈\$1,430)	1,878,500 (≈\$1,700)	zero	minimal
Forecast of cash inflow/year after 5 years	318,850,000 to 398,850,000 (\$289,864 to \$362,591)	At max: 184,000 to 2,824,000 (\$167 to \$2,567) If they don't expand to 3 acres: (\$ -415 to \$ 385)	31,346,800 to 62,706,800 (\$28,497 to \$57,006)	2,880,000 (\$2,618)	500,000 to 1,000,000 (\$455 to \$909)
Net Present Value	511,000,745 to 644,660,146 (\$464,546 to \$586,055)	-2,405,343 to 878,294 (-\$2,187 to \$798)	50,486,760 to 102,881,245 (\$45,897 to \$93,528)	12,054,828 (\$10,959)	1,592,852 to 3,185,704 (\$1,448 to \$2,896)
Internal Rate of Return (in real terms)	315% to 359%	## to 26%	262% to 384%	-	-
Pay Back Period	between 2 and 3 years	>15 to 4/5 years (∞ to 7/8 years at 1 acre)	between 2 and 3 years	0	0

Table 3: Cost benefit analysis of selected projects

Prices are in TZS unless otherwise specified in the table (US\$ 1 = TZS 1100).

Notes and sources:

1. The calculations are made with an assumed yield of 4 to 10 kg of seeds per tree per year (based on information from the interviews) and roughly 2500 trees per hectare.
2. Seed output prices varied according across projects, from TZS 80 (paid by a private multinational company) to TZS 150 (paid by a local NGO). Our calculations are based on the actual reported sales price in each case.
3. The seedlings from Monduli Women's Group are sold for TZS 50-00/pc.
4. The calculations were conducted in constant prices. We used a real discount rate (r) of 9.8%, calculated with the formula $r=(1+i)/(1+p)-1$; in which p is the inflation rate, assumed to be 4.4%, and i is the average interest rate on medium- and long-term loans, which was 14.6% in 2003. Source of data: <http://www.tanzania.go.tz/economicsurvey1/2003/part1/financeinstitutions.htm>, accessed August 2005.
5. Project life span: 5 years
6. Seed yields on plantation (based on information from the interviews): zero in 1st and 2nd years, 50% in 3rd year, 75% in 4th year, 100% in 5th year. I.e., no income from *Jatropha* until year 3.
7. Data about Engaruka project derived from the village ward.

Although the financial performance of the smallest project in the table is way below that of the others, this project has a special significance. The Brothers are primarily interested in achieving energy self-sufficiency and have no commercial motives. Their small-scale *Jatropha* project more or less breaks even, so it is achieving their objective. This suggests that small-scale non-profit *Jatropha*-based energy systems in remote areas could indeed be viable.

The remaining barriers to the growing of *Jatropha* as a cash crop mainly have to do with lack of information by local villagers on specific aspects of the cultivation regime and their attitude towards risk, which is partly culturally determined. However, all these barriers seem to be surmountable through training and demonstrations. In sum, the niche processes all seem to be quite positive for the cultivation part of the chain.

The **oil pressing** part of the *Jatropha* chain shows a more mixed performance from an SNM point of view. With the involvement of a variety of actors, including NGOs, women's groups (press users), equipment producers and subcontractors, and even a foreign university, the *network* is quite good and dynamic. One drawback is that most of the contacts run through one particular NGO, which is also known to be rather selective in the information it wants to share. There are few lateral links.

According to the data furnished by our respondents, the *economics of oil pressing* would be highly promising. On the basis of an 8-hour workday and a 50% capacity utilization rate, we estimate an internal rate of return of 1247% for the ram-press, and 1387% for the Sayari expeller.²² The pay-back period for both would be two years. However, data on actual quantities of oil sold is lacking, so we cannot report reliable profit estimates. The ram-press is highly labour-intensive to operate, but only 165 litres of oil needs to be sold for the investment cost to be recovered. This is feasible even for a small-scale project. For the Sayari expeller, the break-even point is 2000 litres, because its investment cost is much higher. Its profitability could increase further once a productive use for the seed-cake is found (for example, if it could be sold as fertiliser).

The *learning processes* in this part of the chain have been limited to a few technical lessons regarding the operation of the presses and the quality of the seeds, and regarding user acceptance. There have been no broader learning processes in relation to infrastructure yet, about how best to set up a pressing facility or, for example, how best to store the seeds.

