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A promising niche: waste to energy project in the Indian dairy sector

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ABSTRACT

The dairy sector is known to have significant local and global environmental impacts; but it also has proven renewable-energy generation potential. This paper analyzes a specific niche experiment in the Indian dairy industry, wherein cattle waste management is carried out by a multitude of stakeholders. These include the waste collectors, local technology adopters, research institutions, multilateral donor agencies, the Indian government, technology suppliers and operation and maintenance teams who have managed an uninterrupted 1 MWe energy production over the past 4 years. This analysis uses the sociotechnical regime framework to study the interaction of social, technological, economic and policy-related aspects relevant to the niche experiment. The analysis shows a potential to contribute to the development of two complementing regimes—one related to cooperative waste management and the other related to grid-connected renewable-energy-based electricity generation. Key factors for a successful development are not only a long-term financing protection through government subsidies to cover higher capital cost and a preferential tariff related to energy throughput, but also the adaptation of technology, the embedding in the local cooperative structure and the removal of regulatory barriers.

1. Introduction

Livestock, the world-over, accounts for 18% of total of global greenhouse gas (GHG) emissions. Therefore, the global production of meat and dairy products has a substantial the environmental impact (FAO, 2006). The dairy sector in India also is an important source of livelihood for the rural population given the conventional agrarian economy. India's milk production has increased five-fold from 21.2 mMT in 1968–1969 to almost 100 mMT in 2006–2007 (FAO, 2006). The organized sector accounts for 13% of milk production while the rest comes from the marginal land holding farmers, which has been aggregated into a cooperative ownership and management model. The livestock sector contributes to around 6.8% of Indian gross domestic product (GDP) and employs 8% of the labor force (FAO, 2006). As such, the dairy industry sector and its future growth potential hold critical value for the Indian economy.

With growing urbanization, the application of cattle waste for cooking is on the decline. Hence, the treatment and management of cattle waste is becoming a matter of concern. Typically, untreated cattle waste (manure) adds to the local environmental pollution (mainly wastewater and solid waste) as well as global GHG emissions (methane). Abetting the local wastewater pollution is a cost-intensive proposition when treated in smaller plants. Also, decentralized wastewater treatment plants, though reducing the burden on the large facilities, do not receive government support, making their management a challenge. However, centralized large capacity treatment schemes not only need lower investments, but also, when combined with energy recovery, potentially offer two

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main benefits—(a) providing a renewable source of energy from methane capture, thus resulting in more reliable, low-carbon energy infrastructure and (b) abetting global warming impact of an otherwise untreated cattle waste remaining in the environment.

While untreated manure is a waste stream, the cattle waste can also serve as a source of energy, either through direct combustion or by conversion into biogas (methane). Distributed generation opportunities using cattle waste have been tried out over the past several years. Direct combustion of cattle dung as a fuel has serious implications for indoor air quality, and the GHG impacts have been estimated at 377 g CO_2/MJ. On the other hand, the biogas produced through a controlled anaerobic digestion process has different environmental implications, and the GHG impact for this route has been reported as 2 g CO_2/MJ of biogas (Smith, 2002).

Recognizing the huge energy generation potential from cattle waste, the Ministry of New and Renewable Energy (MNRE) of the Government of India (GOI) launched a program titled Khadi & Village Industries Cooperative. The program targeted small size biogas plants through government subsidy resulting in an uptake of over 200,000 small units (MNRE, 2007). While this program still continues with varying levels of success, GOI, through a multilateral donor agency, the United Nations Development Program (UNDP) and with financial support from the Global Environmental Facility (GEF) launched a waste to energy (WTE) initiative targeting high-rate anaerobic digestion in several large industrial sectors in early 2000. The GOI/UNDP initiative resulted in 16 anaerobic digestion plants spread across industrial sectors including pulp and paper, municipal solid waste and food/fruits.

One such intervention in the agro-industrial sector is the waste to energy project at Haebowal dairy complex in Ludhiana (Deodhar and Van Den Akker, 2005). This paper analyzes the experiment carried out at this complex in Ludhiana, a medium-sized city in Punjab, India. The experiment captures relevant interaction between the stakeholders. The project was set up as a protected experiment with funding support from multilateral donors; it also benefited from specific local cooperatives and government actions. The experiment received an international accolade of the ''Best Green Power Plant in Asia'' at the Asian Power Awards 2007.

The dairy sector in India is organized around village and district level cooperatives. This mode of operation has evolved over the past several decades, and it is now the dominant organizational form with regard to the collection, transportation, processing and marketing of milk (Ramdas et al., 1998). While the cooperative structure supports the product quality and distribution, energy and waste management requirements in the milk-processing value chain have not been successfully integrated into the structure so far. Responsibility of providing energy/electricity in the milk-processing and other village-level activities remains in the domain of the regulated electricity market in India. Waste management is governed by local disposal norms that are seldom adhered to.

