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Marco Antonio Pereira Querol

LEARNING CHALLENGES IN BIOGAS PRODUCTION FOR SUSTAINABILITY

An activity theoretical study of a network from a swine industry chain

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Helsinki 2011

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Abstract

This study is about the challenges of learning in the creation and implementation of new sustainable technologies. The system of biogas production in the Programme of Sustainable Swine Production (3S Programme) conducted by the Sadia food processing company in Santa Catarina State, Brazil, is used as a case example for exploring the challenges, possibilities and obstacles of learning in the use of biogas production as a way to increase the environmental sustainability of swine production. The aim is to contribute to the discussion about the possibilities of developing systems of biogas production for sustainability (BPfS).

In the study I develop hypotheses concerning the central challenges and possibilities for developing systems of BPfS in three phases. First, I construct a model of the network of activities involved in the BP for sustainability in the case study. Next, I construct a) an idealised model of the historically evolved concepts of BPfS through an analysis of the development of forms of BP and b) a hypothesis of the current central contradictions within and between the activity systems involved in BP for sustainability in the case study. This hypothesis is further developed through two actual empirical analyses: an analysis of the actors' senses in taking part in the system, and an analysis of the disturbance processes in the implementation and operation of the BP system in the 3S Programme.

The historical analysis shows that BP for sustainability in the 3S Programme emerged as a feasible solution for the contradiction between environmental protection and concentration, intensification and specialisation in swine production. This contradiction created a threat to the supply of swine to the food processing company. In the food production activity, the contradiction was expressed as a contradiction between the desire of the company to become "a sustainable company" and the situation in the outsourced farms. For the swine producers the contradiction was expressed between the contradictory rules in which the market exerted pressure which pushed for continual increases in scale, specialisation and concentration to keep the production economically viable, while the environmental rules imposed a limit to this expansion.

Although the observed disturbances in the biogas system seemed to be merely technical and localised within the farms, the analysis proposed that these disturbances were formed in and between the activity systems involved in the network

of BPfS during the implementation. The disturbances observed could be explained by four contradictions: a) contradictions between the new, more expanded activity of sustainable swine production and the old activity, b) a contradiction between the concept of BP for carbon credits and BP for local use in the BPfS that was implemented, c) contradictions between the new UNFCCC[1] methodology for applying for carbon credits and the small size of the farms, and d) between the technologies of biogas use and burning available in the market and the small size of the farms.

The main finding of this study relates to the zone of proximal development (ZPD) of the BPfS in Sadia food production chain. The model is first developed as a general model of concepts of BPfS and further developed here to the specific case of the BPfS in the 3S Programme. The model is composed of two developmental dimensions: societal and functional integration. The dimension of societal integration refers to the level of integration with other activities outside the farm. At one extreme, biogas production is self-sufficient and highly independent and the products of BP are consumed within the farm, while at the other extreme BP is highly integrated in markets and networks of collaboration, and BP products are exchanged within the markets. The dimension of functional integration refers to the level of integration between products and production processes so that economies of scope can be achieved by combining several functions using the same utility. At one extreme, BP is specialised in only one product, which allows achieving economies of scale, while at the other extreme there is an integrated production in which several biogas products are produced in order to maximise the outcomes from the BP system. The analysis suggests that BP is moving towards a societal integration, towards the market and towards a functional integration in which several biogas products are combined. The model is a hypothesis to be further tested through interventions by collectively constructing the new proposed concept of BPfS.

Another important contribution of this study refers to the concept of the learning challenge. Three central learning challenges for developing a sustainable system of BP in the 3S Programme were identified: 1) the development of cheaper and more practical technologies of burning and measuring the gas, as well as the reduction of costs of the process of certification, 2) the development of new ways of using biogas within farms, and 3) the creation of new local markets and networks for selling BP products. One general learning challenge is to find more varied and synergic ways of using BP products than solely for the production of carbon credits.

Both the model of the ZPD of BPfS and the identified learning challenges could be used as learning tools to facilitate the development of biogas production sys-

[1] UNFCCC – United Nations Framework Convention on Climate Change.

tems. The proposed model of the ZPD could be used to analyse different types of agricultural activities that face a similar contradiction. The findings could be used in interventions to help actors to find their own expansive actions and developmental projects for change. Rather than proposing a standardised "best" concept of BPfS, the idea of these learning tools is to facilitate the analysis of local situations and to help actors to make their activities more sustainable.

Keywords: biogas production, sustainability, sustainable technologies, disturbances, expansive learning, activity theory, learning challenges, and zone of proximal development

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Kasvatustieteellisiä tutkimuksia 240

Marco Antonio Pereira Querol

OPPIMISHAASTEET KESTÄVÄSSÄ BIOKAASUTUOTANNOSSA

Toiminnanteoreettinen tutkimus verkostosta sianlihan tuotantoketjussa

Tiivistelmä

Tämä tutkimus koskee oppimisen haasteita, joita kohdataan uusia kestävän tuotannon teknologioita luotaessa ja toteutettaessa. Tutkimuksen tapausesimerkkinä on Sadia elintarvikeyhtymän Santa Catarinan osavaltiossa Brasiliassa toteuttamaan kestävän siantuotannon ohjelmaan (3S-ohjelmaan) sisältyvä biokaasun tuotantojärjestelmä, jota käytetään siantuotannon ympäristökuormituksen vähentämisen keinona. Tapauksen avulla tutkitaan biokaasutuotannon oppimishaasteita, mahdollisuuksia ja esteitä. Tavoitteena on edistää tietämystä kestävää maataloutta palvelevan biokaasutuotannon (eli kestävän biokaasutuotannon, Biogas Production for Sustainability, BPfS) mahdollisuuksista.

Tutkimuksessani kehitän kolmessa vaiheessa hypoteeseja kestävän biokaasutuotannon kehittämisen keskeisistä haasteista ja mahdollisuuksista. Ensin muodostan tutkittavan tapauksen pohjalta mallin kestävän biokaasutuotannon toimintojen verkostosta. Sen jälkeen rakennan a) pelkistetyn mallin historian kuluessa kehittyneistä kestävän biokaasutuotannon konsepteista erittelemällä biokaasutuotannon muotojen kehitystä ja b) hypoteesin tämän hetken keskeisistä biokaasutuotantoon osallistuvien toimintajärjestelmien sisäisistä ja välisistä ristiriidoista tapausesimerkissä. Seuraavaksi koettelen ja rikastan hypoteesia kahden erilaisen nykykäytäntöä koskevan analyysin avulla: analyysillä toimijoiden henkilökohtaisista syistä olla mukana biokaasutuotannossa sekä analyysillä 3S-ohjelman biokaasutuotantojärjestelmän käyttöönotosta sekä käytössä esiintyvistä häiriöprosesseista.

Historiallinen analyysi osoittaa, että kestävän biokaasutuotannon järjestelmä syntyi 3S-ohjelmassa ratkaisuna ristiriitaan, joka vallitsi ympäristönsuojelun ja siantuotannon keskittymisen, voimaperäistymisen ja erikoistumisen välillä. Tämä ristiriita uhkasi elintarviketeollisuuden sikatoimituksia. Elintarviketuotannossa tämä ristiriita ilmeni ristiriitana yhtäältä yhtymän halun kehittyä ”kestävän tuotannon yhtiöksi” ja alihankintatilojen tilanteen välillä. Siantuottajille ristiriita näkyi eri sääntöjen välisenä: yhtäältä markkinat painostivat tuotannon jatkuvaan laajentamiseen, erikoistumiseen ja keskittämiseen, toisaalta ympäristönsuojelun säännöt asettivat laajenemiselle rajan.

Vaikka biokaasutuotantojärjestelmässä havaitut häiriöt näyttivät pelkästään teknisiltä ja sijoittuvan maatiloille. Analyysi osoitti kuitenkin, että häiriöt muodostuivat verkoston eri toimintajärjestelmissä ja näiden välisissä yhteyksissä. Ha-

vaitut häiriöt voitiin selittää kolmella sisäisellä ristiriidalla: a) ristiriidalla, joka vallitsi uuden, kestävän siantuotannon ja vanhan toiminnan välillä; b) ristiriidalla päästöoikeuksien kauppaan perustuvan biokaasutuotantokonseptin ja biokaasun paikalliseen käyttöön perustuvan tuotannon välillä; c) ristiriidalla UNFCCC:n[2] uuden päästöoikeusvaatimuksena olevan metodologian ja tilojen pienen koon välillä; sekä d) ristiriidalla, joka vallitsi biokaasun käyttöön ja polttamiseen markkinoilla tarjolla olevien teknologioiden ja tilojen pienen koon välillä.

Tämän tutkimuksen tärkeimmät löydökset liittyvät Sadia-yhtymän elintarviketuotantoketjun kestävän biokaasutuotannon lähikehityksen vyöhykkeeseen (LKV). Sitä koskeva malli on tuotettu luomalla ensin yleinen kestävää tuotantoa palvelevien biokaasun tuotantokonseptien malli ja kehittämällä sitä edelleen niin, että se sopii 3S-ohjelman erityiseen biokaasutuotannon järjestelmään. Malli muodostuu yhteiskunnallisen integraation ja toiminnallisen integraation kehitysulottuvuuksista. Yhteiskunnallisen integraation ulottuvuus tarkoittaa, missä määrin kaasuntuotanto on yhdistyneenä muihin toimintoihin tilan ulkopuolella. Ulottuvuuden toisessa päässä biokaasutuotannon tuotokset käytetään tilalla ja biokaasutuotanto on omavaraista ja hyvin riippumatonta, kun taas ulottuvuuden toisessa päässä biokaasutuotannon tuloksia vaihdetaan markkinoilla ja se on kytketty tiiviisti markkinoihin ja yhteistoimintaverkkoihin. Toiminnallisen integraation ulottuvuus viittaa yhdistelmäetujen saavuttamiseen: missä määrin tuotteet ja tuotantoprosessit liittyvät toisiinsa käyttämällä samaa välineistöä monen toiminnan toteuttamiseksi. Ulottuvuuden toisessa ääripäässä on yhteen tuotteeseen erikoistunut biokaasutuotanto, mikä mahdollistaa mittakaavaetujen saavuttamisen. Toisessa ääripäässä on monien biokaasutuotannon tuotteiden yhdistetty tuotanto, jossa tuotetaan monia tuotteita biokaasujärjestelmän tuotosten maksimoimiseksi. Analyysin perusteella näyttää siltä, että biokaasutuotanto on kehittymässä markkinoiden välityksellä tapahtuvan yhteiskunnallisten integraation suuntaan ja toiminnallisen integraation suuntaan yhdistämällä useiden biokaasutuotteiden tuotanto. Malli on hypoteesi jota on tarpeen testata rakentamalla kollektiivisesti kehitysinterventioiden avulla uusi, ehdotettu kestävän biokaasutuotannon konsepti.

Tämän tutkimuksen toinen tärkeä anti liittyy oppimishaasteen käsitteeseen. Tutkimus toi esiin kolme pysyvän biokaasutuotannon järjestelmän kehittämiseen 3S- ohjelmassa liittyvää oppimishaastetta: 1) halvempien ja käytännöllisempien biokaasun polttamisen ja mittaamisen teknologioiden kehittäminen sekä sertifiointiprosessin kustannusten vähentäminen, 2) uusien maatiloilla tapahtuvan biokaasun käyttötapojen kehittäminen, 3) paikallisten markkinoiden kehittäminen biokaasutuotteiden myymiseksi. Yleinen oppimishaaste on löytää erilaisia, toisiaan tukevia tapoja käyttää biokaasua muutoinkin kuin vain päästöoikeuksien tuottamiseen.

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[2] United Nations Framework Convention on Climate Change, Yhdistyneiden kansakuntien ilmastonmuutosta koskeva puitesopimus.

Sekä kestävää tuotantoa palvelevan biokaasutuotantojärjestelmän lähikehityksen vyöhykkeen mallia että tunnistettuja oppimishaasteita voidaan käyttää oppimisen välineinä helpottamaan biokaasutuotantojärjestelmien kehittämistä. Ehdotettua kestävän biokaasutuotannon lähikehityksen vyöhykkeen mallia voidaan käyttää erilaisten, samanlaisen ristiriidan kohdanneiden maatalouden alan toimintojen analyysiin. Löydöksiä voidaan käyttää kehitysinterventioissa auttamaan toimijoita löytämään omia ekspansiivisia tekoja ja kehityshankkeitaan. Tutkimus ei ehdota ”parasta” kestävän biokaasutuotannon konseptia, vaan kehitettyjen oppimisvälineiden avulla auttaa toimijoita kehittämään toiminnoistaan entistä kestävämpiä.

Vakioidun, ”parhaan” biokaasutuotannon konseptin suosittelemisen sijasta pyrkimyksenä on auttaa toimijoita kehittämään näiden oppimisvälineiden avulla toiminnoistaan entistä kestävämpiä.

Avainsanat: biokaasutuotanto, kestävyys, kestävän tuotannon teknologiat, häiriö, ekspansiivinen oppiminen, toiminnan teoria, oppimishaaste, lähikehityksen vyöhyke

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Finally, I should say that this book is dedicated to my two children, Camila Belén and Thiago Javier, who were born and grew up while writing this book. They were my main motivation to produce a work that could contribute to a more sustainable future.

CONTENTS

ABBREVIATIONS

ANT	Actor-Network Theory
BNDES	Banco Nacional de Desenvolvimento Economico e Social (Brazilian Development Bank)
BOOT	Build, Operation, Own and Transfer
BSTE	Bounded Socio-Technical Experiment
BP	Biogas Production
BPfS	Biogas Production for Sustainability
BPCC	Biogas Production for Carbon Credits
BPMM	Biogas Production for Multiple Markets
BPU	Biogas Production for Local Use
BPWM	Biogas Production for Waste Management
CER	Certified Emission Reduction
CDM	Clean Development Mechanism
DNA	Designated National Authority
DOE	Designated Operational Entities
DWR	Developmental Work Research
ECF	European Carbon Fund
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation)
FATMA	Fundação do Meio Ambiente do Estado de Santa Catarina (Foundation of the Environment from Santa Catarina State)
GHG	Greenhouse gases
MLP	Multi-level Perspective
PDD	Project Design Document
SC	Santa Catarina (State)
SI	Sadia Institute
SNM	Strategic Niche Management
TAC	Termo de Ajustamento de Coducta (Term for Adjusting Behaviour)
UNFCCC	United Nations Framework Convention on Climate Change
UPL	Unidade de Produção de Leitões
UT	Unidade de Terminação
3S Programme	Sadia Sustainable Swine Production Programme
ZPD	Zone of Proximal Development

1 BIOGAS FOR AN ENVIRONMENTALLY SUSTAINABLE SWINE PRODUCTION

1.1 The emerging problem of unsustainable swine production in Brazil

A foul wind was blowing over the green mountains. Change was on the way. Most of the governmental support for agriculture had fallen. The prices of agricultural products had crashed. Many farms had been closed. Many farmers, their families and workers had been forced to move to the cities to find jobs. Only those farmers able to concentrate production and specialise were able to continue. This concentration of production and specialisation led to a steady increase in the contamination of water resources and odour and a significant increase in greenhouse gases (GHG) emissions. Now, it was time to solve the problem. But the solution itself was struggling to become sustainable. Something would have to change, but what?

In the south-western part of the state of Santa Catarina (SC), Brazil, local rural communities have faced this situation. During the 1990s, important changes in agricultural and trade policies took place in Brazil, such as the deregulation of prices of agricultural products, the reduction of import taxes and other barriers, and the reduction of governmental support for agricultural activities. These changes forced companies to modernise in order to stay in business. In swine production activity, these changes led in a few years to considerable structural changes in how swine were produced. In the region, for example, in the period 1985-1996, the number of farmers supplying pigs to the food industry reduced by 55%, from 54,176 to 24,382 farmers, while the annual production increased by 180%, from 2,324,740 to 6,515,375 animals, suggesting a huge concentration and intensification of production per farm (Guivant & Miranda, 2005). In addition to the concentration of animals, a steady specialisation among those farmers producing swine was experienced (Testa, 2005). Similar changes were observed in other countries and regions of the world, such as the United States (Thu, 1998).

