Analysing and governing environmental flows: the case of Tra Co tapioca village, Vietnam

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Abstract

Environmental flows are of crucial importance for questions of sustainability. But analysing only the material side of environmental flows brings us half way understanding questions of sustainability. This article reports on the development of a more integrative approach in studying environmental impacts of agro-industrial systems in Asia, taking tapioca (cassava starch) processing in Vietnam as an example. The analysis of material flows and technological options to close material cycles is combined with an actor-network analysis from three angles: a policy, an economic and a social perspective, respectively. The paper finally assesses the additional value of the developed methodology and points out ways for further investigation and development of a more integrative approach to industrial transformations.

Additional keywords: cassava starch, agro-industries

Introduction

Environmental flows are of crucial importance for questions of sustainability. Already in the early days of modern environmental concern, in the 1960s and 1970s, attention was paid to the flow of material substances between the economic subsystem and the ecosystem. Since then, the objective has always been to minimize the material flows between the economic system and the ecosystem, in terms of both additions of material flows to the ecosystem (emissions) and withdrawals from the ecosystem (the use of natural resources). Carson's (1962) path-breaking work on the flow of pesticides through food chains and Massachusetts Institute of Technology's report to the Club of Rome (Meadows *et al.*, 1972) on the spreading of pollutants around the globe and the depletion of natural resources are just two well-known examples of early environmental-flow analyses. Each has, in its own way, put environmental flows on the research, public and political agendas by questioning how to limit the devastating environmental effects of these flows.

Analysing the material side of environmental flows brings us only half way. It provides us with the leaks of material flows coming out of (agro-)industrial systems and with the inefficiencies in the use of resources going into them. But it cannot provide us with insights, understanding and strategies how to successfully and sustainably manage and govern these environmental flows. Which actors inside and outside (agro-) industrial systems need to take action, which (economic, political, social) institutions enable and facilitate such strategies of environmental reform, and where can we expect institutional barriers? For that, integrative approaches are needed, and the AGITS programme aims to contribute to the development of these. The AGITS (Agro-Industrial Production Towards Sustainability) programme analyses the environmental impact of agro-industrial systems in Asia and looks for possibilities to limit this impact. It does so from an integrative perspective, at various levels of aggregation (local to global), related to the South-East and East Asian countries Malaysia, Vietnam, Thailand and China.

This article starts by reviewing three groups of environmental flow studies from a perspective of integration. The next chapter reports on how we have dealt in the AGITS programme with the problem of combining natural science flow analysis with social science studies on the actors and institutions that govern these flows, using a case study at a local level in Vietnam. In the last chapter conclusions are drawn with respect to this integrative perspective.

Environmental sciences, environmental social sciences, and environmental flows

Within environmental studies two major traditions in the study and analysis of environmental flows can be distinguished: (1) the classical analysis of environmental flows in physical terms, and (2) the analysis of environmental flows in relation to the institutions of modern society. Recently various attempts have been made to develop a third more integrative cluster of studies (Figure 1).

Conventional flow analyses

The origin of the classical tradition in the analysis of environmental flows lies in the ecosystem analysis and Odum's (1971) reworking of the Darwinian notion of the 'web of life'. The complex web of life is unravelled via detailed studies of the flow of materials and energy through the ecosystem. The web of life is then to be understood as the physical and biological web of life, the complex and fine-tuned relations, interactions and interdependencies between biological and physical entities of ecosystems via material and energy flows. Ecosystems are defined in terms of the density of the flows within the system, this density being higher when compared with the relations with

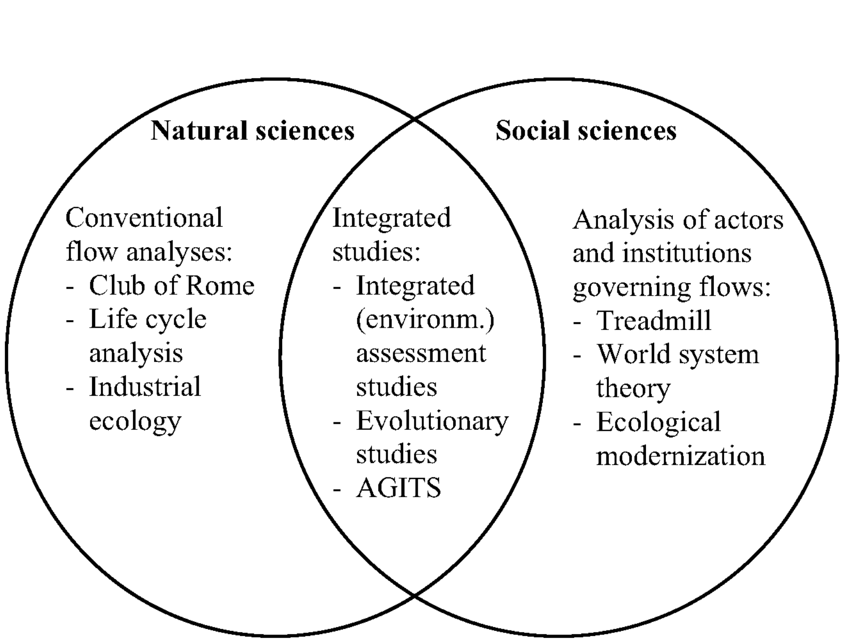

Figure 1. Three traditions in environmental flow analysis.