The niche experiment described here has been analyzed within the multi-level framework on technological transitions, proposed by Geels (2002). A technological transition is a transformation in the way a societal function is fulfilled; it is a process of sociotechnical change as it involves not only technical changes but also changes in user practices, regulations, social networks, infrastructure and culture. Central in the multi-level perspective, is the concept of a sociotechnical regime, the semi-coherent set of rules carried by different social groups. These groups form a multi-actor network consisting of a financial network, suppliers, user groups, societal groups, a producer network, public authorities and a research network (see Fig. 1). These different groups represent the relevant dimensions of the experiment.

By providing orientation and co-ordination, the regime accounts for stability. In the multi-level framework, radical innovations are generated in niches, spaces where radical novelties are (partially) protected against normal selection pressures in the prevalent regime (Geels, 2002). The experiment described in this paper is one of the experiments within the biogas niche. We seek answers to the questions in regard to the experiment such as who implemented the experiment; how was it implemented, and what has been the role of electricity, environmental and other sectoral policies relevant to its implementation. In this analysis we will pay attention to the social network supporting the experiment, the expectations of the stakeholders and the lessons learned. In the system innovation literature the development of experiments and niches usually is analyzed in relation to one dominant regime. However, the experiment described in this paper involves not one, but two regimes—one related to waste management in with links to the existing cooperative structure in the dairy and the other related to electricity generation. We refer to current waste management in the dairy sector and grid-connected electricity generation as regimes, because they represent the rule and dominant practices the new technology has to deal with.

The next section describes the niche experiment in detail. Aspects of the experiment such as the technology, the stakeholders involved, the underlying economics and the relevant policy context are described here. This is followed by the analysis of the relation of the experiment to the two different regimes to understand the implications for scaling-up, primarily focusing on barriers and opportunities for replication of the experiment. The concluding section assesses the importance of the sociotechnical experiment and its relevance to understanding sociotechnical experiments of a similar kind.

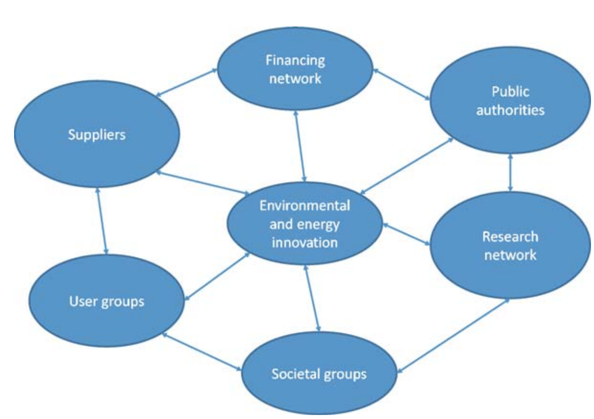

Fig. 1 – The multi-actor network involved in the sociotechnical regime of an environmental innovation.

2. Assessment and analysis of experiment—dairy waste management

The large-scale experiment of waste to energy implemented in Ludhiana has been possible through a combination of converging conditions related to the policy environment, economic impacts from the perspectives of the stakeholders, social aspects including involvement of stakeholders and various local institutions, financial support, availability of technology know-how in India and adaptation of technology from other countries. The different aspects of the experiment evaluated here are represented in Figure 1 (Geels, 2002). The technological aspects will be discussed in the context of resource availability, economics and relevant policy environment. Social aspects relevant for this experiment include elaboration of the institutional arrangements and of the role of the stakeholders involved. Both, the technological and the social aspects will be discussed with respect to the actors' expectations and the learning process.

2.1. *Description of the waste to energy experiment*

As described in the previous section, the experiment is part of a series of anaerobic digestion programs supported by the GOI in several sectors. Out of a variety of projects implemented, the experiment covered in this paper describes the current practice of waste management in a mid-sized community-managed milk collection and processing activity. The milk-processing regime itself is similar to other existing cooperative structures in other parts of India. Key attributes of the project are presented in Table 1 (Singh, 2008).

