Chapter 16
Inter-supply Chain Recycling of Residues

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As discussed elsewhere in this book, any expansion of agri-chains can result in competition for a territory's resources. The rapid growth of agri-chains, which have, over the past half century, become increasingly specialized, integrated, and globalized, has resulted in their disconnection from the territory. Yet, the extent of their sustainability is largely expressed in relation to local segments of the

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agri-chain, and is centred mainly on the local context (in terms of its environmental and, more importantly, social dimensions), a fact that necessitates a response that is specific and appropriate to this context.

The absence of relationships – or, worse, the presence of conflicting ones – between segments of various compartmentalized agri-chains that coexist in territories hinders the sustainable development of these agri-chains, and, more broadly, of the territories concerned. Creating links to the territory by identifying synergies between them could help overcome this limitation. A good example is the case of organic residues on Réunion Island (Wassenaar et al. 2015). More generally, this constraint concerns the consumption of limited local resources (for example, water, soil, agricultural land on which regulations allow waste to be spread, and landfill capacity, in the case of Réunion) or degradation of these resources by the dumping of various substances. In the context of a general and increasing scarcity, industrial ecology (the study of material and energy flows through industrial systems) intends using locally the gains obtained from increased energy and material efficiency via an inter-sectoral approach, known as 'industrial symbiosis'. This term is used in the broadest possible sense to include all production resulting from human effort and is also popularly known as the 'circular economy', which seeks to establish connections between activities, and thus between the links of the supply chains. The promise of the circular economy is to transform such waste into local resources by establishing inter-supply chain relationships that reduce the consumption and degradation of resources.

Local relationships between supply chains, especially between agricultural supply chains, have not all disappeared. Indeed, some of them are well-known and understood, and even promoted, by CIRAD. In the following sections, we will present a set of analyses and conceptions of relationships between local segments of different agri-chains (links of supply chains that transcend territories) using, respectively, socio-economic analyses and flow analyses.

However, where such relationships do not exist, the issue is how to create or re-create links between local segments of supply chains, whether agricultural or not. In material terms, these segments are hardly watertight: to pass on a product from an upstream segment to a downstream one within their supply chain, other incoming flows are generally used, which, in turn, generate still other outgoing flows within their territory. How to connect the lateral flows, which consist of orphan branches going out from a supply chain, to incoming orphan branches of other supply chains (Fig. 16.1), while allowing each segment to grow in step with the development of its own supply chain? This chapter presents the outcome of an initial attempt at industrial symbiosis involving agri-chains.

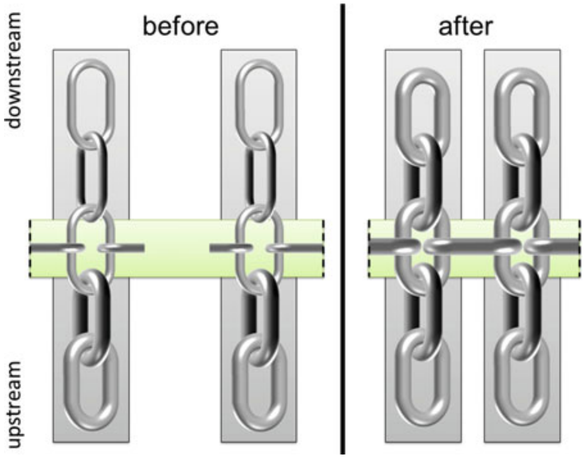

Fig. 16.1 Agri-chains (vertical links) can have segments (represented by links here) within the same territory (horizontal band) In case the development of the agri-chain is hindered by local incoming and/or outgoing flows of these segments, industrial symbiosis could seek to transform them into territorial links

16.1 Socio-economic Analyses of Recycling Situations

A common and age-old practice is for one agri-chain to recycle the organic residue generated by other supply chains. The dynamics of development continue to lead to the opportunistic emergence of new examples of such inter-supply chain links, which are sometimes documented by CIRAD (Box 16.1). Two cases of recycling are analyzed in detail here: the economic analysis of recycling urban waste by peri-urban agriculture in Cameroon, and the link between sugarcane cultivation and milk production in Réunion.

Box 16.1 Chicken manure from eastern Côte d'Ivoire used in cocoa plantations in the country's west

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Cocoa farms in Côte d'Ivoire first began using fertilizers in the early 1980s, in that country's Soubré region. Some farmers, concerned about the early mortality of their cocoa trees due to poor soils in the area, turned to the application of chemical fertilizers, all on their own, without any public or private support. This development would eventually help the 'cocoa fertilizer' market to grow to nearly 80,000 tonnes by 2003.