the outside world. Ecosystem studies focus on the processes of stability and change in the dynamic organization of energy and material flows within the system. Human beings and organizations are analysed, interpreted and given a place in a similar 'naturalistic' conceptualization, i.e., as units in the web of life that consume, process and excrete environmental flows. This classical tradition has developed further through Daly's (1973) notions of input, throughput and output. More recent popular environmental study perspectives, such as industrial ecology, life cycle analysis, ecological footprint analysis, material flow analysis and environmental system analysis, have elaborated on this classical view of ecosystem biology. These modern versions of the very same tradition continue to analyse environmental flows only or primarily in material terms.

Let us, as an example, have a closer look at the rather popular industrial ecology paradigm (e.g. Graedel & Allenby, 1995; Ayres *et al.*, 1996). The core idea of industrial ecology is to study the industrial system from an ecosystem angle. This perspective basically involves two starting points. First, the industrial system itself should be interpreted and analysed as a particular system with an 'internal' distribution of material and energy flows (not unlike the ecosystem). Second, the industrial system relies on (outside) resources and services provided by the biosphere. Both, the flows within the industrial system and the flows between the industrial system and the biosphere have to be optimized from a closed-cycle perspective, as is exemplified by natural ecosystems. Several authors take the ecological analogy further still, and seek to apply principles from biological processes to industrial processes (e.g. the use of solar power as sole energy source and the application of self-organizing processes). Several industrial ecologists, however, do acknowledge that the ecosystem analogy cannot be extended to all aspects of industrial processes (e.g. Boons & Baas, 1997; Lowe, 1997).

Life cycle analyses and industrial ecology studies both analyse the flow of materials and energy through production–consumption chains and systems, with a major focus on input, throughput and output, system leakages and disturbance of the natural ecosystem. These studies, however, pay little or no attention to social systems and social networks themselves [such as the social interactions and dynamics, the power relations governing these material flows, or the non-material (money, information, etc.) flows that parallel these material and energy flows.] Notwithstanding the periodic calls to widen these perspectives with, for instance, a theory of agency (e.g. Jackson & Clift, 1998) or social/industrial network analyses (e.g. Côté & Cohen-Rosenthal, 1998), industrial systems and production–consumption chains remain primarily and predominantly analysed in bio-physical terms, as 'industrial metabolism'. Environmental system analysis, material flow analysis and ecological footprint studies (e.g. Spangenberg *et al.*, 1998) are equally preoccupied with material substance flows through the natural environment, especially via complex modelling on increasingly larger scales. Perhaps the Intergovernmental Panel on Climate Change (IPCC) models of global climate change are among the most well-known large-scale examples of environmental system analysis, consisting of numerous models of water pollution, air pollution and soil pollution, as well as 'integrated models' of nitrogen, carbon and phosphorus cycles.

Social science approaches to flows

The social science or sociological tradition in analysing environmental flows could perhaps best be traced back to Schnaiberg's (1980) study on additions and withdrawals. Not unlike most environmental scholars in the classical tradition, Schnaiberg focuses on the flows of material substances and energy, interpreting environmental problems in terms of human additions to the natural environment (leading, for example, to pollution) and human withdrawals from the natural environment (causing depletion). But the sociological contribution to this 'flow analysis' focuses on the social practices and institutions that 'govern' these additions and withdrawals, by analysing how social dynamics, actor configurations and institutional arrangements and processes structure in a specific way the environmental flows that move in between society/economy and nature; the environmental flows themselves are left untouched. Many have followed this influential work of Schnaiberg and his conceptualization and analysis of environmental flows. In more or less the same tradition – but started more recently – world system theorists (e.g. Bunker, 1996; Goldfrank *et al.*, 1999) study environmental flows primarily in an international context. Their focus on larger social systems seems to give these studies a specific character when compared with the primarily national or local studies conducted in the tradition of Schnaiberg and associates. World system studies can be said to be in the 'sociological or social science' flow tradition, because their emphasis is less on the environmental flows as such and more on the logics of social systems that are constitutive for the specific patterns of the environmental flows under study. In a similar way, most ecological modernization scholars take a Schnaiberg-inspired conceptualization of environmental flows when explaining disturbances of the sustenance base primarily in terms of the design faults of those institutions that 'govern' production and consumption in modern societies (such as markets, states and legal institutions; e.g. Mol, 1995; Spaargaren, 1997).