The cooperative structure in the Indian dairy industry has been supporting technological and operational advancements. In order to address a common waste minimization challenge, close to 1500 smaller dairy owners from Ludhiana grouped together to support cattle waste collection, essential for the energy generation process. The milk produced from the 150,000 animals owned by the 1500 farmers is typically sold either directly in the market or to a central processing unit. Unlike the rural sector milk producers in India, the town of Ludhiana is part of the urban sector, which makes the direct sales of some quantity of the milk more feasible than in the rural sector. The central processing plant in the vicinity ensures offers the opportunity to store the milk for maintaining its quality. Prior to the experiment, dairy farm owners were struggling with waste disposal issues and costs associated with them. As the biomass (cattle dung) availability is the key to generating the required biogas for electricity generation, daily collection of the waste is of importance and thus also, the involvement of 1500 small dairy owners to be a part of the waste collection system. In order to ensure steady flow of the waste collection and its use in the waste management/energy generation plant, the plant management has issued a contract to collect and transport the biomass to a central location. The contract is structured to cater to the daily procurement of biomass resulting in a higher plant load factor for electricity generation. The contractor is made responsible for collection, transportation and payment of the waste collected from the dairy owners.

Table 1 – Attributes of waste to energy project at Haebowal, Punjab.

Plant capacity	1 MWe
Number of animals	150,000
Waste (dung) generation	235 tonnes/day
Type of biogas generation process	Anaerobic digestion using biogas-induced mixing arrangement (BIMA)
Type of engine	Internal combustion—GE Janbacher
Plant load factor	75%
Year of commissioning	2004
Total investment	US$ 3.4 Million (1 US$ = 40 INR)
Greenhouse gas abatement	32,900 tCO_2/year
Electricity production	18,000 kWh/day
Nutrient-rich bio-manure	47 tonnes/day
Sales price	INR 1000/tonne

2.2. *Technology*

The technology will be described in the two subsections here; the first one highlighting the experiment itself and the second one highlighting the industrial network and techno-specific knowledge.

2.2.1. *Technical characteristics*

The process flow diagram of the plant commissioned in 2004 is presented as Fig. 2 (Singh, 2008). The daily collected waste is used in the plant to treat the waste and generate electricity.

The treatment process illustrated above includes primary and secondary treatment steps. Primary treatment includes collection of cattle waste, dilution in a feed tank to ensure consistency and anaerobic digestion process involving biogas-induced mixing arrangement (BIMA), which is at the heart of the process of producing biogas with uniform consistency of methane (CH_4). Secondary treatment includes aeration tanks and secondary settlement of treated solids. Another important component includes gas engines using the biogas to generate electricity and also using waste heat recovery units to maintain a constant temperature in BIMA. The digested waste residue in the anaerobic digester, too, has direct secondary uses. 47 tonnes/day of nutrient-rich bio-fertilizer produced in the system is used effectively in the farming and horticulture sectors, also adding to the cost-efficiency of the operation. The plant operator is allowed to sell the digestate from the plant to farmers and horticulturists at a price of INR 1000/tonne (US$ 25/tonne), the price set by Punjab Energy Development Agency (PEDA). The farmers and horticulturists purchase the digestate directly from the plant without any intermediary responsible for distribution.

It is important to understand at this stage what was happening to the cattle waste prior to the implementation of this project. The waste was getting discharged without any treatment or it was transported by farmers to nearby localities as to be used as a fertilizer (Singh, 2008). The waste management infrastructure in most of the smaller Indian cities is inadequate or is still evolving. Prior to the project implementation, the cattle waste did not have a particular commercial value. As such, the waste to energy project

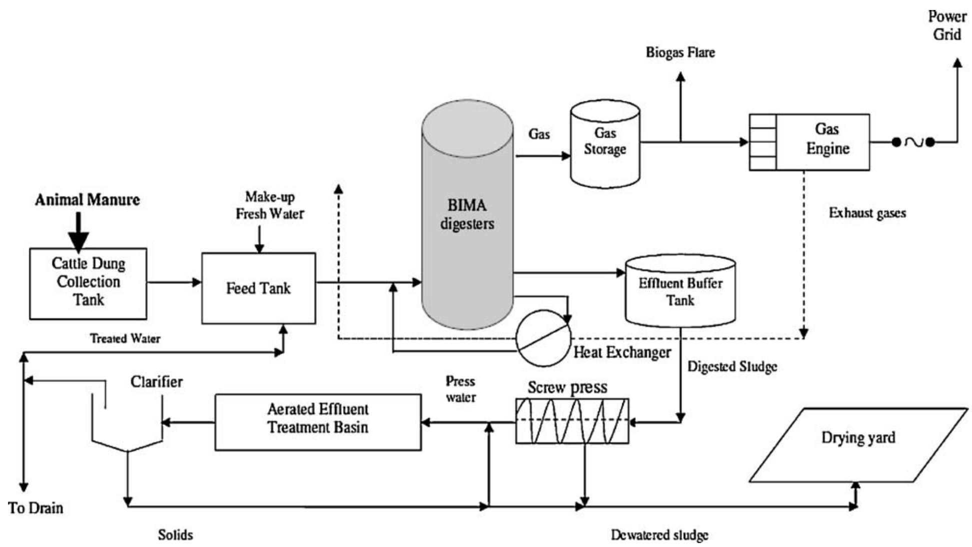

Fig. 2 – Schematic diagram of Haebowal waste to energy plant.

developed in Ludhiana also points to an interesting opportunity to develop a cooperative structure to collect the waste generated at source and to develop resource recovery options. One of the key elements to be considered in new waste to energy projects is resource recovery and/or the productive use of waste stream as a raw material in energy generation.