Just when the fertilizer industry began marketing chemical fertilizers for cocoa farms, family farms initiated a diversification of their fertilization strategies, towards a greater use of organic inputs. The use of chicken manure (the product of a new value chain) as a fertilizer for cocoa began as an innovation around the 2000s, and found considerable widespread acceptance

(continued)

Box 16.1 (continued)

by the 2010s. It was only in 2011 that a section of industry began showing an increasing interest in organic fertilizers, but the inescapable fact remains that chocolate multinationals came to this innovation much later than the pioneering villagers.

This practice was adopted much earlier in the west of the country than in the east, due in part to the poorer soils in the west and a much higher migrant population there. The increase in cocoa prices and improvements in the road network created conditions that were propitious to the development of a relationship between chicken manure and cocoa farms. An entrepreneur identified a potential financial benefit in this interaction: transportation of a by-product from farms in the east, where it had no value, to plantations in the west, where it had substantial and growing value. Profit margins on chicken manure were attractive enough to help overcome the associated costs and risks.

The results of this activity, however, were not uniformly positive. The dosage, location of application, and period for using this input were decided very empirically; some farmers even recorded a higher cocoa tree mortality. (Based on Ruf et al. 2015)

16.1.1 From Collection of Municipal Waste to Preparation of Organic Fertilizers for the Horticultural Chain in Cameroon

In Cameroon, nearly 75 % of household waste generated in the capital city, Yaoundé (two million inhabitants), comprises an organic portion (Parrot et al. 2009a) that is collected along with other waste by a private city-based firm and dumped in a landfill, without it being put to any beneficial use. At the same time, 13.6 % of the households practice urban and peri-urban agriculture in the city's low lying areas where buildings cannot be constructed. No rules or standards govern such production systems, and the use of chemical products has contributed to the pollution of these areas. The proximity of household organic waste dumps to agricultural production areas is conducive to the development of relationships between the horticultural chain and units producing organic fertilizers consisting mainly of organic amendments (compost) (Sotamenou and Parrot 2013). Thus, one third of these producers use organic matter (chicken manure, compost) purchased from artisanal units that have organized themselves into associations (Parrot et al. 2009b) (Fig. 16.2).

Studies conducted in Cameroon have attempted to assess the economic sustainability of the waste recycling chain. They have focused on understanding the economics of the entities involved (agricultural households, artisanal production

Fig. 16.2 Compost being made from household waste in Bafoussam (© Serge Simon, CIRAD)

associations, municipal collection services) in these interactions (Parrot et al. 2009b); on identifying, using econometric studies, the determinants of the adoption of organic amendments and synthetic inputs (Parrot et al. 2009a; Sotamenou and Parrot 2013); and economic analyses to estimate the real value of organic fertilizers (defined by their contents of N, P_2O_5, K_2O and international reference prices) in relation to their market value (defined by their actual selling price on local markets).

The results confirmed the findings of previous studies on how the distance between plots and storage facilities (usually the residence) influenced the use of organic or synthetic inputs. Territorial anchoring, characterized by soil and climate conditions, geographical proximity, and short circuits, plays a decisive role in the use of products whose transportation costs are high. Land tenure security encourages the use of organic amendments, either solely or in combination with synthetic inputs (Sotamenou and Parrot 2013).

In contrast, an agroeconomic analysis has revealed that there is no link between the real and commercial values of organic amendments. In the case study in Cameroon, it was found that the commercial value of compost was overestimated (sold at five times its actual value) because the production process resulted in amendments with poor N, P_2O_5, and K_2O content and very low humic potential. At the same time, an analysis of broiler manure showed that this organic amendment was being sold for one-third its real value. This is an example of information asymmetry in which buyers are not made aware of the real value of products they are buying.

Determining a market value that allows an economic development over the long term depends on the quality of the product which, in our case, in turn depends on the training of these small-scale producers. But to ensure that municipal waste collection is planned in the right perspective, and that the official waste collection chain encompasses a broader territorial and municipal range, its market value must also incorporate the transportation costs between points of collection, processing, and distribution, and assess the agronomic impacts in different soil and climatic conditions. New business models based on local opportunities and constraints are called for.