Three attempts at integration

A third cluster of studies, somewhere in between the two classic types discussed so far, has emerged recently. These studies try to integrate natural science flow analyses with social science perspectives on the actors and institutions that govern these material flows. We provide three examples. A first – not so successful – example is formed by the 'classical' natural science perspectives on environmental flows, to which there is affixed some kind of soci(ologic)al analysis. Integrated (environmental) assessment studies, for example, aim to include economic and social analysis to complement and complete their initially restricted natural science perspective. These models posit nominal or superficial linkages with social actors, institutions and dynamics through either a stakeholder analysis or the introduction of the so-called DSPIR logic: Drivers, State (of the environment), Pressure, Impact, Response (e.g. Spangenberg *et al.*, 1998). Often these studies do little more than list the actors involved and the stakes they have in the industrial system. A second example is schools in the environmental social sciences that considerably enlarge the materialist dimensions of environmental flows in explaining social facts and developments related to these flows. In doing so, they de-emphasize socio-institutional analysis and come close to the industrial ecology and socio-biological schools of thought. Often one can detect in their studies a rather functionalist and unilinear-evolutionary perspective. Fisher-Kowalski's (1997) (see also Fischer-Kowalski & Haberl, 1997) work on the materialist foundations of societies in different stages of development provides an illustrative example. Third, in the AGITS programme we developed a methodology to combine natural science material flow analysis with social science approaches towards actors and institutions that govern these material flows. We shall elaborate that methodology below, especially via a case study.

Environmental flow analysis of family-scale tapioca production in Vietnam

To illustrate the AGITS approach we report on a case study of a small village in southern Vietnam, where family-scale tapioca (cassava starch) production is one of the key sources of income. Tra Co Village (Binh Minh Commune, Thong Nhat District, Dong Nai Province) is a typical traditional tapioca-producing village in southern Vietnam. In 2002 it consisted of 65 households earning money from tapioca production. During the period of cassava harvesting (from the end of December to the end of March), production capacity reaches 6–15 tons of fresh roots per household per day (with an average of 7 tons). In addition to tapioca production, inhabitants in this area also earn money from swine breeding (about 17 households, 30–100 swines per household) and slaughtering (about 6 households). The cassava roots are grown by farmers close to Tra Co Village.

The analysis of environmental flows as described below starts with explaining the production process through a material flow analysis and continues with analysing the options for improving the environmental performance by closing the material flows. Subsequently, we analyse the actors and institutions involved in Tra Co tapioca production in order to assess which of these potential environmental reform options have actual potential to be implemented and how.

Family scale tapioca production

Tapioca production processes among the households in Tra Co Village are largely similar. The common production process is shown in Figure 2. Fresh cassava roots are rinsed to remove the attached earth and dirt. Pieces of hard roots are removed manually during this process. The rinsed roots are ground to suitable size, and the resulting product is transferred to an extractor (mixing tank) where water is added to extract the starch from the ground roots. The starch-containing suspension, called starch milk, seeps through a polyester cloth located near the bottom and is transferred to a series of first-settling tanks. The residual fibre is removed through an outlet just above the cloth and stored in another tank for further processing. Starch milk, which is left in the first-settling tanks for about 8 hours, separates naturally into three layers. The upper layer – called supernatant – consists of impurities and is skimmed from the milk after releasing the middle layer of water. The bottom layer from the first-settling tanks is wet starch, which is mixed thoroughly with water and left to settle for a second time for about 12 hours (second-settling stage). Then again three layers are formed. After releasing the upper layer of water, the third layer of high quality starch is separated from the second layer of dirty starch. The latter is removed and transferred to another tank where it is thoroughly mixed with fresh water to separate the dirt from the unqualified starch. The remaining suspension is then transferred from the mixing tank into the third-settling tank for further recovering of starch after again 12 hours. Whether a third-settling stage is carried out depends on the availability of settling tanks.

Good quality starch from the second- and the third-settling stages are sold as wet starch, or as dry starch after sun drying. Residual fibre, and tapioca milk from the first- and second-settling (called pulp) are sun-dried and sold as raw material for animal feed production. Pieces of cassava roots or hard roots from the root-rinsing step are sun-dried and re-used as firewood.

The two main non-product sources from tapioca processing are solid by-products (including pieces of hard roots, fibrous residues and pulp) and wastewater (from root rinsing and settling stages). These non-product sources, especially wastewater, are contributing to serious environmental deterioration in Tra Co Village. The flow rate of wastewater from the 65 tapioca processing households in this area is up to 2500 m^3 per day. Currently, all wastewater from tapioca production is mixed with domestic, swine breeding and slaughtering wastewater, and discharged without any pre-treatment into existing open ditches connecting to three surface water bodies: Mi spring,