2.2.2. *Industrial network and techno-specific knowledge*

While the anaerobic digestion technology is not new in India, it has been implemented with varying degrees of success in different sectors (Singh, 2008). In certain sectors, such as, the pulp and paper and tanneries, implementation of these processes has been quite successful compared to the challenges in some other sectors. All the 16 anaerobic digestion plants set up under the UNDP/GEF/MNRE initiative are operating successfully (Deodhar et al., 2007). However, the cattle waste to electricity generation plant installed as a part of this niche experiment, needs some more discussion as it also includes successful adaptation of European technology (Entec). Solid consistency of the influent waste, organic content, temperature of the anaerobic digestion basin and mixing arrangements are key process variables in this technology (Singh, 2008). Downstream moisture removal system from the biogas generated in the process is also important in order to stabilize the electricity generation in the installed engines (Singh, 2008). One key challenge to maintain the process parameters related to uniform temperature is the wide ambient variation (close to a minimum of 2 °C in winter up to 48 °C in summer) at the installation site, identified as cold and hot under the Indian climatic classification. As a uniform temperature of 45 °C is essential to maintain yield and quality of the biogas from the anaerobic digestion basin, specific technical interventions are required during the implementation phase (Singh, 2008).

Successful adoption of the technology has been possible with indigenous technology adaptation and development carried out at a premium technology institute—the Indian Institute of Technology, Roorkee. This collaboration also included interactions between the international provider of technological know-how, Entec and the local design, engineering and construction teams. Given their experience with the adaptation of technology, Indian production and construction companies are now fully capable of implementing similar plants in other parts of the country (Singh, 2008). It is important to understand how the technology absorption process has been carried out, because it contributes to the process of scaling-up of this or similar experiments. In addition to the technology know-how available from Europe and the presence of the Indian technical institution, the industrial network involved in the implementation of the required processes, such as, the sulfur-adsorption from biogas to protect engines from corrosion and creation of water-jackets around the BIMA reactors has proven to be important (Singh, 2008). What is unique in this experiment is the technology adaptation process that includes features like the inclusion of waste heat recovery system associated with engine exhaust and improving manure quality to be used as bio-fertilizer.

Some of the technologies explained above (waste heat recovery and bio-fertilizers) have benefited from lessons from other sectors where the anaerobic digestion processes have been implemented. Pulp and paper and sugar sectors have been using the waste heat recovery in the main processes and cogeneration plants, which have been extended to the biogas-based thermal and electrical energy conversion.

2.3. *Stakeholders*

The experiment involves the collection of manure from a specific location, the Haebowal Dairy Complex in Ludhiana. Other stakeholders involved in the experiment included multilateral donor agencies (United Nations Development Program and the Global Environmental Facility), equipment suppliers (Janbacher, General Electric), technology know-how providers from Europe (Entec, Austria), technology adapters (Indian Institute of Technology, Roorkee) and policy makers (Electricity Regulatory Commission, State Renewable Development Agency, the Punjab Energy Development Agency (PEDA)) for a preferential tariff structure for renewable energy. This integration in the central grid system has been supported

by a management contract between the plant owners and the technology suppliers. The joint-ownership model developed by PEDA in Ludhiana has been possible due to the fact that it has been one of the most concentrated cattle management and milk production centers in an urban area. PEDA has been the initiator of the experiment, supporting the central government to develop waste to energy projects. PEDA and the local municipality have been instrumental in involving the dairy owners at the demonstration site.

As a business entity, the plant is managed by Punjab Genco Limited, a wholly owned subsidiary of PEDA. Daily operation and management of the plant has been awarded through a bidding process, the system operator gets an operational fee based on the kWh delivered to the grid, provided that he keeps the treated wastewater parameters within the prescribed limits. The plant operator is also responsible for recovering the feed-in-tariff from the local electricity transmission company. The engagement of an operator to manage the installation has been a significant success factor in this experiment (Singh, 2008).