The concentration of the swine production in small areas and the specialisation of production led to the emergence of environmental problems. Many farmers stopped producing agricultural products such as maize and cassava, and specialised in swine. The specialisation led to the reduction of use of swine manure as fertiliser, while the concentration led to the increase in volume per area. These phenomena led to the aggravation of problems such as odour emission, the contamination of local water resources and the emission of gases, contributing to global climate change (Guivant & Miranda, 1999, 2004; Miranda, 2005).

1.2 Attempts to overcome the environmental impacts of swine production

The environmental problem of the pollution of water resourses caused by swine production in the south-west region of Santa Catarina was already recognised at the end of the 1980s, with increasing reports of the pollution of the local water resources. However, it was only at the beginning of the 1990s that solutions (e.g.,several legal instruments, programmes and technologies) began to be designed and implemented to deal with the problem (Miranda, 2005, see Chapter 6). In 1994, a programme was launched to support the expansion of swine production and manure treatment (Miranda, 2005). The solution promoted in the programme was mainly the implementation of open tanks for storing the manure and the application of the slurry as bio-fertiliser. Several studies have shown that this solution was not able to efficiently reduce water pollution.

The persistence of the environmental problem is confirmed by studies showing the presence in local rivers of high levels of nitrate, nitrite and ammonia as well as of organic matter (Palhares & Calijuri, 2006, 2007) and microorganisms, such as *E. coli,* which has compromised the use of water for human consumption (Palhares et al., 2005). In the literature, two basic explanations are given for the persistence of the water pollution. First, the volume of manure was above the available storage and distribution capacity, which led to an unsatisfactory treatment of the manure (Pillon et al., 2003). Second, it was assumed that farmers would voluntarily take the necessary actions, which in practice did not happen. Tasks that were considered routine, such as avoiding the excessive use of water, were simply not taken into account. Guivant and Miranda (1999, p. 108) point out that *"the simple installation of equipment was not enough to guarantee the control of the pollution if the everyday practices in swine manure management were not transformed"*. Consequently, the local and the global environmental impacts caused by the activity persisted.

Another tentative solution for dealing with the problem during the 1980s was the implementation of bio-digesters for biogas production (BP) (Gaspar, 2003). Biogas is a technology for waste treatment which has been known for several decades. In the 1970s and 1980s, BP emerged in several countries around the world mainly as a solution to the energy crises produced by the sharp increase in petrol prices (Marchaim, 1992). In this period in Brazil, thousands of bio-digesters were implemented in rural areas around the country with the main objective of producing energy and bio-fertiliser as well as of reducing the environmental impact of swine production (Kunz et al., 2004). However, as the price of petrol went down, most of the implemented bio-digesters and the idea of BP technology were abandoned. In addition to the decrease in petrol prices and the reduction of the economic viability of BP, other reasons are cited for the failure such as the low durability (under five years) of the metal cover of the bio-digesters, the large amount of labour required for maintaining the functioning of the bio-digesters, the lack of engagement of other parties (public and private organisations) in collaborating in finding new expanded and efficient ways of using the biogas and the lack of technical assistance for supporting the maintenance of the bio-digesters (Palhares et al., 2003; Miranda, 2005).

Another environmental problem associated with swine production is climate change (Laguë, 2003). This impact is attributed to methane emission and nitrous oxide from internal sources (from inside the animals) and from waste management. Animal production has been identified as one of the most important sources of emissions, contributing to an equivalent of 204,645 million metric tons of CO_2 in 1994, and is one of the main agricultural activities contributing to climate change (Ministério da Ciência e Tecnologia, 2004).

The rising concern about the problem of climate change and the creation of the possibility of using BP for carbon credits by the Kyoto Protocol and the Clean Development Mechanism (CDM) (Yapp & Rijk, 2005; UNAPCAEM, 2007) again raised biogas as an alternative instrument for promoting the environmental sustainability of swine production. In this new phase, biogas production is argued to have evolved: the technology for BP and its use have improved considerably and have become much cheaper, and more benefits can be generated, such as heat, energy and carbon credits (Kunz et al., 2004). In this phase, BP has acquired a new meaning with more benefits and uses. In addition to producing several economic benefits for farmers due to the possibility of obtaining extra income from the use of the biogas as energy and the carbon credits, biogas is also considered to produce a series of environmental benefits, such as reducing the greenhouse gases (GHG) emission, the emission of odour as well as the potential risks of the pollution of water sources (Lima, 2006). However, the benefits from biogas and carbon credits are not automatic, and should not be taken for granted (Guivant & Miranda, 2005). As Olsen (2007) points out, CDM projects, when left to the market alone, do not significantly contribute to sustainable development. In spite of the several benefits, the BP is not and cannot be seen as a definitive solution to the environmental problems caused by swine production, but it should rather be seen as a tool available to mitigate the environmental problems (Kunz et al., 2004; Miranda, 2005; Gonçalves, 2008). Kunz et al. (2004) point out that swine production needs sustainable actions that take into consideration that the activity demands natural resources, which have to be used according to conservation principles.

In this study, I am not interested in assessing whether carbon credits or BP are efficient solutions for the current local or global environmental problems faced by the human race. It may be that these technologies are not sufficient to solve our current problems. As pointed out by Röling (2002), environmental problems cannot be solved by markets or technologies alone. The point in this study is that they cannot be solved without them either. So we need a framework of analysis that combines the economic, social and technological (and in future studies, also the political) aspects or dimensions of the solutions together. The focus of this study is on the process of change, learning and development at the level of practices. I am interested in how the environmental solutions in themselves can be managed to become sustainable. This study is an attempt to combine the educational, economic and sociological aspects of building a complex system[1] of sustainable swine production.

1.3 The 3S Programme – a novel attempt to support sustainable swine production

The specific object of this research is the network of activities involved in BP in a programme for sustainable swine production called the 3S Programme. The basic assumption of the 3S Programme was that by producing biogas for carbon credits, swine production would become more sustainable. Thus, I call it biogas production for sustainability (BPfS), when referring to BP within the 3S Programme. **Sustainability** is understood here in the specific environmental (natural resources) and social context of swine production and biogas production for carbon credits. In this study, there are two kinds of sustainability: *the sustainability of BP* and *the environmental sustainability of swine production*. A sustainable swine production involves minimisation of the environmental pollution of local water resources, the emission of GHG and the generation income for farmers. The sustainability of BP is understood as the emergence and stabilisation of biogas so that social and environmental benefits are stably produced. If BP does not become sustainable, it cannot be used as an instrument for increasing the environmental sustainability of swine production.

The specific network of BPfS is introduced in more detail in Chapter 2. Here, it is enough to mention that the programme was initiated by a food processing company from Latin America called Sadia. The complexity, innovativeness and scale of the programme made it a particularly interesting object of study for grasping the emergence and development of networks of collaboration for environmental sustainability, and provides examples of challenges met in such networks of activities. Moreover, it deals with complex societal and environmental problems related to swine production, such as the pollution of water sources and the contribution to climate change, which are good examples of problems in which local and global components are intertwined.

When I started visiting and interviewing farmers and engineers, I perceived that in spite of the availability of resources (e.g., financial and human resources, knowledge, technologies and services) and the many expected benefits from BP, the programme was struggling to produce the promised outcomes. Up to the last data collection, two years after the beginning of the implementation of the bio-

[1] The word system is used in this study as a representation of a design (e.g., a plan or model) or a representation of something designed (e.g., a technology). In this sense, the word system may refer either to an artefact, e.g.: a combustion system, or to a representation of an object, e.g., an activity system (see section 4.1, Chapter 4).

digesters, the biogas produced was still neither being used for producing carbon credits nor as an energy source. There was still neither continuous maintenance of nor technical assistance for BP and combustion. Moreover, there were difficulties in "convincing" farmers to carry out basic operations for maximising biogas production. This situation puzzled me: why, despite all the favourable available resources, was the programme still not working as initially expected?

1.4 An example of a disturbance process in BPfS in the 3S Programme

Before presenting to the specific objectives of the study, I will introduce a concrete example of a disturbance (for the definition, see Section 5.7.1, Chapter 5) observed in the on-farm BPfS. The description is based on data from field work visits from May 2008, when I was following the work of a field work engineer. Although at first glance the problem, fixing a valve, seems to be one that can easily be solved, a closer investigation proposes that its solution involved a large network of actors who were directly and indirectly connected.

During the visit, the engineer observed that in some farms the biogas was not being burned. Excerpt 1.1 shows a conversation between the farmer and the field work engineer about this failure. In the excerpt, the interlocutors refer to at least to two unexpected events: the biogas was not being burned, and the people responsible for doing the maintenance were delaying to repair the malfunctioning device (the biogas valve).

Excerpt 1.1

> ***Engineer:*** *Is the flare working?*
> ***Farmer:*** *No. There is a problem in the biogas valve. It is not opening to release the gas to burn.*
> ***Engineer:*** *You informed there [to the office], didn't you?*
> ***Farmer:*** *Yes, I did it already. It was already a month ago. A month, no! 60 days ago!*
> ***Engineer:*** *Yes, I made the map. I was the one who made the map for the people [from the outsourced company who took care of the maintenance of the combustion system] to come here.*
> ***Farmer:*** *Yes, it was. But in this case this people were from "Alfa" [company responsible for the maintenance of the bio-digester]. Then, there was nothing to do with... [with the bio-digester]. Because I told Y [the name of the coordinator engineer], and he understood that it [the problem] was in the exit, in the tube. It was not in the tube, it was the biogas valve of the flare. The flare.*
> ***Researcher:*** *So you already informed them 60 days ago that it was not working, and the engineer Y did not ...*

Farmer: *The engineer Y told me that the people who...*
Engineer: *because them, for example, it is like this...*
Farmer: *from Benta*
Engineer: *No, it is Beta.*
Farmer: *Beta [agreeing]*
Engineer: *But it was like this, listen [researcher], when the people from "Alfa" came, they did not tell us that it was not their problem. So the information did not come to us.*
Farmer: *But I informed them again afterwards. On the day after I called engineer Y, then I called on Monday. I do not know what else I can do for these people to come.*
(Field visit to Marcus' farm, May 2008)

In the excerpt, the engineer is trying to explain to me that the delay in repairing the combustion system was due to a misunderstanding about the problem and who should come to fix it. Later on, the farmer corrected the engineer saying that he properly informed the engineer, and the problem was that people were not coming to fix the failure. Here, the disturbance was that the gas was not being burned because no one was repairing the flare.

In exerpt 1.2, the field work engineer explains what the problem was: there was no maintenance service hired yet. The people "from Sao Paulo", the financial administration of the project, which were responsible for hiring the company, had not approved the budget for the maintenance of the bio-digester and the combustion system. According to her, they did not know what was taking place in the field. This was leading to tensions regarding what should be done: "*So they think one thing and we...*"

Excerpt 1.2

Field work engineer: *The situation is this. The question is in hiring maintenance.*
Researcher 1: *Have you hired a company to do it?*
Field work engineer: *In Sao Paulo, it is there in Sao Paulo. It is not in our hands anymore. It is about to be hired.*
Researcher 1: *Ah, so it is not hired yet?*
Field work engineer: *No. It is like this. We will have frequent visits to the digester and to the flare. Frequent!*
Researcher 1: *Because you need control of this... of this equipment. If you leave them, other problems will appear. Then you will only....*
Field work engineer: *No, this is a difficulty we have. Something that we are having.*
[continuation]

Researcher 1: *Yes, now it is lacking that a company has been hired to do the maintenance.*
Field work engineer: *Yes, it is in the hands there, in Sao Paulo. And so on... And there is another thing that they are blocking. People from there, they do not have the vision from the field. So they think one thing and we ...*
Researcher 1: *who are in the everyday work.*
Field work engineer: *Who are in the everyday work, we want the best.*
Researcher: *Is it the Directorate of the Institute, who are you talking about?*
Field work engineer: *No. They are the people from supply [the supplying department], from the money part.*
(Field visit to Ugo's farm, 30 May 2008)

In Excerpt 1.3, another engineer from Sadia Institute (SI) talks on the phone with a person from the company that was supposed to be hired to do the maintenance of the combustion system. The people from the Directorate were waiting to hiring them because there was no income entering yet to compensate for the unexpected high costs of maintenance. The higher costs were related to the technological changes needed to adapt the project to new norms for applying for carbon credits. So, the financial administration of the project was in a dilemma between new higher costs and the lack of income.

Excerpt 1.3

Engineer: *Do you remember that we talked and I told you that I would take the case to the Directorate? Well, we spoke in our last meeting last week on the 19th, and people got scared with the values that were above the initial budget. So the decision was to hold a bit, so it is still under the decision of the Directorate. And the decision was to hold [wait] a bit this process [of hiring maintenance services].*
[...] we did an initial budget of x, we are five times above of what we had planned. [...] when we presented this to the guys: [they said] "We only have one source, the credits [carbon credits], and we still do not start working with it... we haven't started to trade them yet. So, should we assume this cost now?" So the decision was to hold a bit. I will ask you to wait a little bit more.
You know that we were working with the open flare, which was a very simple thing, but the methodology [the UNFCCC[2] methodology for carbon credits] obligated us to make a radical change. We are doing this to

[2] United Nations Framework Convention on Climate Change

all [the BP systems], we have 1,000 [bio-digesters]. We have around 850 [flares] already installed.
(Telephone call, Engineer Reginaldo, May 2008)

The example shows the complexity and the interconnectivity of the disturbances. Without carbon credits, there was no money to pay for the maintenance, and the flare was not repaired. This suggests that BP is a complex system situated between stabilised activities. Therefore, the kind of network it needs is a new type of structure, something above the well-defined network of the activities involved. Such a new kind of network requires collaboration between actors with different perspectives and creates a demand for a new kind of learning, which is neither individual learning nor organisational learning, but learning in a distributed network of activities. This study, therefore, deals with the learning needed to develop the BPfS system.

The disturbance presented above brings attention to several aspects of the BPfS system. First, the local disturbance involved several activities outside the farm, suggesting that an effective resolution would require the involvement not only of farmers and engineers but also actors from other activities. Second, there is a **diversity of perspectives** of the actors, who gave technological, communicational and economic reasons for the disturbance. All the explanations seem to be (partially) valid. For example, the field work engineer may be right that "the people from Sao Paulo" did not know what was happening in the field, but the Directorate had their own reasons for not approving the budget. Third, the technical, organisational and financial factors were interconnected, and call for a resolution at the level of a system rather than on the level of individual actors. The problem is how such a solution can be created when there is no one actor who should or could create it. This leads us to the question of how to understand these disturbances so that they can be effectively solved and the system made to work. In this study, I argue that the disturbances are expressions of contradictions within and between processes involved in the BPfS system, that is, the interdependent processes that are necessary for BPfS in the network disturb each other.

1.5 Explanations for the lack of environmental sustainability of BP

Experiences from the past have shown that the everyday problems present in this case of BP are neither new nor exclusive. BP has existed for hundreds of years (He, 2010), and in the last decades there have been several attempts to implement BP as a sustainable technology in several countries. During the 1970s, for instance, in Brazil many BP projects were implemented to promote it as an energy source, but most of them ended for various reasons. Many studies have been conducted to understand the success and failure of the expansion of BP (see Chapter 3, Section 3.1). In general, the most common explanation for the failure of the projects has been the lack of governmental support either in promoting biogas, guaranteeing markets, subsidies, training, maintenance, financing support and so on. Instead of analysing the broader system of the relationship, researchers have analysed the causes as isolated factors.