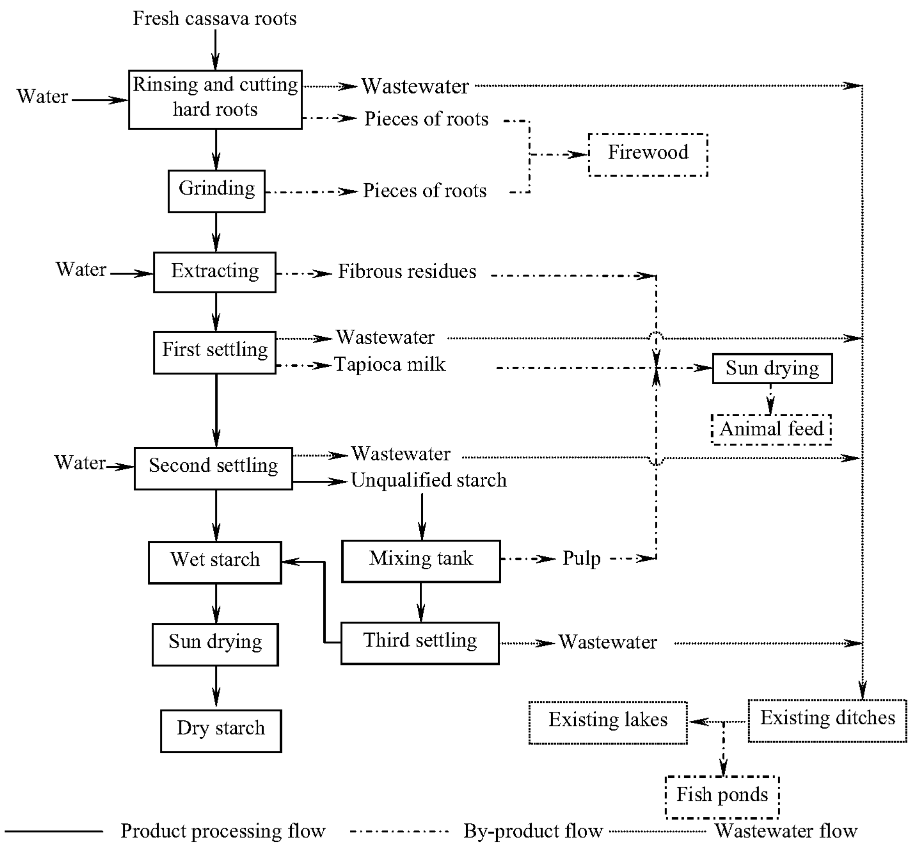

Figure 2. Diagrammatic representation of the family-scale tapioca production process at Tra Co Village, Vietnam.

Dia spring and Song May Lake. From the ditches a small part of the wastewater is used for fish culture. The high pollutant contents of tapioca wastewater (COD = 4000–21,000 mg l^{-1}, BOD_5 = 2000–16,000 mg l^{-1}, SS = 570–2900 mg l^{-1}, Org-N = 63–470 mg l^{-1}) cause heavy pollution of the environment.[1]

Options for environmental improvement

Options for preventing and reducing these environmental impacts can be identified in two domains: (1) prevention and reduction of non-product sources (cleaner production), and (2) external re-use and recycling of non-product sources (waste exchange).

[1] COD = Chemical Oxygen Demand; BOD_5 = Biological Oxygen Demand; SS = Suspended Solids; Org-N = Organic Nitrogen. These are all indicators for organic water pollution.

Options for waste prevention and reduction

Apart from pieces of hard roots, the major solid by-products from the tapioca production process are fibrous residues and pulp. Detailed material balance studies of tapioca processing households show that around 14% (by dry weight) of solid material is discharged together with the wastewater. This explains the high content of suspended solids in settling wastewater (around 600–2900 mg l^{-1}). Some non-tapioca-producing households earn money by recovering pulp from discharged tapioca wastewater. Two simple technologies are used. Wastewater is put into a small earthen tank with a cloth liner. While the water evaporates under the influence of the sun, the pulp remains on the cloth and is sold. Another method is placing cloth bags containing sand across the wastewater flow, which will also remove pulp from the water flow. These activities illustrate both the possibilities to recover and re-use suspended solids (mainly pulp), and the inefficiencies in the current tapioca production processes. We found that the amount of fibrous residues and pulp in wastewater depends on the efficiency of the grinding and extracting stages. The difference between 2 and 5 kg wet starch per 100 kg fresh cassava roots among tapioca processing households in Tra Co Village is explained by the grind sheet used: neither too coarse nor too fine grind sheets should be used.

Space proves to be a critical issue, both in applying three settling stages (which reduces the amount of pulp) and for the recovery of suspended solids in the settling wastewater. If there is sufficient space for the further settling of suspended solids in the first- and the second-settling wastewater, the amount of solid by-products released to the environment is reduced. Proper arrangement of settling tanks in a limited space with consideration of the production schedule may help in this situation.

Wastewater is currently generated from root rinsing and settling. Rinsing methods continuously release unnecessarily large amounts of wastewater into open ditches. Applying the countercurrent principle, as some households do, reduces wastewater from the rinsing stage. The current rinsing tank is divided into three smaller compartments to rinse the cassava roots in three steps. When the water of the last compartment becomes too dirty, this water will be re-used in the second compartment, while water in the second compartment will be re-used in the first compartment. In other words, water flow and cassava roots pass the rinsing tank in opposite direction.

Suspended solids in rinsing wastewater are mainly materials such as cork cells, clay and sand particles and dirt. Re-use is only possible if the clay and the dirt that adhere to the cassava roots are removed during harvesting. Vigneswaran *et al.* (1999) found that washing water can be re-used after sedimentation (dry season) or chemical coagulation followed by sedimentation (rainy season). In Tra Co Village, sedimentation for re-use is technologically possible, but – again – space limitations interfere.