The participants' *expectations* in the pressing stage vary widely. It is not clear in which direction the *Jatropha* chain will evolve: Will small expelling units be installed, or will there be a few big centralised ones? Will the main technology be hand-presses or larger expellers? Currently, the groups are mostly working with ram-presses, but at least one of the groups (in Engaruka) is not satisfied with its capacity. Still, seed production is not yet sufficient to start a large facility. Some other aspects, such as transport, reliable and efficient equipment and its maintenance, and financial support, are also seen to be important barriers. Overall, the SNM processes in the pressing niche have not proceeded as well as in the cultivation stage. In particular, the network needs to develop more lateral relations for more effective learning to take place.

This brings us to the dynamics at the application stage. With respect to the **use of *Jatropha* oil in diesel engines**, there are mainly just positive *expectations*, but no actual lessons from experiments. The different potential options for oil use still remain to be explored. The *actor network* is quite limited, and shows no signs of expansion. Just three actors – a transnational company, the University of Dar es Salaam (UDSM) and a development project – are pushing this application in Tanzania. Perhaps more actors will get moving when UDSM's engine test results are positive and publicised. There are no *learning processes* on the user side yet. The only technical learning processes so far have been some experiments carried out by the multinational in its home base in The Netherlands. Worldwide, of course, many more experiments are being carried out on the

²² We further assumed that all seeds can be bought for TZS 80/kg, and all produced oil can be sold at TZS 2000 per litre. The diesel needed to operate the Sayari expeller costs 1100 TZS/l. Project life span, inflation rate and interest rate used are the same as in the cultivation projects discussed earlier.

properties of Jatropha oil; these seem to point in a positive direction, especially about the possibilities for converted oil. However, some technical uncertainties remain, for example about long-term effects on engines. It is symptomatic for the embryonic stage of this part of the chain that we were unable to gather reliable data with which to conduct an *economic analysis*. All we can say is that conventional diesel is priced at TZS 1100/l at the pump in cities, which is still low in comparison to the prices quoted by Jatropha sellers (about TZS 2000/l). *Expectations* are positive but remain highly vague due to lack of learning.

As far as the **utilization of the seed cake** is concerned, niche formation processes are hardly present. Only one NGO has tried to experiment with a biogas installation, but – as reported earlier – the women users were dissatisfied with its performance. On the positive side, they noted that Jatropha biogas burns well and that the seedcake generates a lot of gas. Much more experimentation and *learning* about technical properties will be needed for this technology to take off. The seedcake could also be pressed into briquettes, which can be used as fuel in wood stoves or ovens. This is practised in one remote village, Engaruka, but information about the experience is lacking.

Using seedcake as fertiliser could be more promising because of its favourable nutritional qualities. This possibility was mentioned by several respondents, but it remains untested as yet. There are no local *learning processes* yet, although *expectations* are slightly positive. Potential *actors* in this domain are farmers who want to use the cake as fertiliser, and the oil pressing facilities, which generate Jatropha cake as a by-product. It would appear to be highly important for this niche to develop, because Jatropha cultivation itself stands to benefit from it. Although the plant can grow on poor soils, it is not nitrogen-fixing, and requires a nitrogen-rich soil for continued good seed production (Openshaw, 2000).

Jatropha as fuel in **oil lamps** is not a well-developed application either. The *network* is rudimentary. Some young people were trained to produce Jatropha oil lamps, but did not use their knowledge. An NGO is the only current producer of the lamps. It claims to produce about 1000 lamps per year, an indication that there is some market. The lamps seem to function well. Households in remote Maasai areas such as Selela and Engaruka use them, probably because kerosene is relatively expensive there, while Jatropha is a common plant in their areas. *Learning* has been limited. A functional lamp has been developed, but this is a very simple adaptation of the ordinary kerosene lamp, with a thicker wick. *Expectations* about the future of this niche are unclear.

There seem to be too many barriers to using Jatropha **oil in cooking stoves** to speak of a potentially viable niche. The stove that has been developed is not functioning properly and users are unhappy. The emissions might even be dangerous. Early *learning processes* for this application were very good. The stove was developed and tested with involvement of various actors. However, the experiments petered out and many actors left when lessons were not widely shared, so a well-functioning *network* was not established. *Expectations* are already very negative. The prospects for this application are not good.

Finally, small-scale **Jatropha soap** making has been undertaken for several years by local women's groups assisted by an NGO. Even though this application is not energy related, its value lies in the many *learning experiences* it has generated for local women and their NGO partner with the cultivation, pressing and using of Jatropha. It has also contributed to *network formation*. The soap itself is a good product with strong antiseptic qualities. There is a niche market for it, both in Tanzania and in neighbouring countries. It commands a high price compared to ordinary soaps, so only a minority of people can afford it. The *expectation* is that this market will not expand much beyond its current size.