16.1.2 Integration of Sugarcane Cultivation and Dairy Farming on Réunion Island

Crop cultivation and livestock farming are important economic activities on Réunion Island. At present, a fodder shortage in the dry season and high cost of inputs (feed concentrates and mineral fertilizers) jeopardize the socio-economic and environmental viability of farms. An option to improve the situation is to create a more self-sufficient cultivation system where livestock manure is used as organic fertilizer in sugarcane fields, and sugarcane by-products (bagasse, straw cane, and cane sprouts) are used as cattle feed.

In order to measure the impacts of a closer integration between crop cultivation and livestock farming, and to better understand the reasons which hinder this integration among some farmers, a mathematical programming model was created, using the General Algebraic Modelling System (GAMS) software. It takes into account the technical, socio-economic, and environmental impacts of sugarcane cultivation and dairy farming in Réunion (Randrianasolo 2012). The model uses a normative approach to identify the optimal solution. The model's objective function is to simultaneously maximize the incomes from sugarcane cultivation and dairy farming.

Three scenarios were studied to reflect the different degrees of integration:

1. minimal integration between the two activities;
2. partial integration;
3. total integration of crop cultivation and livestock farming activities.

Results from different scenarios confirm the hypothesis that an increased interaction between the two agricultural activities, through the adoption of alternative techniques, increases the overall efficiency of the larger production system encompassing both these activities. Gradually, as the degree of integration increases, the margin on direct costs of the combined agricultural activities tends to rise. However, the distance between the place of production and the place of delivery of co-products acts as a limiting factor for adopting this integration. The quantity of fossil fuel used to produce 100 l of milk drops by about 30 % in the third scenario, when compared with the baseline situation. On the one hand, the use of sugarcane co-products reduces the amount of concentrated feed consumed per animal while, on the other, the use of livestock manure reduces the need for mineral fertilizers and, consequently, the energy required to produce milk, making this system more independent and less reliant on external inputs.

The model's outcomes highlight the usefulness of this approach to assess the impacts of modifications in agricultural practices in a context of constantly changing economic and environmental constraints. For example, the economic impact of a tripling of the price of imported inputs (feed concentrates and fertilizers), as happened in 2015 on the world market, on the incomes of dairy farming and sugarcane cultivation is now estimated as a net loss of approximately EUR 32 million per year. The fact that livestock farmers can now rely on alternatives to better utilize their forage resources and local fertilizers increases the resilience of their farms, and consequently minimizes the negative economic and environmental impacts of a rise in input prices. These economically efficient and independent farming systems also fulfil the expectations of society in terms of respect for the environment, job creation, and economic viability.

16.2 Analysis of Recycling Situations Through the Management of Biomass and Nutrient Flows

Understanding the relevance and importance of recycling linkages between local segments of supply chains in terms of mutual benefits (for example, potential economic or environmental gains, or employment), helps conserve, develop, and stimulate them better. It is a matter of quantifying the flow of materials exchanged, and their effects within and around each segment at appropriate spatial and temporal scales. We present here three analyses of existing or proposed exchange systems between segments of two agri-chains: within mixed farms; between farms in urban and peri-urban areas; and between farms at the regional level.

16.2.1 An Analysis of Intra-farm Interactions Between Crop Cultivation and Livestock Farming

Systems that integrate crop cultivation and livestock farming now account for over 50 % of the global meat and food production, and still predominate, especially in the tropics. This integration can be analyzed in terms of biomass recycling: pastures or crops supply plant biomass which can be used as animal feed, while these animals provide organic manure that can fertilize the plants. In recent years, quantitative methods derived from analytical methods to study food webs, with a focus on nutrient and energy cycles, have been applied to quantify the degree of integration between crop cultivation and livestock farming in various regions of the world: in Ethiopia, Kenya, and Zimbabwe (Rufino et al. 2009); Réunion

(Vayssières et al. 2011); Madagascar (Alvarez et al. 2012); and, more recently, in dry areas of West Africa (Bénagabou et al. 2014).