A major amount of wastewater originates from the settling stages. After a certain settling period, wastewater is released from the settling tank by over-flowing, making it difficult to reduce the amount of settling wastewater generated within the production process itself. Re-using the third-settling wastewater for the first-settling stage would be a possibility. But producers are afraid that its quality affects the first-settling process, while good quality groundwater is freely available. Reducing the amount of pulp discharged together with wastewater would reduce the loss of solid by-product and is beneficial for applying anaerobic wastewater treatment processes. With the current production technology only proper operation, such as carefully skimming tapioca milk and pulp out of the settling tank, can reduce material loss with the wastewater. Marder & Trim (1996) showed that application of hydrocyclone technology could conserve water use and reduce wastewater with 50%, whilst maintaining product quality and production levels. Application of hydrocyclone technology in family-scale tapioca production in Tra Co Village would require much investment capital and skilled labour, but reduces wastewater treatment needs.

Options for external re-use and recycling of non-product sources

For unavoidable non-product flows, such as fibrous residues, pulp and wastewater, off-site re-use and recycling can be efficient. Fibrous residues and pulp can be re-used as low-value animal feed or fertilizer (Sriroth *et al.*, 2000) or for alcohol production (Agu *et al.*, 1997; Sriroth *et al.*, 2000), whereas tapioca wastewater can be re-used to produce biogas, and in aquaculture and irrigation (Vigneswaran *et al.*, 1999). Households in Tra Co Village practise the re-use of fibrous residues and pulp as raw material for animal feed production and the re-use of tapioca wastewater as fish feed.

For each category of waste flow the external re-use options can be prioritized, based on criteria of technological and economic feasibility. For solid non-products, the first priority is re-use as raw material for livestock feed production. Composting, together with livestock wastes, comes second. Although technically feasible, alcohol production would require high investments and skilled labour, making application for family-scale units difficult. For liquid non-products, the first priority is re-use in fish culture for human consumption. The remaining wastewater can be treated for re-use in irrigation or discharge into surface waters. The re-use of untreated wastewater for irrigation is possible if the organic loading is controlled properly to avoid deterioration of soil and groundwater quality. Energy (such as methane gas) from anaerobic composting and anaerobic wastewater treatment could be re-used in other production processes, provided its quality were good enough.

An industrial ecology model for Tra Co Village

Based on these potentials for environmental improvement an industrial ecology model for Tra Co Village can be developed (Figure 3), which aims at the reduction of environmental impacts and natural resource consumption by efficient utilization of resources, maximum reduction of non-product generation, and feasible re-use and recycling of non-products.

Compared with the existing situation, implementation of this model would reduce wastewater discharges with 43,040 m^3 per year by directly discharging into the wastewater-fed ponds. The remaining amount of 167,443 m^3 per year (or 1855 m^3 per day during the cassava harvesting season) of tapioca wastewater, together with 2300 m^3 per day of domestic wastewater, could be treated and returned to the cassava fields. So in this case, the presence of a wastewater treatment system (WWTS) would play an important role in the reduction and elimination of generated contaminants, the conservation of water resources and the improvement of cassava cultivation. Besides,