Unfortunately, few studies have analysed the challenges of developing sustainable BP by conceptualising it as a complex, evolving system of relationships. To fill this gap, my colleagues and I have conducted preliminary studies based on one case from Brazil and one from Finland. In the Brazilian case, BP started as a function of waste management and expanded its uses and functions to carbon credits and to sustainability (Pereira-Querol & Seppänen, 2009). In the Finnish case, the initial purpose of BP was a waste management technology and slowly expanded to include the production and use of different products that manage to make it sustainable and to grow (Pereira-Querol et al., 2010). Both studies strongly suggest that the sustainability of BP depends on the involved actors' capacity to combine its multiple uses and meanings and to solve expansively the contradictions emerging in the development of the system of production and use of BP. If this is true, being able to analyse the process of the development of the system in terms of the emergence and resolution of inner contradictions within it may be crucial to facilitate learning.

Recently, learning and networking have been pointed out as crucial for the successful development of sustainable technologies and of BP as well. Some studies have tried to conceptualise such processes (e.g.,Raven, 2005). When taken into consideration, learning in these studies is limited to cognitive changes such as changes in knowledge, values, principles and assumptions, overlooking the fact that cognition is also mediated by the concrete artefacts that mediate actions (see Section 4.2, Chapter 4). In this study, I argue that we should not limit the analysis of learning for sustainability to abstract concepts such as values, principles and assumptions, but also include the concrete, historically evolved artefacts that mediate activities in the analysis.

1.6 Attempts to understand the process of becoming more sustainable

Following the aggravation of environmental problems in recent decades, a discussion has emerged whether sustainability can be achieved at all. It has been pointed out that collective or social learning is crucial. Since then, the number of studies about social learning related to increasing sustainability has grown steadily (Keen et al., 2005; Blackmore, 2007; Wals, 2007). Moreover, it has also been recognised that the problem of "unintended side effects" of the current patterns of animal production cannot be solved only by applying current knowledge and technology. A broader scrutiny of the presumptions of production is needed (Bos & Grin, 2008), which requires what Beck et al. (2003) call reflexive modernisation. According to them, not only a transformation of the key institutions is needed but also of the very principles of society. Reflexive modernisation implies a meta-level change in rules, structure and practices. The authors propose that society is changing towards a second modern society in which the structure coordinates, categories and conceptualisations of change themselves are transformed.

According to Beck et al. (2003), the first modern society assumes that 1) nation-states are defined by territorial boundaries; 2) individuals are the basic societal formation; 3) there is full employment; 4) nature is a neutral source without limits of exploitation; 5) rationality is based on science; and 6) progressive specialisation is better and desirable. Modern society tends to see itself as lasting forever. Problems, when perceived at all, are seen as contingencies that have to be solved so that development can continue towards increasing differentiation, growing complexity and an expanding control over nature. Beck et al.'s (2003) notion of reflexive modernisation has been used by researchers in interventions aiming to redesign whole production systems towards more sustainable ways of producing (Grin et al., 2004; Bos & Grin, 2008).

The concept of reflexive modernisation suggests that society is moving towards an ever more complex society, in which the borders no longer hold within nation-states, knowledge becomes uncertain, and the process and the subject are no longer linear and causal, but complex and multiple. These changes suggest a new form of seeing production and relationships with nature where there is a systemic interrelation between the societal processes of natural-resources utilisation, production and waste threatment.

As suggested by Beck et al. (2003), the expressions of the first society and the potential for altering its course can only be made clear in empirical research. In this study, swine production has been moving towards an increase in scale, technological intensification and concentration, which clearly fits Beck et al.'s (2003) premise of functional differentiation. Such an increase has not taken into consideration the global and local environmental side effects of the expansion, which is also a characteristic of the first-order society. If swine production is to become sustainable and more reflexive, then a production with different relationships with nature, in which the manure is treated, is needed.

1.7 Structure of the Thesis

This study deals with the general **societal problem** of environmentally unsustainable swine production. In this study, I see BP as a potential instrument for increasing the environmental sustainability of swine production. It is assumed here that in order for biogas to be able to produce its potential environmental benefits and contribute to the environmental sustainability of swine production, biogas first of all must itself become sustainable. I follow Kunz and Palhares' (2004) suggestion that biogas and carbon credits should not be seen as a solution to the environmental problems caused by swine production, but rather as a part of a larger and more complex process of making swine production more sustainable.

The study aims at contributing to the discussion on how to make BP more sustainable. The study deals with the questions (see Section 5.1 in Chapter 5 for more details):

- Why and how has BPfS emerged in the Sadia food production chain?
- What are the future developmental possibilities of BPfS?
- What were the motivations of the food industry and farmers?
- How can the observed disturbances be explained?
- What are the challenges for BPfS to become sustainable?

In *Chapter 2,* the BPfS in the Sadia food production chain is introduced as the empirical object of the study. Helped by an ethnographic account, I depict the many actors and activities involved.

Chapter 3 reviews previous research on learning in the context of sustainable technologies. It starts with a review of the empirical studies, which is followed by an introduction of the three main identified theoretical approaches used in the research on learning in the implementation of sustainable technologies. At the end, the contributions and limitations of the dominant approaches are identified and discussed.

Chapter 4 presents the theoretical approach applied in the study, cultural-historical activity theory.

Chapter 5 presents the research questions, the developmental work research methodology, the empirical data and the methods of analysis applied in the study.

Chapter 6 analyses the historical development of the concepts of BPfS, and the emergence and developmental phases of BPfS in the 3S Programme. The analysis produces the first hypothesis of the current contradictions within and between activities involved in the BPfS network.

Chapter 7 analyses the current practices related to BPfS. In this chapter, I make two analyses: an analysis of the sense of BPfS for farmers and the food industry, and an analysis of the disturbances process that could be observed.

In *Chapter 8* the results of the two empirical chapters are summarised and discussed. The concrete future developmental possibilities of BP are drawn.

Chapter 9 presents the contributions of the study, limitations and future research.

2 BIOGAS PRODUCTION FOR SUSTAINABILITY AS AN OBJECT OF RESEARCH

This chapter introduces the network of activities involved in BPfS in the 3S Programme. I start by explaining the reasons why I selected biogas as the object of the study. I proceed by introducing the technology and the network of actors involved in the case study. I make an ethnographic description of two actors: the food industry and the farmers.

2.1 3S Programme

The Sadia Sustainable Swine Production Programme (3S Programme) was initially designed and implemented by a company called Sadia and a consultant company here called "Sigma".[3] Sadia was established in Brazil in 1944, and until the last data collection from May 2008, it was the market leader in many food sectors and one of Brazil's main exporters of meat-based products. It had 12 industrial plants in Brazil, which together produced over 1.3 million tons of protein-based products made from chicken, turkey, pork and beef in addition to pasta, margarines and desserts. Sadia has approximately 10,000 integrated fowl and pork farms by means of its Animal Production Management System, which supplies the raw material for the industrial plants.

Since the end of the 1990s in the south-west region of the state of Santa Catarina (SC), there has been increasing pressure from local communities for farmers and the food industry to deal with the problem of the pollution of local water sources caused by swine production. In 2001, a consortium was formed in the region to promote negotiation between representatives of the food industry and the local communities in order to adjust the farms to the environmental legislation. Parallel to this, Sadia started three Clean Development Mechanism (CDM) projects of BP in its own farms. In 2003, while writing the Project Design Document (PDD) in the application process for carbon credits, the engineers came up with the idea of using the CDM from the Kyoto Protocol, which would allow the farms of the outsourced farmers to be adjusted to the environmental legislation. In the first semester of 2004, Sadia started the design of the Programme. In December 2004, the Sadia Institute (SI) was created to implement the idea.

At the beginning of 2005 Sadia announced the emergence of the 3S Programme, aimed to promote the sustainable development of swine production. Sustainability was understood as the use of resources to satisfy the needs of the present without compromising the needs of future generations (Gro Brutland,

[3] The names of the companies and the actors involved were changed for confidentiality.

1990 cited in the "Training guidelines of the 3S Programme", March 2005). Sustainability in the programme involved elements such as the improvement and the conservation of the fertility and productivity of the soil, the use of low cost inputs, the satisfaction of human needs, the improvement of the quality of life of farmers, ecological adjustment by reducing the environmental impacts and protecting and improving the environment, and long-term sustainability instead of short-term profitability (3S Programme, 2005) (Figure 2.1).

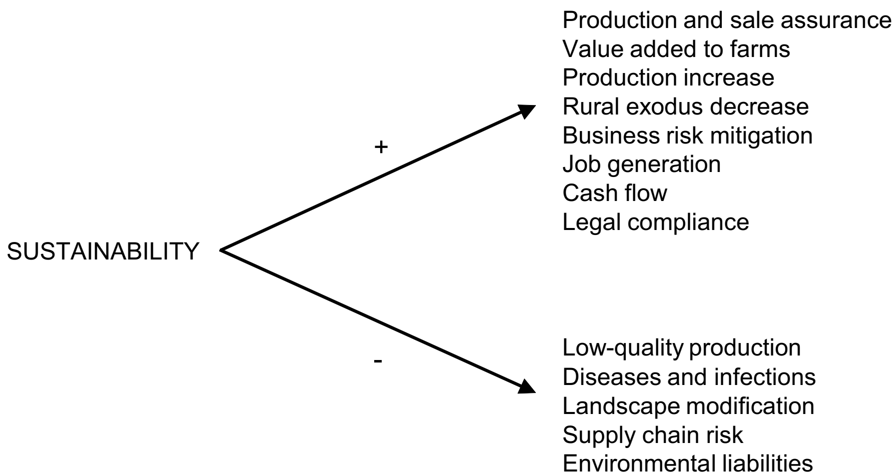

Figure 2.1 The advantages of sustainability according to the 3S Programme (adapted from the 3S Programme Guidelines, March 2005)

The specific objectives of the 3S Programme were to reduce the emission of GHG, to eliminate other environmental impacts caused by swine production (see Figure 2.2) and to improve the quality of life of farmers. BP can contribute to increasing the environmental sustainability of swine production by reducing its negative impacts.

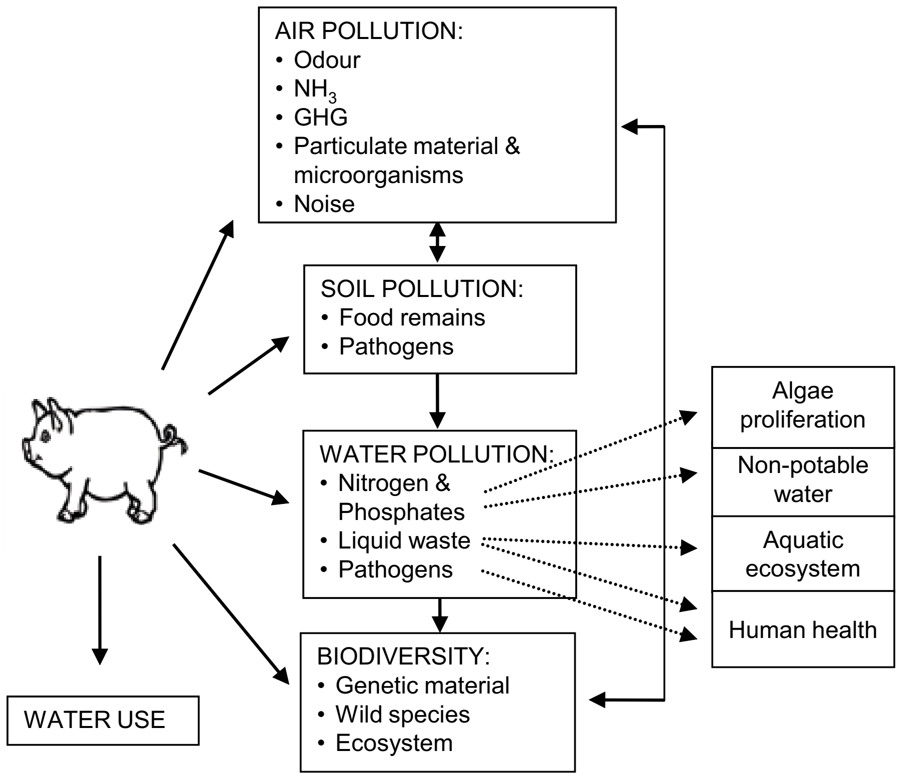

Figure 2.2 The negative environmental impacts of swine production (adapted from the 3S Programme brochure, 2006)

The functioning of the Programme

The idea of the 3S Programme was to implement CDM projects in the company's outsourced farms through the implementation of bio-digesters. These would be used to manage and treat swine manure and reduce GHG emissions. The Sadia Institute (SI) borrowed money from a financial institution (R$ 60 million from BNDES[4], approximately US$ 33 million) for purchasing and installing the bio-digesters and the combustion system in the outsourced farms. The SI would co-ordinate the implementation and maintenance of the bio-digesters, while the farmers would operate the bio-digesters leased to them by the SI, paying back the investment with carbon credits. The institute would negotiate the carbon credits on the carbon market, and the carbon revenue obtained would be used to cover the bio-digester installation and operational costs of the programme. The resulting surplus would be used to improve the social and environmental conditions of the participating farmers (Document MOB-2008). Until May 2008, the 3S Pro-

[4] Brazilian Development Bank

gramme was implemented in all the states in which Sadia operated, Santa Catarina, Paraná, Rio Grande do Sul, Mato Grosso and Minas Gerais.

2.2 The biogas technological system and its products

2.2.1 Biogas

The technology of BP that was implemented in 2008 was basically composed of a bio-digester, a combustion system and an open air lagoon in which to store the treated manure (see Figure 2.3). First, the swine manure was collected in the swine installation and conducted to the bio-digester. Within the bio-digester, the manure was transformed through a process called methanogenisis, in which methanogenic bacteria transformed organic particles into methane (CH_4). From this process, biogas, a gas composed of methane (50–60%), carbon dioxide (CO_2) and other gases is produced. The gas is collected from the digester and conducted to the combustion system, where it is burned and transformed into CO_2. In some cases, the biogas was being used to the heat chicken warehouse or as a source of electricity (Figure 2.4).

Figure 2.3 View of the biogas system (from CDM-SSC-CPA-DD Version 1, 3S Programme)

2.2.2 Bio-fertiliser

The liquid fraction of the manure was stored in an open lagoon and later applied to agricultural fields. The final slurry was an excellent bio-fertiliser, with a composition of nutrients that could be easily absorbed by plants. It was very appreciated by farmers conducting agricultural activities (e.g.,maize production or grass for dairy activities) (Figure 2.4).