With respect to the social network of this experiment, the role of a few key institutions has been significant. These institutions include PEDA and the local municipal corporation that identified and offered land to set up the plant on a long-term lease. PEDA, the state-level renewable-energy development institution has been responsible to implement the renewable-energy projects in Punjab. The leadership provided by PEDA resulted in the setting up of subsidiary that assumed the responsibility to ensure proper operation of the plant. The way the contractor has been operating and maintaining the plant has been exemplary. The local municipal body has played an important role by offering the land on a long lease, which otherwise would have resulted in increased capital expenditure. Other experiments carried out under the UNDP/GEF programs have had varying levels of success. Here the involvement of PEDA in setting up a strong operation and maintenance entity of the project has been important.

2.4. *Economics*

Three institutions have contributed to the funds required for the set up. The total capital investments of US$ 3.4 Million were shared for respectively 40%, 10% and 50% by PEDA, the National Bioenergy Board and UNDP/GEF. As the initial investment for this plant was at least 3 times that of a conventional fossil-fuel-based power plant, the UNDP/GEF support was crucial for the success of this experiment. The initial push has paved the way for a large-scale implementation of similar plants, which has become possible due to the learning processes in regard to technology development and waste management. PEDA, as the main implementing partner in the state of Punjab was also able to contribute land from the local municipality to set up the power generation unit in close proximity to the existing 1500 small dairy plants, which provide the raw material for the anaerobic digestion process.

In the national greenhouse gases inventory for India, methane (CH_4) is listed. Due to the high global warming potential of CH_4, the biogas to energy projects qualify for the benefits defined under the market-based mechanism of the Kyoto Protocol. Among various conditions to be fulfilled to register projects under the clean development mechanism (CDM), the project proponents need to justify additionality conditions (IGES, 2009). Financial additionality of the projects in this context means that without the carbon revenues the project would not have been implemented. In case of this experiment, as the entire project has been set up through a grant mechanism, the CDM financial additionality cannot be justified. As such, the project is not able to generate a revenue stream from carbon sales. However, expanding this experiment is likely to result in other projects that can exploit carbon finance as a key revenue stream. Over the past 5 years, biogas to electricity generation projects are gaining popularity in Asia and the CDM Executive Board has approved methodologies to determine Certified Emission Reductions (CERs) from such plants.

Investments and the net present values (NPVs) from the project proponent with and without the UNDP/GEF and GOI subsidy and carbon revenues are summarized in Table 2 and depicted in Fig. 3. Project benefit and costs have been compared for the project proponent, PEDA. Four scenarios are discussed here, (i) baseline project implemented without GEF subsidy and without CER revenues, (ii) project without GEF subsidy and with CER revenues, (iii) project with subsidy without CER and (iv) project with subsidy with CER.

It is evident that the project NPVs are negative for scenarios in which PEDA, the project proponent, would have implemented the project with 100% equity that is without any grant support from UNDP/GEF and the National Bioenergy

Table 2 – Investment analysis.

Total investments, US$ (millions)	3.4
PEDA contribution, US$ (millions) (project proponent)	1.36
National Bioenergy Board contribution, US$ (Millions)	0.34
UNDP/GEF, US$ (millions)	1.7
Daily waste collection as feedstock, tonnes	235
Electricity generation (kWh/day)	13500
Manure	36
Selling price recovered from electricity sell (US$/kWh)	0.087
Selling price of manure (US$/tonne)	25
Cost of manure collection (US$/tonne)	1.75
Operations cost paid for electricity generation (US$/kWh)	0.075
Annual operations cost, US$ (million)	0.370
Annual total revenues	0.608
Annual revenues without CERs, US$ (millions)	0.239
Total CERs (electricity + methane abetment), tCO_2/year	32,900
Selling price of CERs, US$/CER	7
Annual revenues with CERs, US$ (millions)	0.469
Project proponent net present values	
Assumptions	
Discount rate	14%
Life of the plant, years	20
NPV-baseline – without subsidy without CER	−1.82
NPV – without subsidy with CER	−0.29
NPV – with subsidy without CER	0.22
NPV – with subsidy with CER	1.75

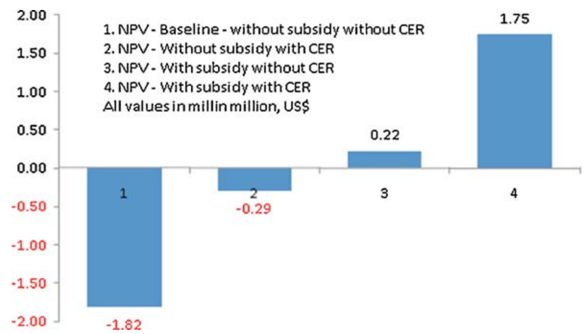

Fig. 3 – Project NPVs with varying subsidy levels.