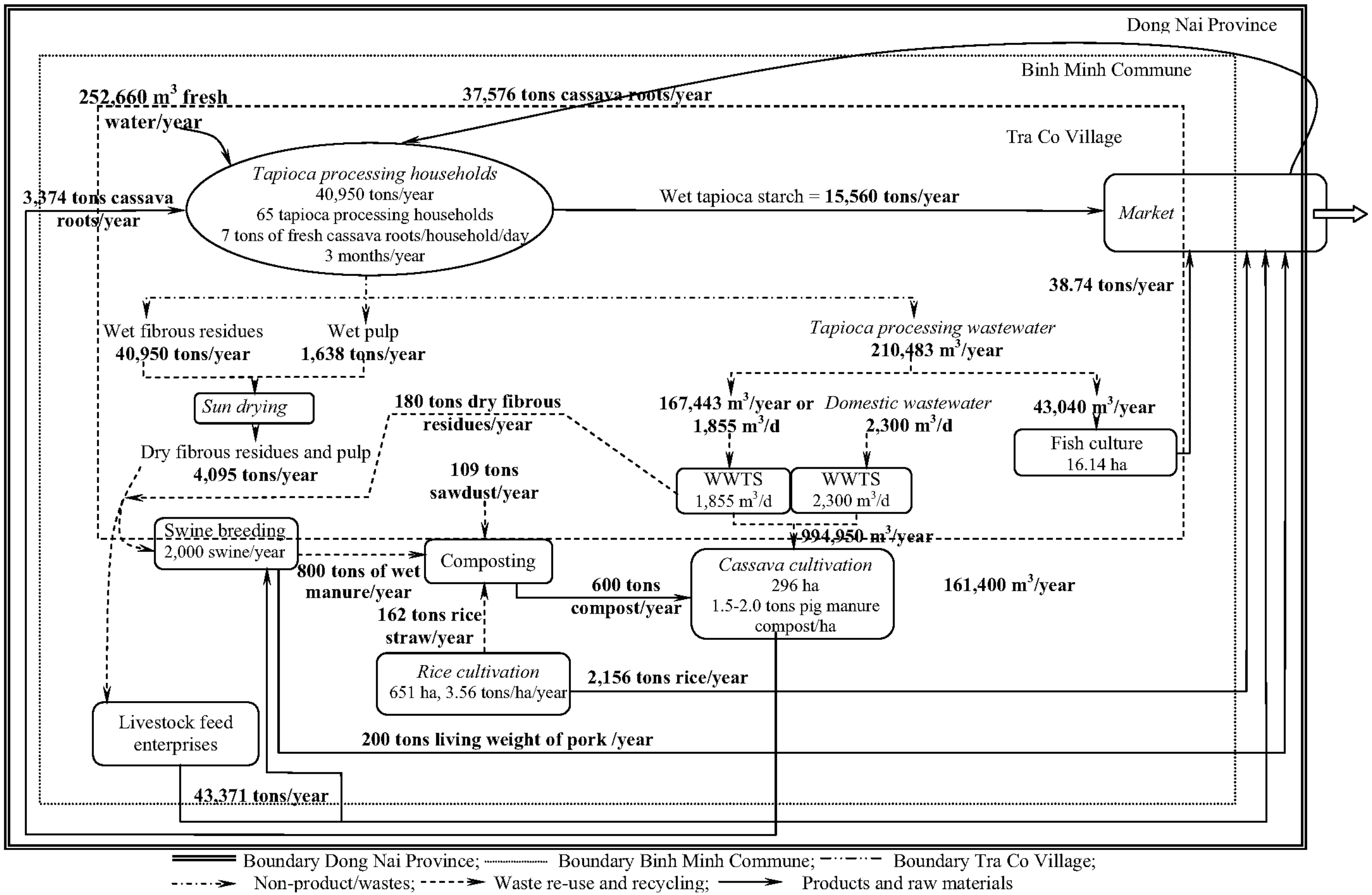

Figure 3. Material balance of an industrial ecology model for Tra Co Village, Vietnam.

re-using the effluent from the wastewater-fed ponds for cassava irrigation is another possible solution to (1) reduce the discharge of wastewater to the environment with some 161,400 m^3 per year, and (2) save an equal amount of water needed for cassava cultivation. Practical experience shows that the re-use of sun-dried fibrous residues and pulp as raw material for livestock feed production promises to be very attractive, not only from a perspective of waste reduction and environmental protection, but also in economic terms. Swine breeding and cattle breeding are typical activities of tapioca processing villages, and fibrous residues and pulp are re-used as swine and cattle feed. In addition, swine and cattle dung produces compost, a cheap and environmentally friendly soil amendment. Implementation of composting would provide about 600 tons of compost per year for cassava cultivation in Tra Co, while creating an opportunity to re-use rice straw and saw dust and reduce chemical fertilizer demand. In this model, the output of non-products or waste materials from tapioca processing are pre-treated and mostly re-used. This principle is also applied for re-using and recovery processes, thus almost reaching a closed material flow system. Three geographical boundaries (of Tra Co Village, Binh Minh Commune and Dong Nai Province) indicate the operational area of each subsystem. Fish culture, cassava cultivation and rice cultivation cannot be developed for Tra Co Village only, but have to take the other two villages of Binh Minh Commune into account. A livestock feed enterprise, for instance, is not even located in Binh Minh Commune but is present at other locations in Dong Nai Province. The market serves as an exchange mechanism and centre, receiving and distributing products among the various elements in the model.

This model presents a 'one moment' solution, while the tapioca market is dynamic. Family-scale produced tapioca is specially used for the local production of noodles, rice paper, cake and candy, and market demand for this starch quality can be expected to remain strong. Nevertheless, the number of tapioca processing households in Tra Co Village showed a 50% reduction over the last 20 years, especially due to the establishment of large-scale tapioca processing companies in the south of Vietnam. This gradual displacement of family-scale production units by larger-scale enterprises might continue, as Vietnam's industrial policy, foreign investments and economies of scale push for large-scale industrialization. Further co-operation and scaling up of tapioca processing in Tra Co Village could increase production efficiency, reduce environmentally adverse impacts, and thus cause changes in the alternatives and scale of re-use and recycling options, leading to changes in our industrial ecology model. But also then, the approach towards a no-waste system would remain the same.