In Madagascar, the quantification of nitrogen flows within farms with integrated systems, using the Network Analysis method (Alvarez et al. 2012), confirmed the vital role of animals in maintaining soil fertility. Modifications in the feeding practices of dairy cows (increased use of concentrates) and the management of livestock waste (storage and application of manure) were simulated and revealed changes in nitrogen flows and in environmental sustainability indicators (nitrogen balance and efficiency, degree of nitrogen recycling, degree of integration of nitrogen flows, etc.). Improved manure management practices lead to reduced nitrogen losses through leaching and volatilization and increased soil nitrogen storage to levels similar or greater than those obtained by the application of additional mineral fertilizers, and, finally, to improved nitrogen recycling on farms. An increase in complementation results in a small improvement in nitrogen efficiency on farms. It must be noted that the association of these complementation practices with improved manure management practices proved to be most efficient in terms of nitrogen utilization at the farm level. Thus, the role of livestock rearing in maintaining soil fertility, through improved nutrients recycling, can be ensured by adopting manure management practices that limit nitrogen losses and can be further increased through the quality of feed.

These studies carried out in the tropics show a wide diversity, as much in between regions as within an area with the same soil and climate conditions. This diversity shows a good scope for progress in increasing the economic and environmental efficiency of agricultural production systems by promoting exchanges between crop cultivation and livestock rearing.

16.2.2 An Analysis by Simulation of the Use of Livestock Wastes in Peri-Urban Market Gardening: The Case of Rufisque (Senegal) and Mahajanga (Madagascar)

CIRAD analyzed the recycling potential of livestock wastes in market gardening in two peri-urban areas, that of Rufisque, a suburb of Dakar (N'Diénor et al. 2013), and that of Mahajanga, a coastal city northwest of Madagascar (Ramahefarison et al. 2013). These analyses were based on a dynamic simulation of a territorial system using a computer model (Guerrin 2001) in order to assess and design suitable methods for using these organic residues.

In the Rufisque department, organic residues are in great demand by market gardeners for two purposes: as a fertilizer for crops, and as mulch to maintain soil moisture. The territory produces large quantities of various kinds of organic residues: dung from draught horses, effluents from livestock (poultry, cattle), waste from agrifood industries (peanut dust, fish meal, and slaughterhouse waste). Several carters operate here to transport the organic residue within the territory, albeit with limited capabilities and only over short distances. As a result, organic residue is not always available to garden farmers, nor is it evenly distributed to be able to meet everyone's needs. Thus, while a shortage of organic matter is a problem for market gardeners, the surplus organic residue that piles up in some local farms that produce it poses risks to the environment.

Market gardening in the suburbs of Mahajanga mainly involves growing leafy vegetables in very short cycles (up to 12 cycles/year). Production is very variable and is dependent on a good understanding of intensification. While there is substantial demand for organic fertilizers, supply is limited due to temporal or spatial unavailability of organic residues. Even then, the city produces 10,000 tonnes of dung and droppings in numerous small-scale urban farms, which is equivalent to about 87 T/year of nitrogen, whereas the nitrogen demand of market gardening is estimated at only 6 T/year. At the same time, manure from most urban farms is not used productively, and thus represents a source of pollution and nuisance.

To simulate the regional management of organic residues, we used the Magma model (Guerrin 2001). Based on the dynamics of systems, it represents the territory in the form of a set of stocks linked by flows. The simulation involves calculating the flow of organic residues between production and consumption units, and stock inventory levels resulting from transport activities and the spreading of organic residues.

Three principal scenarios were developed to help simulate and assess:

1. current practices: excessive fertilization in Rufisque; surpluses and scarcities in Mahajanga;
2. consequences of an environment-friendly fertilization on the supply of organic residues to market gardeners;
3. logistical facilities necessary to transport organic residues to areas distant from urban centres.

Simulations that mirror ground reality in Rufisque show that some consumption units suffer from a lack of organic residues, while others suffer from an excess of it. In scenario 2, adjustments were made to the fertilization practices and, as a result, to the demand for organic residues from consumption units. Transportation and storage were also adapted to improve the situation simulated in Scenario 1. This resulted in a better distribution of organic residues between crops, a reduced risk of nitrogen pollution, and a reduction in labour time. Scenario 3 involved the relocation of some of the consumer units a hundred kilometres from Rufisque, due to pressure from increased urbanization and water shortages. Simulations have helped understand the characteristics of transportation and storage required in this hypothetical situation.