6. Conclusions

The main conclusion has to be that a transition towards Jatropha-based biofuels in Tanzania is still in a very early phase (if it is underway at all), and that its future is still unclear. Despite the favourable constellation of many contextual 'landscape' factors, there remain prominent barriers within Tanzania's existing energy regime. Much still needs to be done before Jatropha's potential can be tapped effectively. Prominent barriers are structural infrastructure problems; technical skill and knowledge gaps; a limited local research infrastructure; lack of actor networking and collaboration; and a considerable price disadvantage for Jatropha oil. Moreover, the government's role has not been facilitative enough.

The niche analysis showed that the Jatropha activities in the different parts of the production chain still consist of a loose set of experiments. One cannot speak of a viable market niche for Jatropha, not even a well-developed technological niche. The processes in the cultivation part of the production chain have proceeded quite well. However, further downstream we see small, incomplete or dysfunctional actor networks, insufficient experimentation and learning, and extremely diverse expectations that are not showing any signs of convergence. All this clearly indicates that Tanzania is still very far removed from embarking on an energy transition. However, the many experiments that have been carried out so far have created much awareness and interest in the Jatropha plant, which future developments can capitalize on.

Our analysis with Strategic Niche Management yielded several useful pointers for action by different actors who could foster a transition process. A useful task for the government would be to facilitate the protection of the niches (especially through a transparent system of taxes and subsidies), and to supervise the system of cultivating Jatropha so that large mono-cultures and its associated risks are avoided, and many small-scale growers get opportunities to participate in an emerging Jatropha sector. Organisations like NGOs, universities and large foreign Jatropha investors should promote production-chain management: they should focus on stimulating simultaneous experiments at all the stages of the Jatropha chain with many different types of actors, building interconnections between these experiments, and disseminating the learning processes widely to all actors involved. Banks should make available micro-credit funds for (groups of) small-scale investors wishing to start Jatropha-based activities. Progressive farmers and active local women's groups could become local niche champions, promoting niche formation at project (experiment) level through actor network building, stimulating learning, and levelling expectations.

The Strategic Niche Management framework proved to be a useful instrument for this study. Distinguishing the landscape, regime and niche levels is a good way to identify and systematically structure all the main elements that determine the potential of a transition process. Furthermore, the approach facilitates a detailed study of niche dynamics through its focus on actor network formation, learning processes, and dynamics of expectations. By asking questions about these three processes, one can get a good and quick picture of how an experiment is going. In that sense, SNM is very suitable for projects in developing countries.

Our use of SNM did uncover some problems. Some of these are specific to its use in a developing country context, but others are not. The most important general limitation of SNM from our perspective is that all the activities undertaken in relation to a new technology are essentially viewed as useful techno-societal experiments, and the more learning and the more networking among these experiments, the better the ultimate outcome is predicted to be. However, from the point of view of contributing to an emergent transition, it is clear that some experiments are likely to be more important than others. That is why we

introduced the concept of a production chain, which shows all the logical relationships between the different activities and hence facilitates a better understanding of the importance of each. This shortcoming of SNM has also been recognised by Elzen et al. (2004) who state that 'from the wide variety of alternatives developed at niche level, it is necessary to select and focus, and to assess which of them should be stimulated in what way'. Our production chain instrument could be a simple aid for that task.

Another general drawback of SNM appears to be its assumption of a single dominant regime. Our research identified at least three other 'supplementary' regimes whose conditions are relevant, in addition to the dominant energy regime that was presumed to be our main subject of study. The problem with SNM seems to be that researchers have studied transitions primarily from the point of view of final user applications. However, the production stages leading up to these applications can be governed by completely different dominant regimes. We advocate the adoption of the production chain concept also for the purpose of identifying these additional regimes.

Limitations of SNM that are specific to its application in a less-developed setting arise from the problems associated with information gathering. In particular, obtaining data for a comprehensive regime and niche analysis is quite difficult. Since many projects take place in remote locations, the interviewer usually has to obtain all the information in one single meeting because it is too time-consuming and difficult to return. Also, problematic relationships with other network actors and negative expectations are almost certainly underreported by respondents since this would be culturally unacceptable. However, these problems are not specific to the use of the SNM method as such; they are part and parcel of the research process in developing countries in general.

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