The governance of industrial ecology: actors and institutions

To implement such a material flow model – or parts of it – in Tra Co Village, detailed network analyses of institutions and interactions that govern the decisions of tapioca-processing households have been carried out using a so-called triad-network analysis (Mol, 1995). Compared with a conventional stakeholder listing, this type of analysis follows a more theory-informed approach. It combines three analytical perspectives and rationalities (an economic, a political and a social-cultural) with three distinct actor configurations (economic, policy and societal actors) around tapioca production

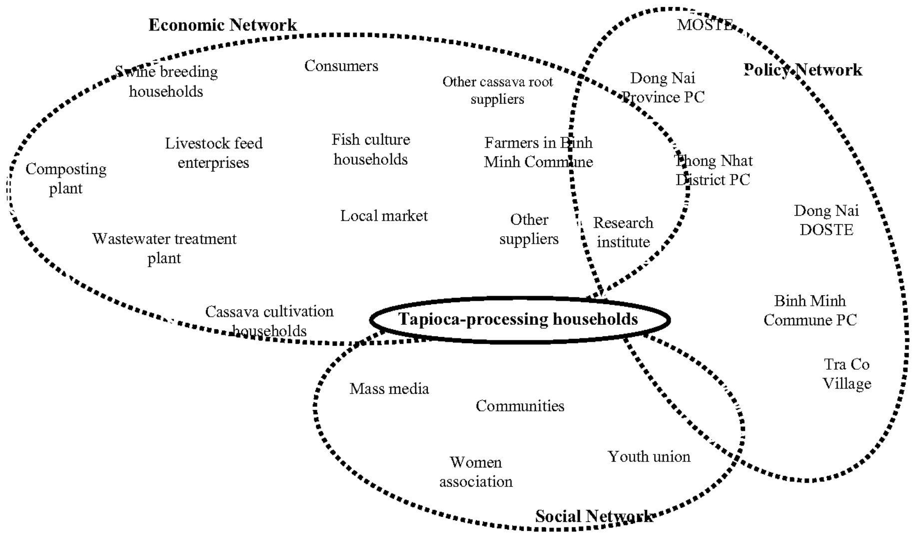

Figure 4. Networks embedding the tapioca processors of Tra Co Village, Vietnam.

(Figure 4). So each of the three interdependent networks constitutes a combination of a specific analytical perspective, distinct institutional arrangements, and a limited number of interaction (collective) actors that are considered to be most important regarding that perspective and rationale. Here we report on the relations within and between these networks, which support or constrain the implementation of the industrial ecology model for family-scale tapioca processing (see also Tran Thi My Dieu, 2003)

Economic networks

Economic networks consist of the economic interactions between economic agents in and around tapioca production. Analysis of these networks focuses on the relationships between tapioca producers and other economic agents, on the economic rules, resource endowments, property rights and contracts that govern these relationships, on the network structures in terms of power, resource dependencies and structure of information, and on the economic processes of continuity and transformation. The intellectual backgrounds of economic network analysis are mainly to be found in industrial organization theory, institutional economics and organizational sociology. Håkansson (1988), Martinelli (1991), Grabher (1993) and Håkansson & Johanson (1993) are relevant volumes that provide valuable conceptual tools for analysing these economic networks in detail. The relations with material flow analyses are evident, but the emphasis is on non-material economic dimensions of, in this case, tapioca production.

For limitations of space we do not report on the full economic network analysis, but present some main conclusions on the economic relations that are crucial in terms of enabling or constraining the implementation of industrial ecology options. First, in reducing water use, the economic arrangements that govern the use of water are crucial. As long as groundwater is obtained privately, free and without monitoring, water-use-reduction options are impracticable. Second, the economic push towards a collective wastewater treatment system could come from re-use possibilities for irrigation and soil structure improvement, but the realization of such a system would need support and co-ordination from governmental authorities or another collective institution. Third, several options pre-suppose further – institutionalized – co-operation of tapioca processing households, which does not yet exist. Extensive fieldwork has proven that until now households have only limited exchange of information and do not co-operate on common (economic) interests, such as marketing or waste treatment. Sharing information and experience – and building institutions for that – could increase starch extraction efficiency. Especially with the emergence of large-scale tapioca starch producers in southern Vietnam, such as VEDAN and Song Be – Singapore Tapioca Starch Company (SSTSC), co-operation is becoming essential to survive competition. Fourth, the limited production of cassava and the low starch content of the cassava roots in the agricultural areas surrounding Tra Co Village make that Tra Co producers increasingly buy their roots from elsewhere. This procurement structure undermines the local closing of substance flows and jeopardizes the re-use of non-product sources in agriculture. Finally, the re-use of non-product sources in aquaculture is a remarkably efficient and economically viable re-use option. It only seems to need further stimulation and optimalization, building upon existing network relations, arrangements and resource exchanges. There is no cultural barrier for re-using tapioca-processing wastewater for fish culture in Tra Co Village, and fish from tapioca wastewater-fed ponds is readily accepted. There are also no public health risks involved, as with some of the other pond systems that are fed with animal manure or other kinds of wastewater.

Policy networks

Within policy networks, interactions and institutional arrangements between state organizations and tapioca producers are primarily governed by political-administrative rules and resources. Policy network studies analyse, amongst other, the interdependencies between these actors, the 'rules of the game' that put these policy networks to work, the resource dependencies (regarding power, knowledge, information, etc.) between the various actors dominant in these policy networks, the common or diverging world views along which communication and joint strategies are developed or not. There is a considerable amount of literature (e.g. in neo-corporatism and policy community studies) that provides evidence of the usefulness of such analyses in understanding transformations and continuities between these interdependent network actors (e.g. Grant *et al.*, 1988; Marsh & Rhodes, 1992; Smith, 1993; Mol, 1995). Such analyses clarify how these relations enable, strengthen or constrain the introduction of industrial ecology options in Tra Co Village.