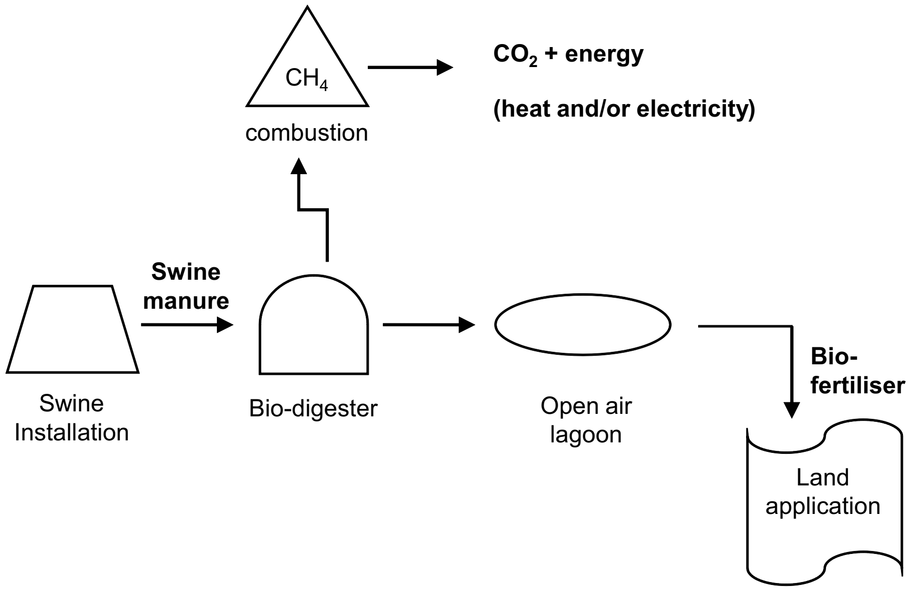

Figure 2.4 Representation of BP and the combustion system (modified from the document CDM-SSC-CPA-DD - Version 01)

2.2.3 Carbon credits

The CH_4 produced within the digester was burned and transformed into CO_2. According to studies, CO_2 contributes 21 times less to the greenhouse effect than CH_4. Thus, burning the CH_4 is considered a mitigation of GHG emissions. In a mechanism of the Kyoto Protocol, projects in developing countries that mitigate GHG emissions can apply for certificates of emission reduction, most commonly known as carbon credits. These are certificates emitted by an internationally recognised institution, e.g., the UNFCCC, which attests that a certain amount of GHG (usually measured as a ton of CO_2) has been mitigated. Once obtained, these certificates can be traded on the market and exchanged for money. The idea is that the organisation that buys the carbon credits can use them to adjust to levels of GHG emissions. In other words, the carbon trade allows GHG reductions to take place in countries with lower costs. This is a brief overview on how biogas is "transformed" into carbon credits. More complete explanations can be obtained elsewhere (Yapp & Rijk, 2005).

According to the plans, the BP would also produce carbon credits. For the food industry and farmers, the carbon credits were a potential tool for paying back the costs of implementing the BP system and an alternative source of income for farmers. However, applying for the certificates was a rather difficult and expensive process. Up to the last data collection (May 2008) no carbon credits had yet been obtained in the programme.

2.3 The network of actors of BPfS and the main processes in the 3S Programme

In the case study, BPfS involved a rather large and diverse network of stabilised activities. Figure 2.5 illustrates the complexity of this network. Although the figure is a static picture, it may be useful to visualise the actors involved in May of 2008. The actual production of gas took place within the outsourced farms (1). The farmers were responsible for the basic tasks of the actual gas production. This involved, among other steps, mixing the dejections accumulated at the bottom of the bio-digesters at least twice a month, taking care of the quality of the dejections that enter (e.g., avoiding disinfectants), and communicating any irregularity in the system to the SI.

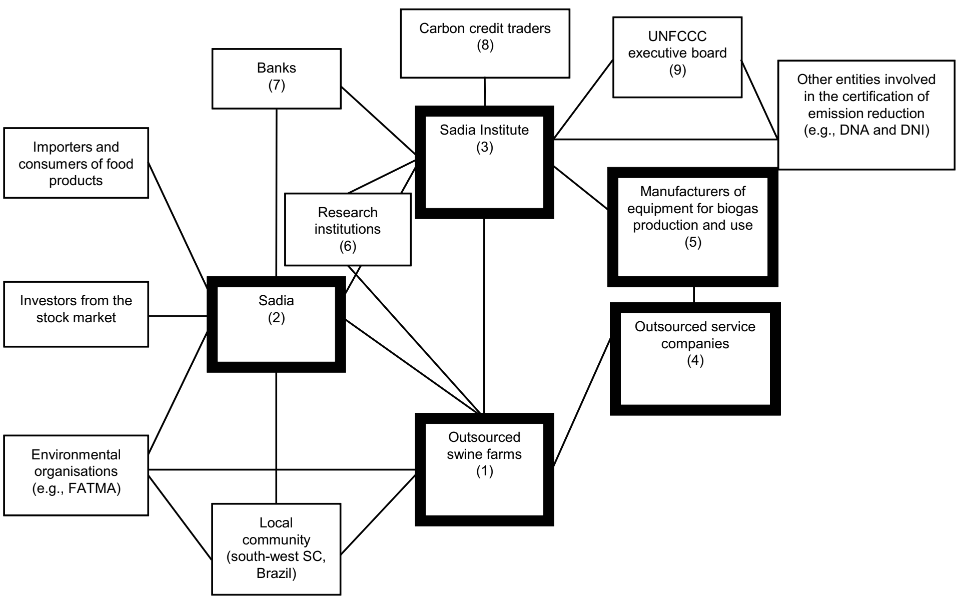

Figure 2.5 The network of the main actors related to biogas production (BP)

The main actors

Other central actors were the food processing company Sadia (2) and the SI (3). Formally, Sadia was the guarantor of the SI's loan for implementing the 3S Programme. In practice, there was no clear boundary between the two organisations as most of the staff working at the SI were volunteers from Sadia (engineers, technicians, lawyers, etc). The SI was responsible for developing, purchasing, installing and maintaining the BP equipment in the outsourced farms. It would be also responsible for commercialising the carbon credits in the market and distributing the revenue among the farmers (according to their potential of emission reductions). It would also provide technical assistance, and would periodically monitor the technological system to assess its functioning. According to the plans, the SI would recover the investment made in the implementation and the operational costs of the programme by charging a fee when trading carbon credits.

Another important group of actors were the outsourcing service companies (4) that provided installation and maintenance services for the bio-digesters. Manufacturing companies (5) were responsible for producing and sending equipment to the farms or to the outsourced service companies. There were also other actors, such as researcher institutions (e.g., Embrapa) (6) responsible for developing new technologies, banks that loaned money, such as BNDES (7), organisations that buy the carbon credits (European Carbon Fund) (8), international organisations, such as the United Nations (UNFCCC) (9), responsible for establishing the methodologies for carbon credits and emitting them.

The main processes

The process of *financing* was taken by the SI from a Brazilian National Development Bank, BNDES. The bank offered a loan with interest rates lower than the market rates. Sadia was the guarrantor of the loan.

The process of *design* was conducted mainly by Sadia and the SI engineers. Within the design an important process was the technology development. This process started with the selection of technologies by Sadia and SI engineers. The engineers searched for and contacted manufacturers that produced the needed components or were interested in developing new ones. The components were tested, either in Sadia's own biogas plants or on the outsourced farms. The engineers conducted the tests and selected the supplier and the technology that had the best cost-benefit relation, signing a contract to supply a certain amount of equipment in a certain period of time. Another way of developing the technology was by approaching research institutes and universities. Once the technology was defined, the SI hired an outsourced company to assemble and instal the technological systems in the outsourced farms, and to provide maintenance services.

The process of certification of the carbon credits was rather complex, involving several steps and actors which are too lengthy to mention here. In a brief description, based on the UNFCCC methodologies available, the SI prepared a project design and sent it to a series of entities, which assessed the project in several respects. If approved, the project was sent to the UNFCCC for validation. When the project is officially registered, the carbon credits can be traded on the market and sold in exchange for money. In the case of the 3S Programme, the carbon credits were traded in advance, being sold to the European Carbon Fund.

The process of applying for carbon credits through the CDM of the Kyoto Protocol starts when an organisation with a project for mitigating the emission of GHG writes a Project Design Document (PDD). In the 3S Programme this organisation was the SI. Such projects are guided by the methodological prescription of the UNFCCC. Once the PDD is ready, it is sent to a Designated Operational Entity (DOE) for a process called validation, and to a Designated National Authority (DNA), which evaluates whether the project contributes to clean development. If the DNA considers the project to have positive impacts on this development, it sends a letter of approval to the UNFCCC. Once the DOE and te DNA have approved the PDD, the applicant makes a request of registration of the project. The moment of registration is called moment zero, at which the credits begin to be counted. After a certain period, a process called verification is conducted by the DOE to check whether GHG are being properly reduced according to the original plans (Interview with Santos, 2007).

The process of the actual production of biogas takes place on the farms. The volume of gas burned as well as the temperature, pressure and other measurements are registered in a computer, which would be constantly monitored by Sadia's field work technicians. The training of farmers and monitoring of the technologies is done by the SI staff, but the responsibility is expected to be transferred to Sadia as soon as the project is registered by the UNFCCC.

2.4 The food processing company and farmers

It is difficult, if not impossible, to say which actors were the most important, as they were all needed for the system to function well. However, I focused the ethnographic description on two groups, the farmers and the food processing company, based on the fact that they are closely related to the actual level of production, and therefore, the ones that directly produce the environmental outcomes.

The company owned more than 12 industrial plants. Among these, the one located in the city Concordia, SC is considered the company's headquarters (Figure 2.6). I had selected this area because, according to the managers of the 3S Programme, it was the most challenging due to the size and diversity of the farms.

Figure 2.6 Geographic location of Concordia, SC, Brazil[5]

2.4.1 Sadia's systems of swine production

The food processing compamy Sadia, as well as the majority of the companies in the food industry in Santa Catarina, outsourced the production of raw material (turkey, pigs and chicken) to farmers, which were called **integrados.** Until May 2008, there were mainly two kinds of outsourcing swine production systems: the **breeding farms** (called Unidade de Produção de Leitões – UPL) and the **market farms** (called Unidade de Terminação – UT).

In the breeding farm system, the farmers were responsible for mating the males and sows, managing the gestation period, and raising the piglets until they were about 60 days old and approximately 22 kg, when they were delivered to the market farms. In 2008, the breeding system was subdivided into at least two parts. In the first one, the **independent** system, farmers owned the sows and males, and were responsible for buying and preparing the food and medicine given to the animals. In the second, the **comodato** breeding system, the food processing company owned the variable means of production (sows, males, food and medicines).

In the market farm system, farmers received a certain amount of piglets established by the food processing company according to the market demand. The piglets were fattened for 120 days or until they reach an average weight of 130 kg, when they were finally delivered to the food processing company's slaughterhouse. Like in the comodato breeding, the farmers received the food, the medicines and other inputs as well as advisory services from the food industry. The farmers were responsible for supplying the labour force, water, energy and the physical infrastructure (such as warehouses), maintaining the infrastructure in good condition, following the technical advice, and treating, using, transporting and distributing the swine manure according to the environmental legislation. The farmers were

[5] Source: http://www.transportes.gov.br/bit/inmapa.htm, and http://www.amauc.org.br.

paid according to the market price of the swine, indexes of performance and bonuses. The payment was based on a formula that aimed to maximise the use of the inputs provided by the food processing company and the production. The payment, obligations of both of the parties, negotiations, penalties, restrictions, the volume to be produced, the payment of guarantees and technical specifications were established in a commercial contract signed by the farmers and the food processing company (Miele & Waquil, 2006).

2.4.2 The diversity of the farmers and uses of the biogas

The agriculture in the south-west region of Santa Catarina is characterised by family farming (small- and middle-sized farms with the family as the main source of labour). The main agricultural activities are those with intensive use of labour (chicken and swine production), and their location has an important impact on production costs. Other agricultural activities such as grain production are not considered competitive because the farms are too small to allow for large-scale production and the topographic conditions do not favour mechanisation.

The farms of the region are relatively highly diversified (with multiple farming activities) in relation to other regions of the country, where monocultures are more common. Such diversity is an important strategy, especially among the small-size market farmers, for reducing risks and guaranteeing a constant income. In the market system of production, for instance, the farmer receives the payment for the production only after the "set of animals" is finished, which can take up to three months. This means that during this period the farmer does not have any income. The diversity, thus, was a way to compensate for the seasonality in income. Milk production was widely used for this purpose as it was based on weekly payments. Among the breeding farmers, the time between payments was not as long. This reduced the need to combine activities. The frequent source of income allowed them to specialise in the production of piglets. In general, the diversification of production was more common among market farmers (UT) than among breeding farmers (UPL).

The diversity of activities among and within the outsourced farms is an important aspect for BPfS at least for two reasons. First, it is important to understand the diversity of meanings of biogas and carbon credits. For example, for farmers producing swine and chickens, biogas has an important meaning as a heating source for the animals during the winter, while farmers solely engaged in hog production, which has alow energy demand, were not interested in using the gas. Second, small-size farmers were interested in receiving the money from carbon credits in weekly payments rather than once a year.

For simplification, I will categorise the farmers into three groups according to their demand for the biogas. The first group is the **breeding farmers with no other farming activity**, who were usually interested in using the biogas for heating for the piglets' warehouse during the winter. In most of the farms, the heating was supplied by electric lamps, which demanded a high amount of energy during the winter (one or two months per year). Usually, there was no further need for heating during the rest of the year. Although some breeding farmers may also have other farming activities, I will not consider this as a possibility as it was not common. The second group is the **market farmers with no other farming activities** or with activities with a low energy demand. These farmers were not interested in using the gas on the farm. In some cases, the farmers had the idea of using the gas to produce electricity to be sold to the electrical network. The third group of farmers was the **market farmers with other farming activities** with high energy demands, such as chicken and food production. For example, those market farmers engaged in chicken production were usually very interested in using the biogas for heating the chicken warehouse during the winter. Chicken production demanded a high quantity of heat, which was at that time mainly supplied by wood fire or LPG (liquefied petroleum gas). Though the wood fire was a cheaper source of energy, it demanded a high amount of labour for obtaining the wood and controlling the temperature inside the chicken warehouse.

2.5 The script of operations and the plans of implementation of BPfS in the 3S Programme

In this section, I present the scripts and plans of BPfS in the 3S Programme. As mentioned in Section 5.7.1 in Chapter 5, scripts refer either to the plans or daily operations of BPfS. A *plan of change* refers to the steps of implementation of the project (writing the project design, installation of the bio-digesters), i.e., how the changes have been planned to proceed, while the *script of operations* refers to the expected course of actions needed to keep the system working (the roles of the actors).

I present the way in which BPfS was described in the documents and how the Sadia engineers explained the plans. The script from the farmers' perspective was not possible to be reconstructed in detail mainly for two reasons: first, due to the diversity of the plans and operations, and second, due to the lack of data about them. Each farm had rather different expectations towards BP, different relationships with the SI technicians and different tools available to do the operations. Therefore, each farm differed regarding the routines that they followed and their plans. Moreover, in contrast to Sadia, the farmers did not have their plans and routines documented, and they could not easily describe their operations in detail. In order to obtain their script, it would be necessary to follow the farmers' practices for a longer period of time than what was covered in this study. Thus, I would have to follow another research strategy to explore the farmers' scripts.

The farmers' scripts are implicit as to what they regard as disturbances. As mentioned in Chapter 5, script and disturbance are mutually defining concepts. It means that an undesirable event such as the malfunctioning of a machine may also indicate a desirable or expected event. Analogously, a desirable action may indicate an undesirable action. The farmers' scripts and disturbances in their activity are explored simultaneously in the analysis of disturbances presented in Chapter 7.

2.5.1 Plan of implementation of the BP project

The plans for the implementation of the 3S Programme changed during the period of the data collection. The process of writing the PDD started already at the beginning of 2006. In the original plans from 2005, the writing of the project and the installation of the bio-digester and the combustion system were supposed to be conducted simultaneously, but the methodology used in the project changed. The initial proposal for the 3S Programme was to use the approved AMS 0006 methodology; however, in 2006 the methodology was put on hold and the project was reorganised. In 2007, the UNFCCC Executive Board approved the PoA methodology, and the SI decided to use the new approved methodology.

The implementation of the technological system and the actual production was initially planned to be conducted in three phases: the recruitment of farmers, the installationtion of the bio-digesters and flare, and the implementation of biogas technologies for use of biogas. However, the change in the methodology divided the second phase in two, and the installation of the flare was separated from the installation of the bio-digester.

The enrolment of the farmers started in 2005/2006 through meetings organised by the SI aimed at introducing the programme and its benefits and though field visits by the Sadia technicians, who introduced the programme to each farmer. Those farmers interested in joining the programme signed a contract and then started the second phase, the installation of the bio-digesters and flare. The first bio-digester installation began in March 2006 (Document ROE – 2006) and continued until 2007.