In Mahajanga, simulations of scenario 1, based on current practices of repeated application of organic manure and chemical fertilizers, revealed excessive fertilization in consumption units. A significant amount of livestock manure (63 %) generated in urban areas was lost as it could not be used by market gardens located at a distance, on the periphery of Mahajanga. The shortage of manure during peak market gardening season was mainly caused by a lack of transportation between production units and consumption units. In the current situation, simulations helped quantify excessive fertilization and inefficient use of surplus manure, which poses obvious environmental pollution risks. Adjustments in the dosage and frequency of application of organic residues and chemical fertilizers (scenario 2) partly helped reduce these risks. The relocation of some farms or the transportation of waste to the town's outskirts (scenario 3) would result in a better utilization of organic residues and to minimize environmental risks. To be effective, this new strategy should be supported by improved transportation facilities between production and consumption units, and the use of new logistical means (for example, trucks) to transport the manure produced in the city to farmers located at a distance of 30–90 km from Mahajanga who need organic residues.

These examples show the importance of coordinating supply and demand for different types of organic residues over space and time to ensure proper distribution in territories with several hundred farms. Modelling allows us to simulate dynamically the functioning of these territorial systems and to attempt to improve it from an agronomic and environmental point of view.

16.2.3 Nutrient Balance at the Territorial Level in a Perspective of Exchanges Between Livestock Farms and Fish Farming Units in the Red River Delta, Vietnam

A boom in pig production in Vietnam since 1990 has resulted in an average annual growth of 10 %, which has been maintained at this high level for 25 years. Thai Binh Province is one of 18 provinces in the Red River Delta, southeast of Hanoi, in northern Vietnam. This delta supports 18 million people, with record population densities of more than 1200 inhabitants/km^2. A rapid and continuing increase in the demand for animal products is forcing traditional livestock farms to adopt more intensive industrial techniques.

CIRAD and the National Institute of Animal Husbandry (NIAH) developed a tool in 2005 and 2006 to calculate the nutrient balance at the provincial and local levels in Thai Binh Province. Assessments of the nutrient absorption capacity of crops and ponds were thus compared with the production of livestock wastes, in particular pig dung. Results showed that fish ponds can consume significant amounts of livestock wastes, since they can make use of both liquid and solid effluents. The surface area of market gardens is not large enough to absorb all the liquid pig effluent, resulting in surplus amounts, which are steadily increasing from the already high levels in 2004, posing a real danger of chronic pollution. During winter, there is a marked mismatch between the stock of effluents available in the rural communes and the ability of crops to absorb them.

Very conscious of the environmental dangers that livestock farming poses, provincial authorities have validated the established diagnosis. Calculating spatial balances has become a common practice within a framework such as of territorial ecology that encompasses all the territory's sectors and agri-chains. As far as organic matter is concerned, the balances of different elements over the entire territory, at various scales, constitute valuable information to define targeted and relevant public interventions.

16.2.4 Lessons Learnt from the Situations Studied

The analyses presented indicate that, in addition to exchanges within mixed farms, there is significant potential for value enhancement and exchange of products between specialized farms belonging to different agri-chains, and this at various geographical scales. Although these analyses are mainly based on nitrogen or phosphorus requirements – other elements being either in surplus or supplemented by chemical fertilizers –, they show the potential of deriving value from waste produced by different agricultural or agro-industrial units by using it in cropping systems and fish farming. The importance of organization and coordination also partly explains why exchanges at these supra-farm scales exist rarely without external intervention. It also shows us that, at the geographic scale of the territory, the latter should be treated like an entity, that is to say a network of actors sharing and regulating activities within an area. Techniques can then be used to create or strengthen links within this network between actors of distinct and relatively compartmentalized agri-chain segments, but with a potential linkage on the basis of common interests. We can, nevertheless, ask ourselves whether the partial apprehension of the territory that such a relationship constitutes represents the most suitable exchange for the entire territory from the agronomic and economic points of view. How easy it is to find an answer to this question depends on the complexity of the territory concerned.

16.3 Creating an Industrial Symbiosis Between Supply Chains: An Example of Integrated Management of Organic Residues on Réunion Island

This section presents an industrial symbiosis approach to ensure the promotion of relevant exchanges between actors of (multiple) segments of (multiple) supply chains that make up a complex territory.