Board. NPVs with the UNDP/GEF and National Bioenergy Board subsidies are positive, both with and without CERs. A sensitivity analysis of the impact of the revenues from manure sales has also been carried out, but removing these revenues has only a limited impact on the NPV. This cost-benefit analysis has been calculated assuming a 75% plant load factor and a plant life of 20 years, as reported by the plant operators (Singh, 2008). The cost of the land made available for a long lease by the local municipality has not been included in the investment numbers. It is clear that the capital subsidy offered by UNDP/GEF is important for the project proponent to recover the investments. In both cases, with or without subsidy, the CER revenues improve the NPVs only marginally. Although the UNDP/GEF and PEDA subsidies have been once-only, the MNRE subsidies to waste to energy projects are still available. In any replication project, the MNRE subsidies would still be available to support the project viability. Revenue generation due to the sales of manure are 56% of the overall revenues.

As the local dairy owners, too, are important stakeholders, their revenue generation through sell of cattle waste is an important component in the success story. The local stakeholders earn approximately US$ 0.15 million annually through the sales of 235 tons cattle waste per day. The actual revenue realization for the cattle owners is less than this amount as an interim operator has to be paid to collect and transport the waste from individual dairies to the central plant. Prior to the setting up of this plant, the waste collection was not a continuous process with waste disposal being the responsibility of no one in particular.

2.5. *Policy environment*

The Indian power sector uses fossil-fuel to an extent of 60% of the total power generation (MOP, 2008). Given the power deficit of over 20% in India, GOI, Ministry of Power (MOP) and MNRE have identified renewable energy as a key option in the Indian new capacity generation. While small biogas plants have been implemented in India over the past three decades; large-scale biogas plants and energy generation thereof are not common. UNDP/GEF support and MNRE actions in India have resulted in setting up a long-term capital subsidy regime related to the installed capacity of the biogas-based plants. While the capital subsidy regime is essential and has evolved during the development of the niche experiment, subsidies linked to the energy generation activities are required given the varying levels of success.

As the experiment generates electricity that is supplied to the grid, another policy that supports the financial viability is the feed-in-tariff (FIT), applicable to renewable–energy projects. Indian regulators have defined the rationale for setting up tariffs for renewable-energy sources based on (i) return on equity, (ii) interest on loan capital, (iii) depreciation, (iv) interest on working capital and (v) operation and maintenance expenses (CERC, 2009). PEDA and the state regulatory commission awarded a FIT and priority access for electricity generated by grid-connected distributed generation plants.

In order to support replication of the niche at other locations, MNRE offers a capital subsidy of US$ 400,000/MWe of biogas-based plants. Policies set up at specific socio-economic settings also draw widely from some of the global voluntary actions. One such voluntary action is the ''Methane to markets'' partnership launched by countries including those operating in the Asia Pacific region (M2M, 2009). PEDA and MNRE are also discussing with the methane to markets partnership to develop voluntary endorsement labels to certify adequate functioning of the anaerobic digestion process (Singh, 2008). This voluntary action is also expected to lead to a mandatory policy evolution in support of the replication of such initiatives.

2.6. *Learning from the experiment*

The waste to energy experiment described and analyzed in above indicates that there are several important success parameters. A key factor has been the fact that the split ownership of the plant and the involvement of an independent management contractor have not had a negative impact on its sustenance. Involvement of local technology adapters and local presence of technology supply-chain has helped the overseeing of the flow of raw material, maintenance of the plant and delivered output. A unique feature related to paying management fees to a separate contractor by PEDA, providing the capital subsidy during the initiation phase, has proven to be quite important (Singh, 2008). Another key factor that has played an important role in the project conceptualization and implementation has been UNDP/GEF and GOI grants. Both the grants have resulted in positive NPVs of the project.

3. Implications for replication and scale-up

This experiment can have far reaching benefits for the development of the biogas niche but also for some of the problems the two regimes identified here, are being dealing with. It can lead to an adaptation of the existing dairy regime to include waste management. It also can contribute to the evolution of grid-connected renewable-energy systems. The experiment created a grid-connected 1 MWe electricity generation plant, running on biogas that has proven to be the most reliable application in the dairy sector commissioned in India so far. The other waste to energy projects have shown varying levels of success (Deodhar et al., 2007). In the Haibowel dairy complex plant operation and energy production have been geared to each other, something that has been missing in

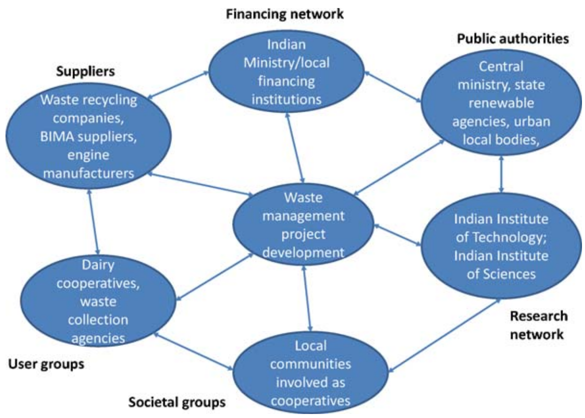

Fig. 4 – Constituents of a dairy sector waste management sociotechnical regime.

most of the subsidy-driven projects. In order to extend this experiment to other applications, it is important to set up a process where operational performance of the plant including plant load factor, daily electricity generation and manure processing need to be an integral part of the process of monitoring and verification.