The first bio-digesters installed in 2006 had open flares. However, the change in the methodology regarding to the combustion system led to a delay in the installation of the flares, which were installed in a third phase during the second semester of 2007. During my last field visit, in May 2008, most of the new flares were already installed.

Parallel to the installation of the bio-digester and the flare, Sadia planned to write the PDD and validate the project so that it could be registered as soon as the installation was ready. The registration would allow the trade of carbon credits, and the SI could start paying back the loan and other costs such as the administrative and maintenance costs of the system. The carbon credits were initially planned to be delivered from 1 January 2007. These plans changed several times when difficulties emerged in identifying the proper technology for combustion and while writing the PDD. In May 2007, it was expected that the carbon credits would be obtained at the beginning of 2008 at the latest, when the the loan from the Brazilian Development Bank (BNDES) would start to be repaid. It was expected that once they had the carbon credits, it would take between 5 and 10 years for farmers to receive the money from the carbon credit sales. This estimation was difficult to make because the value of a ton of carbon credits changed, and SI did not yet have an estimate of all the costs involved. It was planned that the farmers could use this money to invest in improving their life quality, but this issues was not further specified.

The use of the biogas was planned to take place once the flare was installed and the carbon credits obtained. However some of the farmers started using the gas as soon as the bio-digesters were installed in 2006. Due to several problems, the outsourced farmers were asked to discontinue their use of the biogas. The use of the biogas was considered an important issue for engineers and the SI staff, but it was not a priority in 2007 and 2008. According to the engineer Jorge, the priority at that time was to have the combustion system installed and obtain the carbon credits. Once these steps were done, the engineers would focus on the use of the biogas. The SI engineer would first have to establish the minimum safety criteria for its use, and then identify and certify the equipment and suppliers needed for that purpose.

2.5.2 Script of daily operations

Sadia's industrial department was expected to assume the responsibility for the operation of the project once it was registered by the UNFCCC (interview with Reginaldo from the SI). Thus, the delay in having the project registered led to a delay in passing the responsibility from the SI to Sadia. Appendix 2.1 presents some of the tasks of the SI field work technicians planned for the phase of installation of the bio-digesters in 2006.

Sadia's technicians would be responsible for following up on the operation and functioning of the system. If any problem emerged, they would be responsible for identifying it and giving recommendations on how to solve the minor problems. Moreover, Sadia's technicians would be responsible for collecting data about the volume of burnt gas on the farms (Interview with Engineer Jorge May 2006).

The staff working in the SI was composed of volunteers and hired people. In 2007, the engineer Jorge was appointed operational manager, responsible for the functioning of the technological system and the technical part of the programme, which included tasks such as defining the technologies to be used, the use of the biogas, the elaboration of the PDD, the coordination of the installation of the bio-digesters and the maintenance of the equipment. Under the supervision of the operational manager were three sets of workers: field work engineers, an engineer for managing the technologies and a person specialised in writing the PDD (Interview with Engineer Jorge May 2007).

The coordinator of the programme was responsible for contacting external actors such as banks, researchers and the media.

Farmers were co-responsible for the operation of the bio-digester system and monitoring its leaks in order to maintain a maximum BP (e.g., removing the residues accumulated at the bottom of the bio-digester, cleaning the entrance boxes, mixing the slurry) and to avoid accidents. The tasks that were expected to be conducted by farmers were presented in the Guidelines (Document MBO-2006, MBO-2008). Appendix 2.2 presents these tasks in more detail.

A few other tasks were conducted by outsourced companies. There were two significant companies, one that was already hired in 2006 which I call "Company 1" and the other hired in 2007 which I call "Company 2". Company 1 was responsible for installing the bio-digesters according to instructions pre-established in a contract, and for any problem related to the quality of the material and the service. The company also fixed problems that emerged with the bio-digester, e.g., leakage or rupture of the canvas caused by the misuse or inappropriate operation of the bio-digester. Company 2 provided similar services as Company 1 for the combustion system. It was also responsible for the assemblage of the combustion system from pieces from several manufacturers and installing them in the farms according to instructions pre-established in a contract. Additionally, it was responsible for delivering basic services related to the quality of the equipment and services.

3 PREVIOUS RESEARCH ON DEVELOPMENT AND LEARNING IN BP AND SUSTAINABLE TECHNOLOGIES

In this chapter, I will first present a brief review of empirical studies on BP with regard to previous knowledge about the challenges of BP, used and potential theoretical approaches, and the strengths and weaknesses of the studies. Second, I present three approaches used in the field of sustainable technologies and discuss their contributions and limitations. I finalise with a discussion of how these previous empirical studies see the relationship between learning and development.

3.1 Empirical studies on biogas production (BP)

BP has attracted the attention of researchers from several research groups and disciplines. In a quick search with *Google Scholar* using the key words “biogas production”, more than 42,000 results (15 November 2010) were found. Most of these documents are analyses of specific techniques or technical aspects of anaerobic digestion. Here, I am specifically interested in reviewing studies on the development of BP, not only regarding new techniques, but also its social, environmental, economic, political, institutional and organisational aspects. In order to direct the search to these studies, I included key words such as “challenges”, “opportunities”, “barriers”, “prospects”, “development”, “learning” and “state of the art”. This search produced a large number of studies evaluating the performance or development of BP.

3.1.1 Empirical studies assessing BP development vs. national policies

The majority of the identified studies were studies evaluating BP at the level of national policies (see Appendix 3.1). Their common characteristic was that they tried to identify factors or reasons that hindered or contributed to the expansion of BP in different countries. I will give just a few examples of the content and main conclusions of this type of study. Tricase and Lombardi (2009), for example, in a recent study evaluated the state of the art of the use of biogas produced from animal waste in Italy. They concluded that in spite of the increase in the production of biogas, its actual use is well below the potential. According to the authors, the main short-term limits to the development of the use of BP to produce energy from animal waste are ineffective digestion technologies and dispersive and complex administrative procedures. They propose a legislative reform to offer incentives to make energy production from biomass more efficient and to support investment in this sector. Guatam et al. (2009) come to similar conclusions.

According to them, BP in Nepal is also far below its potential due to the lack of financial and technical support and to insufficient technological development of biogas production in cold regions. In another study, Mirza et al. (2009) propose the creation of financing programmes for renewable energy technologies. Prasertsan and Sajjakulnukit (2006) assessed the potential opportunities of and barriers to the development of BP in Thailand. They concluded that despite several kinds of financial incentives, the dissemination rate of biomass energy technologies is still unsatisfactory due to institutional, technical, financial, policy related and information-related barriers.

The studies at the national level seem to be unanimous regarding the importance of governmental support for the successful expansion of BP. They strongly support the view that national policies affect the development of BP. The findings are usually based on comparisons of policies in countries that are successful with policies in a country in which expansion or dissemination has not been as prominent. The conclusions and recommendations are usually that more programmes and incentives from the government are needed. Some studies give general recommendations, such as the need for more financial incentives, while others are more specific, proposing certain actions or measures. However, as Prasertsan and Sajjakulnukit (2006) point out, the barriers are not always known, and new approaches are needed. In general, most of the assessments of national trajectories come to the same conclusion: development is enhanced by long-term governmental support for building the market, providing financing, as well as for creating institutions and networks.

Another important group of studies focus on the economic assessments of the viability of different concepts or models of BP. This group includes the economic analysis of costs and the profitability of different concepts of BP (e.g., Walla & Schneeberger, 2005, 2008; Blokhina et al., 2010; White et al., 2011) as well as the effect of scale and location on the profitability of BP plants (Amigun & von Blottnitz, 2010). The assessments have been based either on modelling or on data from real cases. Srinivasan (2008), for example, maintains that the economic viability of BP can be achieved by incorporating in it the indirect economic benefits gained through BP, such as GHG emission mitigation. He proposes that mechanisms should be created to economically and financially compensate the producers for the global and local benefits produced by BP. Also, the environmental impact of BP should include not only the direct environmental benefits related to energy, but also those related to land use and waste handling (Börjesson & Berglund, 2007). In general, these studies show that BP becomes more profitable and economically sustainable and viable when more of its benefits are taken into account.

According to this review, social, political and cultural aspects have been acknowledged to be important in the success of BP development. However, only few studies have analysed these aspects in more detail (e.g., Jian, 2009). Ratner and Gutierrez (2004) pointed out that the main challenge in working in public projects and projects in other domains is the integration of project planning and implementation into processes of community building. Gruber and Herz (1996) propose that subsidies alone are not sufficient to motivate farmers to invest in BP. They suggest that more consultation and training are needed, but they do not explain how these should be delivered and by whom. Therefore, it can be concluded that although individuals' motivation and socio-cultural conditions and learning are recognised as important aspects, only few studies take these aspects seriously. More knowledge is needed about the different market- and non-market-related ways in which farmers use biogas in their everyday activities (Yiridoe et al., 2009).

3.1.2 Limitations of the empirical studies

There is no doubt that the findings from these empirical studies are of paramount importance in helping policy makers to focus efforts and support. However, despite the similarities among the findings, without a theory, it becomes rather difficult to explain and generalise them to other countries, regions and projects; thus they remain limited in time and space to the context under investigation. Most of the studies (not all them, however) lack a clear theory with which to explain the findings, in other words, to explain why and how the identified factors affect the development of BP.

3.2 Theoretical approaches applied in studies of the development of BP and sustainable technologies

In this section, I analyse some studies that have a theoretical interpretation of learning in and development of BP. In the analysis, I focus on their unit of analysis, which is understood here as the way in which the object of the study is conceptually delineated. In the analysed cases, the object of the study is the development of biogas production in a specific area.

3.2.1 Theoretical approaches used to analyse learning and development in BP

Many studies have pointed out the importance of socio-economic aspects for the adoption and expansion of BP (e.g., Gruber & Herz, 1996; Ratner & Gutierez, 2004; UNAPCAEM, 2007; Jian, 2009). Among the studies reviewed, I identified a group that attempted to conceptualise the changes in and evolution of BP. Within these studies, the main theoretical approaches used were: 1) innovation system theory (e.g., Negro et al., 2007; Hillman et al., 2008; Negro & Hekkert, 2008; Negro et al., 2008), 2) strategic niche management (SNM) theory and 3) the multi-level perspective (MLP) (Raven, 2005; Geels & Raven, 2006, 2007; Raven & Geels, 2010). Below, I analyse the application of innovation system theory and the multi level perspective on the basis of two studies conducted by Negro et al. (2008) and Raven and Geels (2010).

Functions of Innovation Systems

Negro and colleagues (2008) propose the functions of innovation systems framework (see also Negro et al., 2007; Hekkert & Negro, 2009) to explain the success and failure of the emergence of a biomass gasification technology.[6] The study tried to answer the question: what are the inducements and blocking mechanisms that have determined the evolution of biomass gasification in the Netherlands? For this purpose, they used the notion of an **innovation system** as unit of analysis. An innovation system is understood as a set of actors and institutions that determine the generation, diffusion and utilisation of a new technology. The study is based on the assumption that for a technology to become successful, several activities need to occur. The factors that affect the development of an innovation system can be depicted through processes that take place within an innovation system. These processes are called **functions of innovation systems**, which are defined as the contribution of a component or a set of components to the performance of a system.

Negro et al. (2008) point out seven functions of innovation systems: a) entrepreneurial activities, b) knowledge development (learning), c) knowledge diffusion through networks, d) guidance of the search, e) market formation, e) resource mobilisation, and f) counteracting resistance to change (also support from advocacy coalitions). To understand the inducement and blocking mechanisms of technology development, diffusion and implementation, the functional pattern of the related innovations system must be described and historically analysed.

As stated by the authors, the development and diffusion of knowledge is crucial for the success of innovation systems. They refer to the processes of 'learning by searching' and 'learning by doing' as encompassing the function of knowledge development, referring to Lundvall (1992). They use three indicators to map this function: 1) R&D projects, 2) patents and 3) investments in R&D. Negro and colleagues (2008) found that the main inducement factors contributing to the development of biomass gasification in the Netherlands were high expectations and optimism, which led to virtuous cycles. The main blocking factor – throughout the entire period – was the absence of a clear and consistent policy on biomass gasification by the national government. They arrive at the general conclusion that there was a structural misalignment in the institutional framework within which the technology and the technical requirements could be developed. According to them, the government should have intervened by creating the right conditions for emerging technologies such as biomass gasification, for instance, by stimulating the system functions.

[6] Biomass gasification is not the same technology as the production of biogas from the bio-digestion of swine manure.

Although Negro et al. (2008) recognise that learning is at the heart of the innovation process and is one of the most important functions of innovation systems, it remains unclear how learning takes place. Learning is seen as a function of knowledge development among other innovation systems. However, they are not explicit about who the subject of learning is. When analysing learning (understood as knowledge development), they refer to the existence of activities and investment in R&D as indicators of learning. It remains unclear who are learning, and why and how the learning takes place. Learning is seen as something necessary to the evolution of a technology (biomass gasification). However, knowledge development does not appear in the results as having influenced the innovation under study. The main inducing factors were high expectations and optimism, while the blocking mechanism was the absence of a clear and consistent policy.

Socio-cognitive evolution

Raven and Geels (2010) have developed a model of socio-cognitive evolution for studying the development of BP in Denmark and the Netherlands. The study is interesting because it further explains the learning process in the model of socio-cognition (Geels & Raven, 2006, 2007). Moreover, the authors make some further clarifications regarding how SNM incorporates evolutionary theories and social constructivist approaches. Raven and Geels (2010) emphasise two important insights from SNM. First, they point out that SNM emphasises that the co-construction of new technologies involves learning and experimentation. They understand experimentation as a special type of learning which is important in producing new technologies. SNM emphasises the importance of real projects as experiments in adapting technologies to the market. Within these projects, users, producers and other stakeholders interact and engage in a mutual learning process. Second, they point out that in SNM, learning is not only data accumulation but also sense making (Raven & Geels, 2010).

According to Raven and Geels (2010) the cognitive-evolutionary way of conceptualising learning is useful but focuses on individuals. They argue that a more social-oriented model is needed. To achieve it, they make three additional conceptualisations. First, in regard to the concept of retention, they introduce the concept of the **global level** of technological development. They argue that in addition to the local level (niches), whivh involves local practices and artefacts as well as technology development, a global level must also be involved that consists of cognitive rules and an emerging community. This global level is socially and cognitively constructed. Regarding the social dimension, they make a distinction between local networks, which are understood as those actors that work on specific local projects, and global networks, which are understood as those actors from local projects and those that provide general resources (e.g., policy makers and professional societies). With regard to the cognitive dimension, they differentiate between the local, specific knowledge, and the global, abstract generic knowledge shared in the community. They propose that retention occurs at the global niche level through the **aggregation, formalisation and codification of experiences** in local practices (Geels & Deuten, 2006). These global cognitive rules (abstract theories, technical models, problem agendas and search heuristics) guide practical activities in local practices, but they leave room for variety at the local level (Raven & Geels, 2010). Second, the authors propose the concept of expectations, visions and strategies to explain variation at a social level. They argue that expectations are important for two reasons: a) they give direction to innovation activities because they are translated into search heuristics, and b) they are used to make promises to attract the attention of and resources from sponsors. They propose that expectations mediate between global cognitive rules and local projects. Third, Raven and Geels (2010) introduce the notion of **social learning,** referring to the process in which the outcomes and experiences created by local projects are interpreted and translated into generic lessons that can become part of global cognitive rules. Collective and social learning acts as a selection process. Referring to Weick (1979), they propose that learning at the community level is a process of collective and negotiated sense making.

Based on these three contributions, they present a model that aims at representing the dynamics of the socio-cognitive evolution of technologies. In this model, there are three elements of a population: rules, actors and artefacts. Actors within a network have their expectations and visions about a certain concrete technology. Based on these visions and expectations, actors invest resources in projects. These projects produce results (outcomes and experiences), which are learnt and change the rules. If positive, these results may attract new actors to the network. These new rules again affect visions and expectations, and affect whether the actors are willing to further invest or not in the projects (Figure 3.1).