As a formerly centrally planned economy, Vietnam still has a strong governmental organization heavily involved in economic production. Government control is also significant in small-scale production in rural areas, for instance with respect to access to resources. But this control does not include environmental flow management.

Authorities from Tra Co Village and Binh Minh Commune show no interest in facilitating or strengthening any of the options towards industrial ecology. They share with tapioca producers a short-term, production-oriented outlook. Environmental monitoring, control and enforcement of rules in tapioca processing in Tra Co Village is the formal responsibility of the environmental authorities of Dong Nai province (DOSTE). With only 7 professional staff and 6 assistants, and a working area comprising 10 major industrial zones (with hundreds of large firms) and some 2000 small and medium sized enterprises outside these zones, it is no surprise that environmental pollution at Tra Co Village has hardly received attention. With a heavy reliance on command-and-control regulation but scarce resources for monitoring and effective enforcement, the (future) role of these authorities in pushing Tra Co Village towards more environmentally sound production is limited. A strong preoccupation with conventional end-of-pipe treatment systems, rather than the waste minimization and waste exchange options that are so central in industrial ecology, also complicates the adoption of several options. Few policy network relations thus support implementation of an industrial ecology model.

Societal networks

Societal network analysis aims at identifying relations between tapioca production and civil society organizations and arrangements associated with what is usually called 'the life world' (e.g. Habermas, 1981). It is the rich tradition of social movement research that provides the conceptual tools to analyse the interaction patterns – and their continuity and transformation – between on the one hand environmental, consumer and community organizations and on the other tapioca producers. With the absence of any environmental and consumer NGOs in Vietnam, so-called community-driven regulation of producers is the only likely arrangement facilitating industrial ecology options. Community-driven regulation refers to environmental regulation of industrial producers, which is strongly triggered by local communities complaining and reporting about environmental deterioration (cf. Phung Thuy Phuong, 2002; O'Rourke, 2003). In Tra Co Village, however, where the local community equals the producers and others who benefit from the processes that cause environmental problems, this model can play no significant role. Either the households have an interest in lax environmental enforcement as they generate waste or they earn money by recycling waste. In addition, most people living in this area are poor with low levels of education, and existing social organizations such as the youth union, the women association, and the veterans have shown no interest in environmental issues yet. Consequently, the present societal network relations and arrangements have limited relevance for governing environmental flows towards a more sustainable industrial ecology.

Epilogue

By adding to our industrial ecology model an analysis of the actor networks and institutional arrangements in which tapioca processing in Tra Co Village is embedded, a more realistic assessment is made of the potential for steering present-day small-scale tapioca processing into more sustainable directions. Insights into the institutional environment and the actor relations and dependencies enable us to opt for the most feasible paths into sustainability (e.g. strategies of re-use and recycling of wastewater and waste in fish ponds and agriculture that rely on the existing economic networks and do not need a strong state). By the same token these insights prevent us from being too optimistic in relying on policy arrangements and civil society pressures to manage environmental flows. Although we can design various environmental improvements (e.g. collective treatment systems), the institutional bottlenecks are far from marginal and not easy to lift. Our study highlights the social, economic and policy conditions that need to be met when technological options are to be realized.

How do we now assess the integrative potentials of this AGITS approach? The combination of material flow analyses with actor network models, as developed in the AGITS programme and exemplified in the case of tapioca production in Tra Co Village, forms an attempt to overcome the disciplinary dichotomies that still exist in scientific environmental flow analysis. Although the current approach has proven its value in the case of Tra Co Village, as well as in other AGITS studies at higher levels of aggregation, it should not be seen as the final answer in integrative studies in the field of environmental flows. Two reasons can be given for this. First, in this approach the level of true integration between the material flow analysis and the social actors and institutions governing flows is still limited. There is creative combination and linkage, but not so much integration. Second, the AGITS approach remains dominated by the natural science material flow analysis. The material flows set the agenda for the network analysis. For both reasons, the AGITS approach can be seen (like similar developments in the industrial ecology school of thought) as a limited social science amendment to the dominant paradigm of natural science environmental flow analyses. A relatively recent attempt to turn the tide of natural science dominance in environmental flow analyses is the development of the sociology of networks and (environmental) flows. Building upon recent developments in social theory (Castells, 1996; 1997a, b; Urry, 2000; 2003), environmental sociologists have started to develop a sociology of environmental flows (Spaargaren *et al.*, 2006). Whereas, as we have indicated elsewhere (Mol & Spaargaren, 2005), such a perspective diverts from existing social science approaches to environmental flows and gives the social sciences pride of place in environmental flow analyses, its usefulness for the integration of material and social dimensions still has to be proven.

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