Réunion Island is an apt example of a territory exhibiting high potential for industrial symbiosis centred on organic residues. On the one hand, the agricultural sector remains heavily dependent on fertilizer imports. On the other hand, the island also imports large amounts of nutrients, both to meet the needs of its inhabitants and of its livestock farms. Since economic outflows in terms of nutrient exports are very low, the resulting structural surplus has a substantial impact which is increasing in tandem with the population, which is growing at a rate of about 10,000 inhabitants/ year on the island. The pressure this population growth puts on land resources further restricts the development of agricultural activities which, given the national and European regulatory frameworks, is already hard-pressed to achieve its goal of increasing the share of local production in the local market (products from market gardening and livestock rearing). At the same time, it is becoming increasingly difficult for the already overflowing landfills to handle organic residues from urban and agro-industrial activities. The desire to use and derive value from these new residues in agricultural activities has given rise to competition for agricultural land on which regulations allow waste to be spread.

While their motivations may vary, the concerned actors are willing to consider changes to overcome this impasse. Therein lies a prerequisite for industrial symbiosis: the benefits of participating must more than compensate the costs of mutual commitments. It follows that an integrated management of a territory's organic residues is perceived as beneficial since their accumulation will hinder the development of all the value chains concerned. However, other conditions are necessary, as experience has shown that initiatives rarely emerge spontaneously, even in such a situation. This is where the research community can play a dual role, which its status as a disinterested party without any direct interest in the value chains allows it to do: to catalyze a process of consensus by offering solutions; and also supporting this process with its knowledge, while facilitating consultations to arrive at a consolidated and acceptable solution. In order to fulfil this role of catalyst, the legitimacy of the research community's abilities must be recognized on the basis of its knowledge of the local situation.

16.3.1 The Approach and Its Implementation in Réunion

CIRAD has legitimate competency to initiate such a process in Réunion due to its extensive knowledge of local organic residues, of the benefits of their use under local conditions and the attendant risks, and, more generally, of the local agriculture. This skill set allowed it to bring together an initial group of stakeholders based on a framework proposal, and then to study it in its role of an actor involved in the implementation of the approach (Wassenaar et al. 2014). A comprehensive group of stakeholders' representatives was created to study the following assumptions:

- the management of organic material would benefit from being organized at the inter-communal scale;
- raw organic material is not suitable to be directly applied to crops, or to meet farmer needs;
- the production and marketing of standardized organic fertilizers from organic matter present in the territory, adapted to the needs of crops and farmers, would

go some way in solving local environmental problems in a sustainable manner and in reducing imports of synthetic fertilizers.

The approach adopted was based on several methodological proposals. Douthwaite et al. (2002), basing themselves on their method called 'Follow the Technology' (FTT), proposed involving stakeholders in an *in situ* assessment of workable technological solutions. The researcher, in this approach, becomes a supporter of farmers' innovations. Companion Modelling or Commod (Étienne 2011) is based on the same principle of extending support to actors for exploring organizational innovations. This approach uses modelling stages to study conditions and consequences of scenarios, without necessarily any practical implementation. The approach adopted for this study is based on both these methods by providing support to the stakeholders' representatives in exploring conditions and consequences linked to implementing a technology considered workable.

It was decided to study and understand the inter-communal level of Territoire de la Côte Ouest, a partner in the project with a population of 180,000 inhabitants, in a complex and dense institutional and regulatory context. The consultation system implemented endeavoured to support the reflection process within three arenas pertaining to different legitimacies (Queste and Wassenaar forthcoming; Wassenaar et al. 2015, for the co-construction stages):

- at the institutional level: a steering committee brought together representatives mandated by their institutions (governments, companies, consular chambers, etc.) to discuss and comment on the project guidelines. These steering committees have provided an institutional legitimacy to the project and the solutions studied;
- at the technical level: *ad hoc* working groups were established based on the co-optation principle. They brought together individuals identified by members of the project team as having knowledge, know-how, experience, or expertise relevant to discussions underway. The participation of these experts provided scientific and technical legitimacy to solutions co-constructed within the project framework;
- at the practical level: participatory workshops were organized that brought together members of any of the twelve target groups directly concerned by deriving agricultural value from organic matter (livestock farmers, green-areas maintenance services, planters, etc.). The participation of these representatives of target groups provided a twofold legitimacy to the project. First, it could claim to have taken into account, at least to some extent, the interest of stakeholders and, second, a regular consultation with these actors on solutions developed reinforced their social acceptability.

16.3.2 Proposals for Co-constructed Solutions

This process culminated in two prospective scenarios (detailed description in Wassenaar et al. 2015). These differ significantly from the original proposal, in terms of residues used (for example, the sludge from waste water treatment plants was finally excluded due to institutional reasons), treatment processes (for example, various regulatory constraints led to the abandoning of methanisation) and scale (for example, due to industrial design constraints, one of the planned recycling chains can only be implemented at an island-wide level, thus exceeding the inter-communal scope).