3.1. *Cooperative waste management regime*

Specific to the experiment, several Indian and international actors have taken key positions and made specific contributions. The regime concept proposed Geels (2002), including the financial network, suppliers, user groups, societal groups, public authorities, and the research network is used to describe this regime. Fig. 4 illustrates the specific constituents of the regime, followed by its description.

The experiment involves several actors and institutions who played a role in the implementation. The network of local actors has carried the experiment, whereas the global actors, such as the GEF and the evolving methane to markets mechanism, has supported and provided protection by funding the experiment and enabling the transfer of knowledge and technology. Fig. 4 presents the constituents of the waste management regime and the actors involved: market and user practices (involvement of user groups), financing and physical infrastructure (providers of grants and land), sectoral policy (relationship with macro-policies in the electricity market) and industrial network and techno-specific knowledge (domestic and international technology providers). Interaction among the actors and their established linkages has made development of this regime possible. While the availability of finance and sectoral policies have supported the implementation, interactions between actors from the industrial network, research institutes providing techno-specific knowledge and commercial partners and users, have resulted in creating a reliable energy source. However, despite the success of the technology adaptation in the Indian dairy sector, in order to be expanded further, the experiment needs similar local network support the experiment in Haibowel acquired. This goes much beyond the subsidy currently provided by the MNRE. The local network of the technology providers and adapters also needs to evolve, making a self-reliant supply-chain. Most importantly, the cost of \$3.4 million/MWe of electricity needs to be substantially reduced close to \$1 million/MWe of fossil-fuel-based power generation. In similar experiments, care also needs to be taken to determine the capital costs correctly so that the investment numbers and the associated subsidy are matched in an optimal manner. In order to enable the regime to adopt this technology, it also needs support by implementation of the existing waste disposal norms of the GOI, which up to now may not be implemented stringently.

Mentioning some of the new opportunities and barriers relevant to small to medium systems in the rural sector is important in this discussion. An important component of the dairy regime is the local storage of milk that is collected in small villages. A key problem in rural areas has been the non-availability of adequate local storage facilities resulting in milk perishing; it also results in loss of livelihood opportunities for the rural population. The dairy regime has the potential for further development and expansion, if it can provide local, village-level storage facilities. Those local facilities could work on electricity or energy generated in the smaller biogas plants. There are several other, more advanced technological options to tackle this storage problem. One option is to use electricity generated by biogas for waste heat-based absorption cooling techniques that can be installed in the villages to create a closed energy loop. This system can be used for preserving milk and other perishable rural products, including fruits and vegetables. Expanding the dairy regime further to include solar-based chilling techniques is also a possibility given the improved reliability of hybridized systems working on gas and solar energy as motive source to generate cooling or electricity. Though not included in the initial project design, PEDA is currently in the process of designing such a unit as would be used by the local dairies in the storage systems (Singh, 2008).

Similarly, as is evident from Table 2, selling the manure to the processing plant improves the financial position of the farmers. Also, the expectation is that the use of the digested waste residue will reduce the use of chemical fertilizers in the farming and horticulture sectors. This is financially attractive, as less expensive artificial fertilizers have to be purchased by these sectors, but it also is attractive from an environmental point of view, because the production of these fertilizers requires a lot of energy. However, this opportunity needs attention from the network of actors of the dairy waste management as the current horticulture and agriculture crop production is heavily dependent on chemical fertilizers.

3.2. *Grid-connected renewable-based electricity generation regime*

The technical potential of electricity generation, based merely on the amount of cattle waste produced in the country is enormous. One of the key success factors in the Ludhiana experiment has been the linking of plant management contract with the energy generation and feeding it into the local electricity grid. However, the opportunity costs of the biomass not being available for the conventional uses, such as cooking, needs to be addressed, considering the alternative fuel sources that have to be made available. Fig. 5 illustrates the actor network of the grid-connected renewable-energy