In their findings and conclusions, Raven and Geels (2010) argue that expectations are important for providing direction to variation, the building of local and global social networks, the selection of a social learning process, and the retention of lessons. Moreover, they found that the bricolage approach (modest steps, low-tech, bottom-up experimentation and gradual up-scaling) proved more successful for biogas development than a breakthrough approach (big steps, high-tech, leap-frog idea, rapid up-scaling). The empirical analysis also showed that external regime development (cultural, environmental, political and regime problems and discussions) are also important. The broader national energy and agricultural regimes are also important factors in explaining the development paths. Their study also shows the importance of formal rules, such as subsidy schemes and investment grants (Raven & Geels, 2010).

Their analysis of the case study showed the importance of local projects in the development of BP. They note that biogas plants are a configurational technology, where the challenge is to enable multiple components to work together. They argue that local projects are crucial for the learning process in biogas development, even though this may not be true for other technologies. They found a relationship between changes in the direction of development and changes in the content of expectations (visions about functionality). The changes in visions about functionality led to new search heuristics that changed the direction of the learning process and technical trajectories. They also found interaction between niche trajectories. The outcomes in the trajectory of farm-scale BP influenced the trajectory of centralised BP. They concluded that the non-linearity and changes in niche expectations are related to both internal learning processes and external developments.

The model of Raven and Geels (2010) seems to be good at explaining how the technology and network of BP improved and developed. However, the model does not recognise the existence of essentially different interests and expectations on the level of local practice. This weakness has been pointed out by researchers who argue that the MLP does not pay attention to the dynamics that occur within and between the projects and networks of actors involved in innovation processes. According to them, this may result in a gap in understanding the processes through which developments at the niche level interact with those at the regime level (Smith, 2007; Elzen et al., 2008).

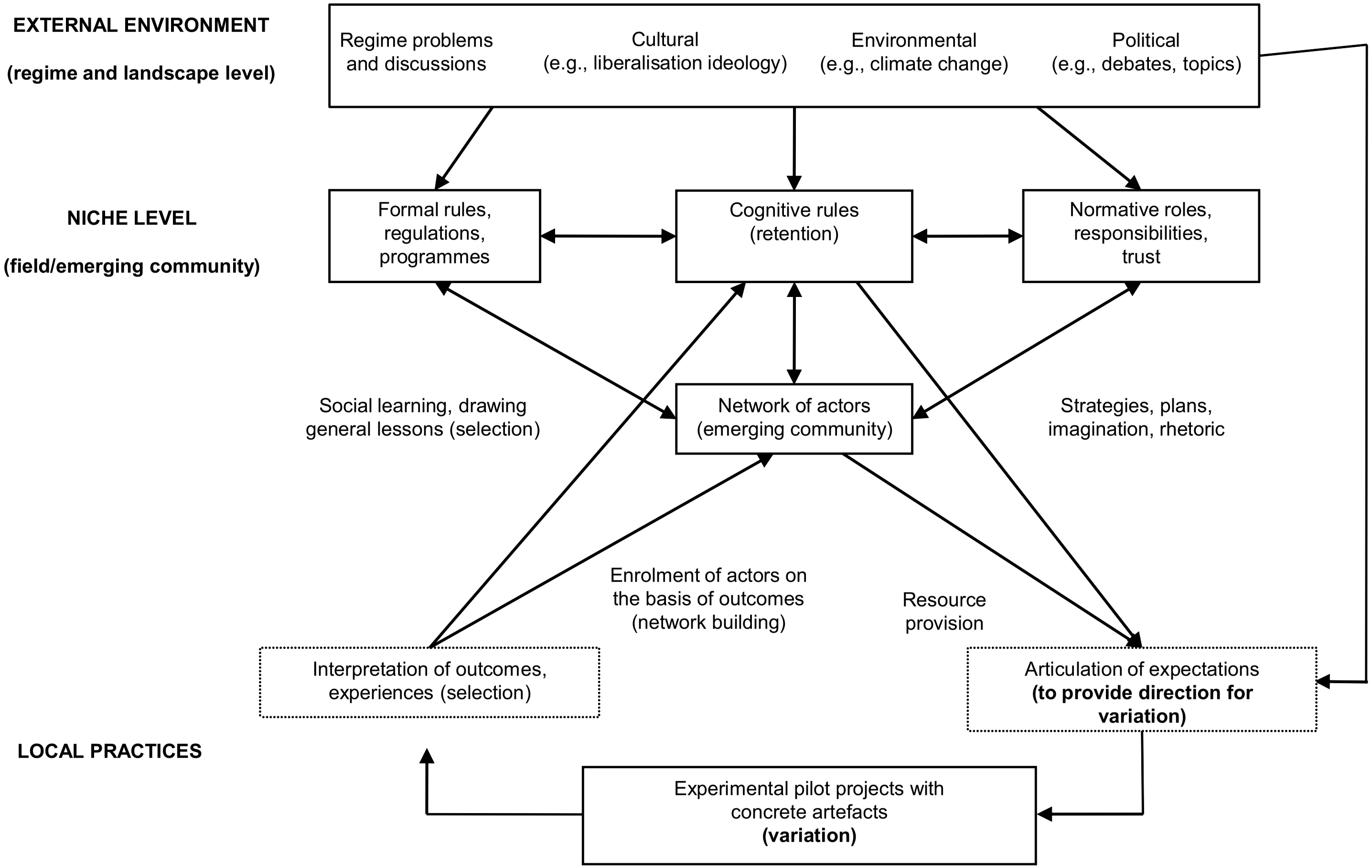

Figure 3.1 Dynamics in socio-cognitive technology evolution (adapted from Raven & Geels, 2010)

3.2.2 Theoretical approaches applied in studying the development of sustainable technologies

An extensive literature of studies focuses on social learning and natural resources management, some of which have been reviewed, for example, by Röling and Wagenmakers (1998), Leeuwis and Pyburn (2002), Keen et al. (2005), Blackmore (2007), and Wals (2007). In this study, I decided to proceed by cross-checking the references used in the studies of Negro et al. (2008) and Geels and Raven (2010) to broaden my discussion of the development of sustainable technologies. In this context, BP has been seen as an example of sustainable technology, comparable to other green technologies, such as greener buildings, sustainable transport and so on. Within this context, I found three influential approaches: the innovation systems approach, the transition management approach and the social shaping of technology. Below, I proceed by analysing how learning is conceptualised within these approaches. I summarise them in Table 3.1 at the end of the section.

Transition management (Bounded Socio-Technical Experiments, BSTEs)

I selected a study by Brown and Vergragt (2008) to illustrate the transition management approach. In the article "*Bounded socio-technical experiments as agents of systemic change*", the authors propose a conceptual framework for mapping and monitoring the higher-order learning processes which take place in BSTEs, using a case study of a zero-fossil-fuel residential building in Boston (US). They use the concept of an **BSTE**, which they define as an attempt to introduce a new technology or service on a scale bounded in space (which is defined geographically as a community, or by a number of users) and time (years). In this approach, learning is seen to take place within protected experiments allowing technologies to stabilise and to diffuse through society. A BSTE is a collective endeavour carried out by a coalition of diverse participants, including businesses, the government, technical experts as well as educational and research institutions, NGOs and others. A BSTE has a cognitive component in which at least some of the participants explicitly recognise the effort to be an experiment (Brown & Vergragt, 2008).

A BSTE is successful when a) the experiment meets the initial expectations and becomes a social, environmental and commercial success; b) there is occurrence of high-order learning among the participants; c) there is a change in an interpretative frame or problem definition among the users of the new technology and the community of practice that is represented by the participants in the experiment. The social component of social learning is seen as the transmission and diffusion of new ideas and knowledge from the participants to the broader community of practice.

With regard to leaning, Brown and Vergragt (2008) make a differentiation between first-order learning and higher-order learning. According to them, both kinds of learning are needed in order for a BSTE to become successful. Referring to the work of Schön (1983), they define **first-order learning** as a change in the tools used in solving a problem, such as engineering analyses, cost–benefit analyses and risk analyses. Learning at this level does not involve reflection on the objectives of the project or questioning of the compatibility between the social problem and the solution that the particular technology represents. **High-order learning is** understood as changes in the assumptions, norms and interpretive frames which govern the decision making process and actions of individuals, communities and organisations. This kind of learning can be seen in practice as changes in the actors' way of defining a problem.

As they explain, learning takes place through a feedback-stimulus mechanism

> *"when the existing, well accepted, time tested and trusted interpretive frames and competences receive feedback on their performance in solving a problem or advancing specific objectives. If, as a result of this feedback, it becomes apparent that the desired results are not forthcoming, these cognitive constructs become subject to reassessment and, if necessary, are replaced with new ones. A sense of urgency is an important facilitator of learning because it forces repeated trying (and failing) that is central to the learning process (Ibid, p. 110).*

Higher-order learning is stimulated from threats to the survival and success of the organisation, such as failures, disasters and other surprises. Brown and Vergragt (2008) build their conception of learning based on the work of Grin and van de Graaf (1996), who proposed a multi-level discourse to examine the learning processes occurring during constructive (or interactive) technology assessment.

The findings of the study showed that a BSTE can indeed induce higher order learning (at the level of problem definitions and interpretive frames) among its participants. Brown and Vergragt (2008) found as key factors contributing to this kind of learning: the presence of a clear focus and boundaries for the project (e.g., creating a building); the intense and sustained interactions of several professionals; agreement among the participants about the vision for the project, its social mission and the process; agreement among the participants about the core social values; and overlap of the participants' interpretive frameworks. These factors were the foundation on which the participants could interact, solve problems, reflect on their individual interpretive frameworks and make changes in individual problem definitions. In addition, they found that the availability of funding also positively influenced learning.

At the team level, they found that learning involved the gradual formation of a team that has the capability to carry out the socio-technical experiment envisioned by the "project champion" (Brown & Vergrat, 2008, p. 126). A necessary condition for this kind of learning to take place was that the participants have a wide agreement on the fundamental values and interpretive frameworks.

Innovation Systems Approach

Van Mierlo et al. (2010) have developed a new framework for studying learning in sustainable technologies at the niche level and have tested it in two projects in two different contexts. The first case study was an intervention in the context of water management called the Zaandam-Oost project of Value of Water (the VoW project). The second was an intervention in the context of "green" products, called the Companies for Companies project of Market Chances for Sustainable Products (the MSP project). They analysed the individual and social learning processes. In their study, van Mierlo et al. (2010) analyse system imperfections that block learning and innovations towards more sustainable systems.

Van Mierlo et al. (2010) aimed to "develop an analytical framework for studying learning processes in the context of efforts to bring about system innovation by building new networks of actors who are willing to work on a change towards sustainable development". The framework developed by the authors integrates elements from the innovation systems approach with a social learning perspective. They present the concept of **innovation systems**, and refer to Metcalfe (1995), who defines innovation systems as a set of distinct institutions that jointly and individually contribute to the development and diffusion of new technologies and which provide a framework for governments to influence the innovation process (Metcalfe, 1995). Van Mierlo and colleagues (2010) also present the concept of **system imperfections** (Klein Woolthuis et al., 2005), referring to obstacles that block learning and innovation by actors, and the concept of **systemic instruments** (Smits & Kuhlmann, 2004), referring to interventions that in one way or another aim to solve these obstacles. Van Mierlo and colleagues' (2010) main argument is that the solution of system imperfections or failures (e.g., infrastructural, institutional, interactional and capability failures) requires not only changes in individual organisations or changes in the relationship between organisations, but also changes on the level of the system.

Van Mierlo and colleagues (2010) refer to Röling's (2002, p. 35) notion of social learning as a "*move from multiple to collective or distributed cognition*". They argue that 'collective cognition' is more likely to take place when there are groups of homogenous actors, suggesting that within innovation systems a 'distributed cognition' is more likely to occur. This means that in order to have sustainable innovations, it is not obligatory to have shared cognition (or to share an understanding of what has to be achieved), but it is enough that actors have a congruent meaning.

Van Mierlo et al. (2010) differentiate between two levels of learning: single- and double-loop learning (Argyris & Schön, 1996). Van Mierlo et al. (2010) recognise that both kinds of learning are necessary to have successful innovation systems. **Single-loop** learning refers to learning how to do things better. According to the study, single-loop learning is operationalised when new insights emerge regarding the ways in which a given goal can be accomplished or new problem definitions emerge. **Double-loop** learning refers to changes in perceived goals, values, norms and interests. It is more demanding and requires, for example, that people experience a serious problem which is urgent and be visualised.

Van Mierlo and colleagues (2010) define learning based on Leeuwis' (2002) ideas. According to Leeuwis (2002), there are different areas of perception (experienced social pressure, aspirations, trust in the social environment, perception of one's own role and responsibility, actions, risk perceptions, belief in one's own capacities, knowledge perception of reality) that may be subjected to "learning" (Figure 3.2). In this context, van Mierlo et al. (2010) define learning more broadly as involving a change in any of these areas of perceptions. According to them, in line with the earlier presented definition by Röling, social learning can be seen to have occurred when different actors more or less simultaneously change their 'mindset' in such a manner that it leads to new patterns of effective coordination of action (van Mierlo et al., 2010).

The authors hypothesise that induced learning processes through interventions must somehow address specific system imperfections. A learning process can lead to changes in human perception and action at the level of individual actors, temporary networks (the group of people participating in the intervention), represented organisations and even systems.

Van Mierlo et al. (2010) found both kinds of learning, individual and social learning, in the VoW project, while in the MSP project social learning was much lower if not inexistent. They tried to explain the reasons for the failure and success of learning in both cases. They explained the differences in three ways. First, they found that in the VoW project the actors were more committed, which was related to the compatibility between the systemic interventions and systemic imperfections (the problems faced by the actors). This confirms the authors' assumption that people must feel committed to a project and have to feel that the intervention focuses on problems and aims that they can personally identify with. Second, they found that a feeling of interdependence in the MSP project was lacking. Third, they also found a difference in the quality of the interactions. In the VoW project the participants felt that they were "owners" of the project, while in the MSP project the process was owned by the interventionists.

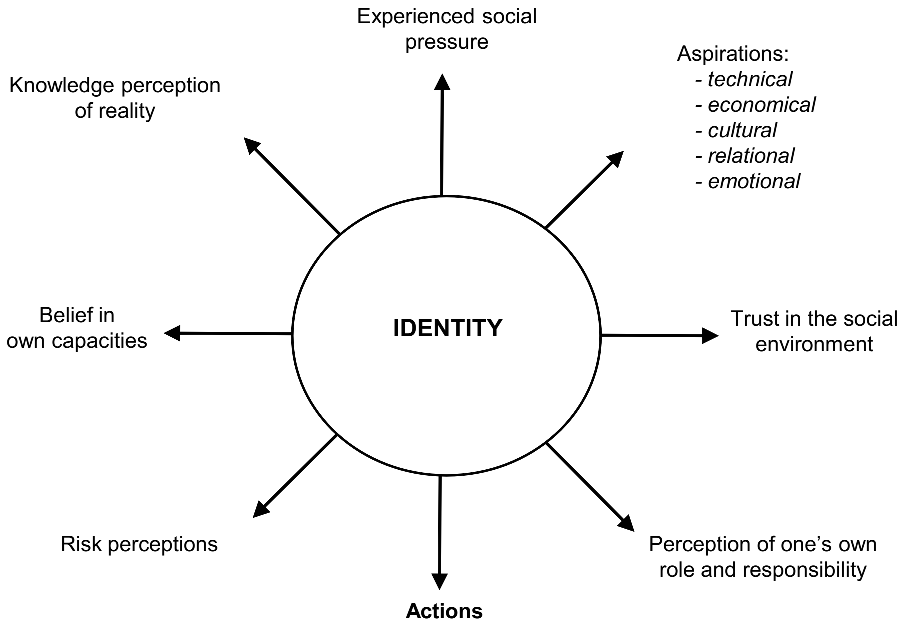

Figure 3.2 Different areas of perception that may be subjected to 'learning', e.g., perceptual change (Leeuwis, 2002)

They concluded that there is a relation between the conditions in which activities address imperfections and the feeling of interdependence:

> *"In order to stimulate learning the composition of a temporary network [the project] must be meaningful in view of experienced urgencies and system imperfections, otherwise feelings of interdependence are bound to be weak, which poses an additional disincentive for social learning" (van Mierlo et al., 2010).*

They concluded that systemic instruments can serve to enhance various conditions for social learning and negotiation, and such processes may result in learning effects that contribute to system innovation by confronting system imperfections.