In the 'minimal' scenario, a value chain for a new fertilizer product will be introduced. A mixture of shredded green waste, poultry litter, and hog manure will be composted at a facility. The finished product would conform to the organic amendment standard NFU 44–051. This product will be of interest to market gardeners, as it would give them a complete fertilizer to be used once every two or three crop cycles. It could also be used as an exclusive fertilizer for sugarcane and pastures, but only when applied using mechanical means, which greatly reduces the extent of the area that can be benefited. The 'optimal' scenario extends the first scenario by developing a second value chain to produce both organic and organo-mineral fertilizers to cater to the needs of the main fertilizer market already identified: manual fertilization of the sugarcane ratoon crop. The challenge here is to produce a fertilizer that meets the annual needs of sugarcane without exceeding the maximum acceptable dose for manual application, estimated by farmers to be 2 T/ha. This value chain will be composed of many small co-composting plants whose products would form the organic base. These raw materials would subsequently be transported to a complementation and granulation factory that would develop two products meeting the NFU 42–001 standard.

Value can thus be derived from a huge part of the recoverable pool (which, in the case of pig manure, for example, remains well below the total quantity available). In the case of livestock wastes, this part goes up from 40 % for pig manure to 90 % for droppings from broiler chickens, and reaches 100 % for laying hens. The requirement of co-composting facilities for shredded green waste is half of the currently available quantity and thus will not jeopardize the needs of those who use green waste compost, including municipal green-areas maintenance services. The amount of waste which would finally have to be managed would decrease, resulting in economic, societal, and environmental benefits. Furthermore, the planned production of fertilizers would substitute a substantial amount of chemical fertilizer (about 1850 tonnes), which would fulfil an important objective collectively identified at the start of the project.

The creation of these value chains, which would be a practical application of the circular economy principle, requires, based on the conditions of the territory under study, considerable public financial support (Wassenaar et al. 2015). Even if such support is obtained, other obstacles will remain:

- long-term coordination between actors of a value chain will remain to be established;
- market constraints and price volatility of chemical fertilizers will limit profitability and rapid return on investment;
- the lack of certain technical references required to predict the agronomic effects of planned products, and the impossibility of producing them in the available time.

Following this participatory research, Qualitropic, a competitiveness cluster of industrial and agricultural actors in Réunion, is taking forward this project of industrial production of organic fertilizers and is working towards removing these obstacles.

16.4 Conclusion

In a world that is constantly evolving, links between different agri-chains or with other supply chains appear and develop with little contribution from the research community. While their very existence is a proof of their usefulness, these links are usually very short-term, opportunistic, and often unstable. This organizational instability is compounded by an inefficient utilization of agricultural products, resulting from an imperfect knowledge of materials and requirements, as illustrated in Box 16.1: the link between poultry litter and cocoa farms is very unstable, with raw chicken manure probably not very suitable for the requirements of cocoa trees. Other instances of bilateral exchanges are tried out in an opportunistic and *ad hoc* manner. All this justifies the usefulness of going beyond these tentative and unsystematic efforts.

Existing or desired relationships between local segments of supply chains are clearly very diverse in extent and nature, varying in complexity, magnitude, scale, involvement, etc. Through several examples, this chapter proposes different methods and tools for analyzing such systems of relationships, and for foresight and support, in both the technical and organizational dimensions. The diversity of situations described is largely explained by the composition of the territory and the dynamics of its development. A general rule seems to emerge: the more one endeavours to tailor these relationships to contribute to sustainable development – relationships that we would therefore want to be stable –, the more complicated they become and the more difficult to build. Direct and bilateral relationships are the ones that often form spontaneously. At the other extreme is the industrial symbiosis within territories in rapid development and often not sustainable. In this latter case, these relationships are recognized as new value chains: short-term, local, circular, transversal, which challenge the notions of the supply and value chain themselves. Similarly, the question of the scale of sustainable development arises: agri-chain, territory, transversal recycling chain, or a combination of all of them. The imperative of sustainable development compels us to find common ground between the point of view of the territory and that of the agri-chain. Thus, the territorial anchoring of agri-chains, through the development of inter-supply chain links, helps make these meeting points springboards for mutually beneficial relationships.

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