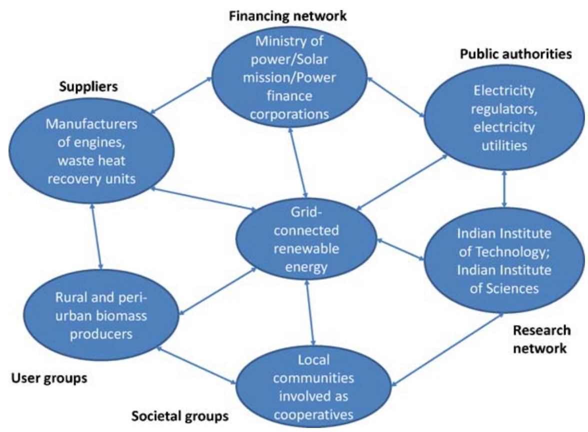

Fig. 5 – Constituents of a grid-connected renewable-energy sociotechnical regime.

regime. These actors have to address the current barriers in order to realize the potential.

Systemic challenges in the Indian electricity system, both grid and off-grid, have been related to the subsidy regimes that have supported capacity addition in place of energy (electricity) production. As a result, in the case of certain types of renewable-energy plants, part the capacity installed is not been used. Although, the feed-in-tariff regime evolving in the Indian power sector tries to amend this by targeting the energy delivery over the capital subsidy, the current FIT in the Indian power sector has not yet been adapted for electricity generation by digestion plants. The current FIT is structured for biomass gasification-based electricity generation working on a Rankine cycle. A specific intervention to include also other biogas-based electricity generating options is needed by the electricity regulators.

Expanding the experiment to smaller versions is the key to successfully utilizing biogas as a renewable-energy source coming from the dairy waste. Unlike the Ludhiana example, most of the other dairy plants are located in the rural sector where the electricity generation potential may be between 100 and 500 kWe. In such small to medium-scale plants, the availability of technology, the operation and maintenance is not easy, leaving room for failure. Also, the internal combustion engine technology providers in the international market typically provide plants that are 250 kWe and above. Thus, local technology adopters capable of guaranteeing electricity throughput at the desired levels are important stakeholders. The lack of connections to the electricity grid and its poor reliability are barriers in the rural sector. However, some of the GOI projects related to rural electricity provision can provide support to the grid development requirements in the medium or even short term. In such cases, providing additional financial incentives to the state transmission and distribution companies resulting in faster grid extension and development also is important.

4. Conclusions

The dairy waste management example discussed above illustrates how a technology can link up with two regimes—one related to the cooperative waste management and the other related to grid-connected renewable-energy generation. The description of the experiment clearly identifies the relevant stakeholders, from local and global financing agencies, the local adaptation of global technologies by companies, the participation of local dairy owners in the waste collection process, the involvement of an operation and maintenance contractor to ensure waste collection and energy throughput. The experiment also exemplifies the requirement of a grant and other financial support to finance its inception and sustenance. This form of protection has been absolutely crucial for the success of the experiment. The GOI official subsidy of close to US$ 400,000/MWe of installed capacity using biogas as the primary source and feed-in tariffs offered through the electricity policies have provided the required protection.

There is a great potential for replication of the experiment and the expansion to other parts of the dairy sector, in particular the rural sector. A lack of adequate storage of the milk is one of the main problems for the development of the dairy regime in non-urban areas. Biogas production from manure offers great opportunities to contribute to the solution of this problem, perhaps in combination with the introduction of new advanced technologies. The dairy waste management experiment illustrates that support by a broad local network of technology suppliers, users, policy makers, etc. is crucial for a successful implementation of waste to energy projects. In particular, the example highlights the importance of the way the waste processing and energy generation is organized and fit in the existing cooperative structure. Waste to energy projects in the dairy sector also have the potential to improve local systems of energy supply in India, grid-connected or not. For a successful diffusion adaptation of the technology is still necessary. For the grid-connected systems some regulatory barriers have to be removed as well.

An interesting point is that both regimes—one related to the waste management and the other related to grid-connected renewable-energy-based electricity generation are non-exclusive and have a symbiotic evolution potential (see also Raven and Verbong, 2007). The experiment and, more generally, the biogas niche provide opportunities for tackling persistent environmental and social problems in both the dairy waste management regime and the emerging renewable electricity regime. The first regime related to cooperative waste management supports the mitigation of methane, a highly potent greenhouse gas and the abetment of local water and solid waste pollution. This regime combines waste management with securing the required waste stream as a raw material in the energy generation process. The second regime relates to the grid-connected renewable-energy-based electricity generation. The possible linkage of this regime with urban or rural end uses around the dairy sector is in itself an important feature. Whereas in urban areas connection to the grid is rather obvious, in rural areas another option is the development of local sustainable energy systems. Waste to energy projects can became a major constituent of such systems. In both cases waste to energy projects can contribute significantly to reduce the environmental impact of the dairy sector.

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