They present some recognised limitations of the study and point out four methodological aspects necessary in the development of the analysis of learning in system innovation. First, they recognise that the innovation systems' perspective makes less explicit reference to political processes and dynamics as part of radical change processes. They suggest that a methodological and theoretical approach is needed to examine the power dynamics in the interventions. Second, the time horizon of both the cases and the study did not allow them to investigate the relationship between learning within the networks and its influence on the system imperfections themselves. They suggest that a methodological set-up with a longer time horizon, which can also asses learning and change beyond the immediate participants in the networks, is needed. Third, they propose that the relationship between system imperfections based on a system analysis and participants' perceptions of system imperfections has to be further elaborated. Finally, according to them, it would be good to develop additional methodological strategies by means of which learning and negotiation can be observed and analysed as they take place in social interaction.

Van Mierlo et al. (2010) explicitly differentiate between individual and social learning. They point out that learning can take place among individual actors, temporary networks, represented organisation, and even learning systems. In the study, they focused the analysis on individual learning and learning in **systemic interventions.** Such interventions are composed of representative organisations and systems, and are called temporary networks (group of people participating in an intervention) by the authors. The occurrence of learning is explained by the good match between systemic interventions and systemic imperfections as perceived by the actors. Learning is considered to occur when interventions address people's problems and aims. Moreover, they also explain learning according to the process conditions, such as the feeling of interdependence. If a feeling of interdependence does not exist "naturally", it has to be stimulated throughout the intervention so that learning can occur. Finally, they point out that the feeling of owning the project also affects whether learning occurs or not.

Social Shaping of Technology and Actor-Network Theory (ANT)

The social shaping of technology approach has been raised as a potential and promising approach for studying the development of sustainable technologies and innovations when networks are unstable and under construction (Jørgensen et al., 2009). Within this approach, actor-network theory (ANT) has been pointed out as an alternative and complementary theory with which to understand to the process of the construction of networks (e.g.,Steins, 1999; Burges et al., 2000; Steins, 2002; Kortelainen, 2004; Hommels et al., 2007). ANT seems to be especially useful for dealing with the dualisms between the individual and the collective, micro and macro, agency and structure, or object and subject.

ANT started as an attempt to provide an alternative approach to science and technology studies (Callon & Latour, 1981; Callon, 1986; Latour, 1988). The first studies applying ANT aimed to show how networks were formed and become stable. It focuses on the movement between two extremes: actor and network, individual and structure, or micro and macro. In doing so, ANT follows some strategies and assumptions. First, it redefines "macro" and "micro" as "practical and related to a very local and tiny locus" (Latour, 1999). Something "big", for Latour (1999), means something that is connected, blind, local, mediated and related. This definition has three implications. First, it implies that in exploring the structure of the social, the researcher should not leave local sites. Second, ANT is not interested in what an actor does but rather what provides the **actants** with their actions, subjectivity, intentionality and morality. Third, ANT allows following the movement without the need to change the scale from global to local, but allows the researcher to flow locally through networks (Latour, 1999). It is especially useful as a tool for analysing how networks are constructed and co-constructed, how actors are enlisted, and which means are used by actors to make networks durable. The principles that seem to be present in most of the studies are the principles of symmetry, mediation through objects and the concept of translation.

ANT theorists propose three methodological principles: agnosticism, general symmetry and free association. The principle of **agnosticism** establishes that no point of view needs to be privileged and no interpretation censored. The observer does not fix the identity of the actors if the identity is still being negotiated. The principle of **generalised symmetry** establishes that a single repertoire has to be used to describe both nature and society. The choice of which vocabulary to use is a task given to the observer. The principle of **free association** implies abandoning the distinction between social and natural events. Such division should not be taken as a starting point, but rather should be the results of the analysis. As Callon (1986) explains, the main idea is that both human and non-human actors must be considered in the social analysis. ANT theorists have shown that human actors are able to rely not only on social relationships but also on more 'durable' materials. Thus, networks that are usually taken for granted are not merely formed through social relations but also through non-human actors (objects).

The principle of symmetry is an attempt to overcome a deadlock that the social sciences were facing in explaining science and technology. As Latour (1992) points out, our explanation of the world alternates between poles: one that is societal and one that is purely natural. Latour's (1990) solution is that we should neither see something as purely constructed nor as purely objective, but we should see it as a circulation of things. As Latour (1992) points out, knowledge and artefacts should not be seen as static but as trajectories, a process or a circulation of things. Several terms such as quasi-object, actor-networks, collectives of humans and non-humans, and heterogeneous networks have been used to define such trajectories.

The relationships between humans are mediated both by objects and people, as well as by networks of people and objects (Law, 1992). Non-human artefacts (or objects) are so important in ANT that, according to the theory, social institutions would not exist without them. By adopting such a definition of the actor-network, ANT rejects reductionist explanations. It is neither people nor objects that determine the character of the social or the stable, but they have to be understood as being in a relationship (Law, 1992).

To explain the formation of an actor-network, ANT introduces the concept of **translation.** This concept was developed by Callon (1986) in his work on the domestication of scallops in St Brieuc Bay. The process of translation is the process in which a spokesman (e.g., an entrepreneur, researcher or engineer) enrols different actors by transforming their interests, forcing them to line up with his/her own interests. In addition to displacements and transformations, translation is also about expressing in one's own language what others say and want, why they act in the way they do and why they associate with each other: it is to establish oneself as a spokesman (Callon, 1986).

In ANT, **agency** is seen as a network. What counts as a person is an effect generated by a network of heterogeneous, interacting materials. An agent is seen as an actor-network, or as a heterogeneous network composed of human bodies with their respective attributes, such as knowledge, skills and values, and also by non-human entities. ANT states that agency is only possible through the association of human and non-humans, and people's agency exist due to the fact that they inhabit a network of materials. ANT recognises that agency is not located in bodies alone, but always relies on heterogeneous networks of objects. The same is said about objects (e.g., machines) and institutions, which can only be agents because they are associations of people and non-human objects, which are constantly offering resistance (Law, 1992).

To identify the network under investigation, ANT offers as the main methodological principle: "follow the actor". It means that one would have to identify the strongest actor and follow him/her/it to see how he defines and constructs the network, that is, how the spokesman translates other actors' interests and proposal to suit his solution.

The two main theoretical concepts of ANT, translation and the principle of symmetry, give tools to identify how actors themselves construct the network, but do not give an explanation for how a network works. Therefore, the theory is not an explanation but rather a tool. ANT as a theory (or a method) sounds very promising. However, when the principles and concepts are put into practice, some difficulties emerge.

In regard to the methodological principle of symmetry, the selection of the most active actor seems to be arbitrary. Unfortunately, ANT offers no tools for selecting the actors that compose the network and the definition of a network remains very open; therefore, the kinds of results achieved from any analysis of how a network emerges and develops also remains very open.

With regard to its explanation of the formation of networks, ANT starts from an already existing problem without investigating why and how problems emerge. The problems are taken for granted without seeking any relationship that they may have with societal history and the transformation in production. A strength of ANT is its explanation of how a problem is articulated and used to build the network, but explanations of how these problems emerge are weak. The use of very open and general concepts, such as the translation process, leads to overlooking the role of history in the emergence and development of networks. It is not clear in ANT what the role of human history is in the emergence of problems and in their solutions.

ANT can provide extremely important criticism towards the way in which networks should be understood. It is useful especially when the interest is in understanding the power relationships between the actors and how innovations are attributed to one actor (Lehenkari, 2000). Moreover, ANT provides a useful criticism on the division of sciences in the explanation of a phenomenon. The dualism between explanations that are purely natural and those that are purely social is just one example of the problem (Latour, 1992). However, the same methodological principle that aims to overcome these dualisms leads to overlooking human intentionality and the capacity of acting purposefully. As Miettinen (1999) points out, this principle leads to the impoverishment of the specific vocabulary used in the network under study. Moreover, it also leads to an even more important problem, a lack of tools for determining what the network under study is. It remains arbitrary which actor should be selected as a spokesman, i.e, the most active actor.

3.3 Dilemmas in the previous theoretical approaches

Regarding learning and development, the studies have tried to apply two basic ideas. First, the studies analysed have been deeply influenced by the idea of levels of learning (Bateson, 1972; Argyris & Schön, 1996), in which there are two levels: first/lower-order learning and second/higher-order learning. The basic idea is that the achievement of more sustainable actions or the development of sustainable technologies requires not only learning "how to do things better", but also changes in people's aspirations, assumptions, and principles. Second, most of the approaches also recognise that sustainability requires not only changes among individuals but also in communities, systems and whole networks.

The studies presented above provide several tools and contributions for explaining learning, such as the concepts of vision, expectation and system imperfections. However, they have limitations regarding three general problems: a) explaining the relationship between the individual and social learning, b) explaining how and why new innovation systems, or socio-technical systems, emerge in the first place, and c) defining what is the relationship between learning and the development of a system.

3.3.1 The relationship between individual and collective/social learning

The starting point in most of the studies is the assumption of the existence of a societal problem to be solved. In order to solve this problem, local experiments, interventions and projects are initiated. To solve such problems, different levels of learning are needed. One of the limitations of the studies is that they do not provide any clear conceptualisation of how problems emerge, how individual learning and social learning are connected, and what the relationship is between the learning that takes place in the local projects and the learning that takes place in society.

The second limitation is related to the explanation of people's motivation to learn and and transform their activities towards sustainability. Learning does not necessarily imply agency. The studies reviewed present several concepts for explaining what drives people to participate in the creation of sustainable solutions. Brown and Vergragt (2008) point out that a vision - in a tangible sense, the innovative product or service – provides a focus and a shared language for discourse; it provides a platform for reframing the clashing interpretive frames, in case of conflict. Visioning is suggested as an important technique for facilitating social learning. A vision is something that is being socially constructed, e.g., a sustainable mobility or a "green building". Raven and Geels (2010) use the terms expectations, strategies and visions. They claim that expectations are important to attract attention and resources from social networks, and to give direction to the development of a technology. The notion of expectation is related to promises of future outcomes. Van Mierlo et al. (2010) talk about aspirations, interests, goals and the feeling of interdependence. They argue that people must feel that the achievement of their outcomes relies on collaboration with others.

Table 3.1 Theoretical approaches for studying learning and development in BP and sustainable technologies

Unit of analysis	Approaches and empirical studies	Research interest	Methodology	Concept of learning	Main outcomes and explanatory concepts
Bounded socio-technical experiments	"Bounded socio-technical experiments as agents of systemic change" (1)	Propose a conceptual framework for mapping and monitoring higher-order learning processes which take place in Bounded Socio- Technical Experiments – BSTEs	Participatory observations at project meetings, interviews and documentary analysis	First-order learning is changes in the tools used in solving a problem, such as engineering analyses, cost–benefit analyses, and risk analyses. High-order learning is changes in the assumptions, norms and interpretive frames which govern the decision-making process and the actions of individuals, communities and organisations.	They found that higher order learning is supported by the presence of a clear **focus and boundaries** for the project (e.g., creating a building); the **intense and sustained interactions** of several professionals; agreement among the participants about the **vision** for the project, its social mission and the process; agreement among them about the **core social values**; and overlap among the participants' **interpretive frameworks.**
Innovation system	"The bumpy road of biomass gasification in the Netherlands: Explaining the rise and fall of an emerging innovation system" (2)	Explain the success and failure of the emergence of a biomass gasification technology (2)	Historical event analysis	Learning is seen as a function of an innovation system, more specifically the function of knowledge development, mapped through a number of workshops and conferences.	The main inducement factors contributing to the development of biomass gasification in Netherlands were the high **expectations** and **optimism**, which led to virtuous cycles. The main blocking factor was the absence a clear and consistent **policy** towards biomass gasification. There was a structural **misalignment** in the institutional framework within which the technology and the technical requirements could have been developed .
Innovation system	Learning towards system innovation: Evaluating system instruments (3)	"Develop an analytical framework for studying learning processes to bring about system innovation by building new networks of actors who are willing to work on a change towards sustainable development" (3)	Two rounds of in-depth interviews with almost all the participants of the projects within the selected program	The authors differentiate between individual and social learning. They define learning as "as involving a change in ... the reasons that shape human practices. In line with the earlier presented definition by Röling, social learning can be seen to have occurred when different actors more or less simultaneously change their 'mindset' in such a manner that it leads to new patterns of effective coordination of action." (3)	They found a difference in the processes of individual and social learning between the two cases. They explain such differences in three ways. First they found a relation between the **commitment** of the participants and how **system imperfections** are addressed. The project that had more intensively addressed imperfections had more social learning. Second, they found that the feeling of **interdependence** also affects the learning. Finally, they found that the feeling of **ownership** of the learning process also affectst learning (3).

Socio-cognitive evolutionary trajectory	Socio-cognitive evolution in niche development: Comparative analysis of biogas development in Denmark and the Netherlands (1973–2004) (4)	Explain the different patterns in biogas development in the Netherlands and in Denmark	Analyse the trajectory of BP in Netherlands and Denmark. The data were collected from several sources, such as policy documents, research reports, conference proceedings newspapers, and interviews. (5)	Introduce the notion of *social learning* referring to the process in which the outcomes and experiences created by local projects are interpreted and translated in generic lessons that can become part of global cognitive rules. Collective and social learning acts as a selection process (4)	**Expectations** are important for providing direction for variation, the building of local and global social networks, **selection** as a social learning process, and the **retention** of lessons. A bricolage approach (modest steps, low-tech, bottom-up experimentation and gradual up-scaling) proved more successful for biogas development than a breakthrough approach (big steps, high-tech, leap-frog idea, rapid up-scaling. **External regime development** (cultural, environmental, political and regime problems and discussions) affect the development of technological trajectories. **Formal rules**, such as subsidy schemes and investment grants, play an important role in the development of a technological trajectory.

(1) Brown & Vergragt, 2008; (2) Negro et al., 2008; (3) van Mierlo et al., 2010; (4) Raven & Geels, 2010; (5) Raven, 2005

These concepts do not explain how individuals' interests, aspirations, problems (or imperfections), goals and visions are related to the societal or collective ones. It is not clear whether people become involved in learning and environmental actions for their own benefit and/or for solving a general societal problem. This problem is expressed by Brown et al. (2003) as the dilemma between individual and organisational interests. Brown et al. (2003) showed the existence of a tension between individuals' interests and their institutions' interests. This tension led the actors to avoid taking radical steps within their organisations, especially making major institutional commitments of resources. Brown et al. (2003) point out that finding a specific problem that the innovation could solve can help to overcome this dilemma. They claim that the dilemma is particularly pronounced in those BSTEs that are driven by an attempt to introduce a new technology to solve a general societal problem.

A closer analysis of the assumptions of the studies concerning the motivation to learn and develop shows that they are internally contradictory. On one hand, the studies state that a shared vision (Brown & Vergragt, 2008; Brown et al., 2003) is not a necessary condition for solving societal problems. On the other, their definition of the success or failure of a project or a technology is assessed in terms of a change in the goals, values, norms, interests, perspectives and problem definition. It remains highly unclear what has to be shared (rules, perception, problem definitions and vision) as a pre-condition for building a sustainable technology and how individual interests, goals, problems, visions and expectations are related to the societal ones. Do they have to be shared, congruent, similar or overlapping, and what does "shared", "congruent", "similar" or "overlapping" mean in this context?

3.3.2 How is the "new" created?

In the reviewed studies, learning or the lack of it seems to be regarded as the most critical aspect in the development of sustainable production. In the studies, learning is related to the emergence and creation of the new rather than appropriating culturally existing knowledge. Brown and Vergragt (2008) showed that a sense of urgency, in the form of risk taking, financial stakes, reputations or the posing of the problem in need of a solution, is the most effective driver of social learning. The sense of urgency is a perception that some result has to be necessarily achieved. But what? Van Mierlo et al. (2010) go a step further, explaining differences in learning with the compatibility between system intervention and system imperfections as perceived by the participants. People are committed to a project when they feel that the project focuses on their problems and aims. In this sense, urgency not only refers to the urgency of the problem, but also to a belief in a proposed solution. The theory does, however, not explain how this feeling of urgency emerges. Not all system imperfections create an experience of urgency. On the contrary, people live all the time with imperfections.

Raven and Geels (2010) stress the importance of protected spaces for supporting learning and the emergence of new technologies. Projects are spaces for experimentation and for the alignment of different issues. In their case study, they explained the changes in trajectory in reference to whether outcomes were positive or negative, and/or whether problems emerged. They found a clear relationship between outcomes, expectations and the number of projects. They use the concepts of cognitive, formal (laws, regulations, subsidiary programmes) and normative (role relationships, responsibilities, behavioural norms) rules for conceptualising the content of learning. Rules function as a retention mechanism, and also guide actions and variations. However, it is not clear how rules can generate variation. As Miettinen and Virkkunen (2005) point out, the concept of rules is more useful for explaining stability and continuity rather than change. Geels (2004) presents other concepts, such as mis-alignments, tensions and instability, as useful tools to understand transitions in systems, but he did not use them in the study analysed above. It remains unclear why and how variations emerge at the very local level through the agency of individuals.

The studies give hints on how innovations are created. Somehow they claim that problems, mismatches, or imperfections are important driving forces for learning and innovation. People, networks and systems learn because the actual way of doing things is not in accordance with the long-term visions, expectations and aspirations. This inconsistency calls for new cognitive frames, rules, practices and collaboration. These concepts seem to have explanatory potential and deserve to be further conceptualised.

3.3.3 The relationship between learning and development

The studies analysed in Section 3.2 speak extensively about learning and the importance of learning for the development of a network or a system. However, these studies do not say much about the relationship between learning and development. What the studies say is that learning is needed in order to develop a sustainable technology. In other words, first a person or a group must learn, and then the system can be developed. From the studies presented above, the studies on social technical cognition provide the most sophisticated theoretical framework regarding the relationship between learning and development. These studies propose that people install experiments and learn from them, which then affects development in a cyclic way. However, the studies have a limitation when we think about learning something that does not yet exist. How can we learn something if there is no experiment for it, and how can we experiment if we do not know anything about the new?

According to Raven and Geels (2010), learning is understood as a change in the rules, which is a much broader concept than the concept of a cognitive framework, capturing not only knowledge, theories and values but also normative and formal rules, such as responsibilities, trust and regulations. The recognition of rules is a step further, but is still limited when trying to explain how the new is created in the first place. They propose that there is a process of the accumulation of rules, in which at the beginning there are no rules, and as a regime starts to develop, these rules accumulate and solidify. This proposition does not solve the problem of how we can learn something that does not exist.

The problem with these studies is that learning is limited to cognition and does not recognise that learning also makes use of the materialised socio-cultural structure of the activity, such as cultural artefacts and forms of organisation. Cultural artefacts are not only an outcome of learning, but are necessary conditions for learning. Experiments are preceded by tools that allow us to visualise beyond the current regime and create new ones. People make use of shared tools to visualise, plan and assess experiments, and design new possibilities. Raven and Geels (2010) recognise artefacts, saying that they are interrelated with rules, but they do not say how artefacts are related to learning.

3.4 Conclusions

In general, the studies analysed above focus mainly on the development of a technology or the broader system that supports the development of the technology, rather than focusing on the problems which the technologies are expected to solve. The development of the technology cannot be an independent purpose of its own. Rather, it has to be seen as a tool for increasing the sustainability of production. Therefore, the object of research must be broadened to the whole network of activities involved in the production of biogas as well as to the activities that make use of it, farming and food production.

The studies on learning in sustainable technologies that were reviewed here make a significant contribution in presenting many factors that affect the development of BP, but they are rather weak in explaining the process of learning and development. These studies recognise that different kinds of learning are needed to deal with environmental challenges. They recognise the existence of different levels, which depend on the content of learning. The functioning of environmental technologies requires not only learning new solutions, but also new perspectives, goals, values, aspirations and so on. Moreover, they recognise that individual learning is not enough; it is also necessary to have social learning, or learning within networks or communities. Learning requires changes in practices and structures (innovations in systems or regimes).

The review showed that an explanation of how the individual level of learning is related to the collective one is currently lacking from these studies, i.e., how changes in individual practices and individual cognitive frames are related to changes in shared structures. In addition, the studies recognise visions, aspirations and expectations as driving forces for learning, but they fail to explain how individual motivation is related to collective ones. In general, theoretical concepts that explain the connection between the individual and the collective are missing.

The analysed studies in the literature of sustainable (or green) technologies reviewed here take the temporal dimension seriously. These studies are usually case studies describing the evolution of a technology in a certain space, e.g., a nation. Raven and Geels (2010), for example, analysed the evolution of biogas in Denmark and Netherlands in the period 1973–2004. In general, these studies take history into consideration and have an important contribution in showing how a technology develops, but they fail (except van Mierlo et al., 2010) to conceptualise how the technology emerges and what challenges are faced by such technologies at the very local level of individual actors, especially the challenges related to the existence of multi-perspectives. Moreover, although these studies usually take into consideration expectations and visions as crucial to the emergence of sustainable technologies, they do not take into consideration the process of how different expectations and visions from different actors merge and change. Usually, only societal motivation is taken into consideration, overlooking the fact that local actors may have different multi-motivations. In the next chapter I propose activity theory as an attempt to fill these gaps.

4 ACTIVITY THEORY AS AN ALTERNATIVE APPROACH FOR STUDYING THE EMERGENCE AND DEVELOPMENT OF BIOGAS PRODUCTION

In this chapter, I introduce cultural-historical activity theory as an alternative theoretical approach to the study of biogas production. Traditional studies on biogas production usually take the point of view of technology and, therefore, overlook the relation between biogas production, swine production and their respective environmental problems. Before introducing how activity is understood in this study, I will briefly introduce the history of the key concept of cultural-historical activity theory, the concept of activity.

4.1 Why focus on human activity?

The concept of **activity** was introduced by the German philosopher Hegel, who was the first to recognise the role of material, productive activity and the instruments of labour in the development of knowledge (Engeström, 1987; Lektorsky, 2009). He proposed the ideas that human consciousness is formed under the influence of knowledge accumulated by society over history, and that this knowledge is objectified in the world of things created by humanity. The ideas of Hegel were further developed by Karl Marx, who considered man not only as a product of history and culture, but also as a **transformer** of nature and a **creator**. This idea is of crucial importance for understanding the emergence of new objects of environmental protection, and it is one of the key differences between the approach suggested here and other system-oriented approaches.[7]

In the *Theses on Feuerbach* (1845/1984), Marx explains the importance of the "human-sensuous, practical activity" by which the opposition and separation of object and subject, mind and world, is overcome. With this idea, he refers to the

[7] Systems theory can be divided into two waves or orders according to the ontological and epistemological assumptions (Bawden, 1991; Ison et al., 1997; Midgley, 2000). In the agricultural context, Bawden (1991) classifies systems theories into two groups: ontosystemics and episistemics. In the first group, Bawden (1991) includes those theories in which the word 'system' is used to describe the world. In this group, a system (e.g., a farm) is seen as something that exists in the "real" world independently of the viewer or observer. In the second group, the word 'systems' is used as an epistemological device to explain how we know about the world. In this study, I adopt a third philosophical definition of system, a dialectical materialist interpretation (Ilyenkov, 1977). In this view, a system is neither purely a set of objects that exist independently of human interpretation nor a purely subjective interpretation (a model or a concept), but both. A system is understood as a tool that can be used to transform and create human activities. Thus, it is something that is located between the given situation and the product of human action. As any other tool, the concept of a system emerges through a process of transformation of the objects, through human actions and activity.

need to take the **active** aspect of humans into consideration (Engeström, 1987). Humans are able to purposefully change the world and create new things that go beyond their actual capacity, rather than simply adapting to changes in the environment. This active aspect of man, or human activity, should be understood as being subjective and objective, human and natural. Marx (1867/1976) developed the concept of the labour process as the transformation of nature to "satisfy needs of one kind or another", as he explains:

> *Labour is, first of all, a process between man and nature, a process by which man, through his own actions, mediates, regulates and controls the metabolism between him and nature. He confronts the materials of nature as a force of nature. He sets in motion the natural forces which belong to his own body, his arms, legs, head and hands in order to appropriate the materials of nature in a form adapted to his own needs. Through this movement he acts upon external nature and changes it, and in this way he simultaneously changes his own nature. (Marx, 1867/1976, p. 283)*

During the 1980s there was a growing recognition of the importance of practice in the field of sociology of knowledge and organisational learning. An example of this recognition is the work of Jean Lave and Etiene Weger (1991), which introduced the notion of community of practice. This concept is now widespread and has helped to change the focus of learning from the individual to the whole community involved in a productive practice. Later, Weger (1998) further developed the notion of communities of practice so that it could be used as a toolkit for organisational design and knowledge management. In spite of the many contributions of the concept of community of practice towards expanding the understanding of learning from the individual to the collective and towards the recognition of learning through participation in communities as being as important as learning within schools, the concept has some important limitations. Neither Lave and Wenger (1991) nor Weger (1998) situate the concept of a community of practice in the history of society and in patterns of the organisation of work. As Engeström (2007) points out, Lave and Weger's (1991) notion of community of practice glorifies a historically limited form of community as a general model for all times. Thus, there is little recognition of the relationship between changes within a community and macro cultural and societal changes.

Marx's concept of human activity is useful for overcoming the limitations of current theories on human practice by recognising the role of history and societal mediation. The concept of activity is based on a dialectical view of development and recognises that humans, as well as any other living creature, are active and interact with their environment. Rather than seeing the environment as external factors and variables, dialectics propose that the relationship between an organism and its environment is internal in that they model and define each other through a process of evolution (Tolman, 1981).

Marx proposes a different way of seeing this relationship as an internal, dialectic one. It is through labour that man becomes man, human and natural (Foster, 2000). It is an absurd to say that man is not natural. It would be the same as saying that man has no body. By using the concept of labour, Marx (1867/1976) transcends this dualism. Marx proposes that man can change neither himself without changing the material world around him, nor the world around him without changing himself. This dialectical relationship between man and nature is fundamental to the way that Marx understands the evolution of human society through the transformations of nature. Marx's concept of labour leads one to see BP as both a natural and a social process, and to reject any conception that separates the natural and technical from the social. Marx's idea, that man transforms both nature and himself through labour, can also be applied to BP: the creation of a system of BP contributes to how man regulates and controls the metabolism between himself and nature and at the same time creates a more complex form of knowledge and social organisation.

Marx's concept of labour has some particularities that are worth highlighting. First, according to him, labour is a universal condition of man's existence. This means that man is always involved in labour processes in order to live. People must always transform things to satisfy their needs. This gives us a unit of analysis that takes human motivation into consideration. Second, Marx's concept of labour gives an alternative dialectical way of seeing the relationship between humans and nature, which overcomes the persisting dualism between them. Traditional learning theories separate nature from man, society and culture as well as object from subject, agency and structure, determinism and free will.[8] Although in such theories, it is recognised that man and nature are in connection and affect each other, this connection is based on the cause and effect logic of an external relationship, in which changes in the environment demand that man adapt.

Another important contribution of Marx's (1867/1976) concept of labour is the purposefulness of labour. Marx (1867/1976, p. 284) stresses that labour is not simply the transformation of nature to satisfy needs, but also the purposeful change of nature. This implies that special attention has to be given to the purpose of labour.

As Virkkunen and Kuutti (2000) argue, in order to understand activities, their problem, and the possible means of solving them, we have to take into consideration the history in which they are embedded. They argue that learning and problems are determined by the local and historical form of the activity and the available cultural means of solving the problems. Cultural-historical activity theory gives us tools for understanding human behaviour that take into consideration the history and the system of internal relations.

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[8] This dualism is considered to be one of the reasons for the crises in science and in its capacity to explain the world, and solve the problems that are challenging us (see Latour, 1992, 1999; Foster, 2000).

4.2 Cultural-historical activity theory

Cultural-historical activity theory has its roots in Russian psychology of the 1920s and 1930s in the work of L. S. Vygostky (1978). This approach started with studies on child development and has expanded to studies of everyday working activities, such as banking, health care, legal work and organic farming. The main idea of activity theory is to take a historically developing activity as the theoretical unit of analysis.

L. S. Vygotsky (1978) created the idea of the cultural mediation of human action, a concept that became central in activity theory (for a recent review, see Roth, 2007). Cultural mediation means that the relationship between the subject and the object is mediated by cultural means or artefacts used as signs and tools (Figure 4.1). According to Cole (1996), an artefact is defined "as an aspect of the material world that has been modified over the history of its incorporation into goal-directed human action". An artefact is both material and ideal (conceptual). For example, a table is both a material object and an embodiment of a human idea of the function of a table. There cannot be an artefact without these two characteristics, the material and the ideal. This is also true about words: no word exists apart from its material carrier (Cole, 1996, p. 117). According to Cole (1996), the concept of an artefact as a product of human history offers a way to overcome the duality between the internal and external, the ideal and material.

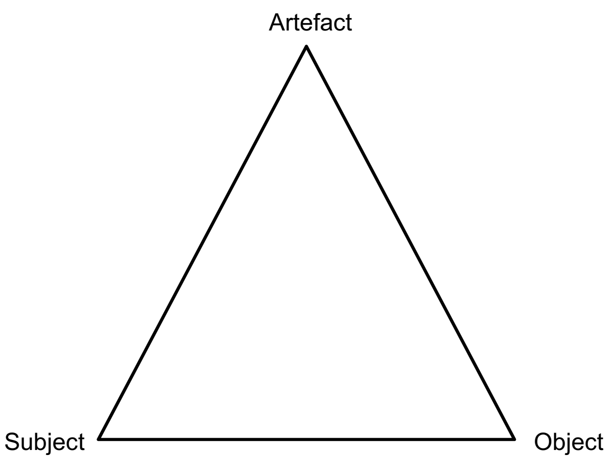

Figure 4.1 The basic mediational triangle proposed by Vygostky (Engeström, 1987)

The theory of cultural mediation is useful for understanding human agency. In activity theory, agency is understood as the ability to construct and transform one's own activity. Vygotsky argues that intentional actions are mediated by artefacts.

> *The person, using the power of things or stimuli, controls his own behaviour through them, grouping them, putting them together, and sorting them. In other words, the great uniqueness of the will consists of man having power over his own behaviour other than the power that things have over his behaviour. But man subjects to himself the power of things over behaviour, makes them serve his own purposes and controls that power as he wants. He changes the environment with the external activity and in this way affects his own behaviour, subjecting it to his own authority. (Vygotsky, 1997, p. 212)*

Agency originates and requires the use of external artefacts. Agency depends not only on individual capabilities but on the access to and command of adequate conceptual and practical tools as well as on the prevailing social norms and relationships of collaboration in the community (Virkkunen, 2006).

Engeström (2006) proposes a model of causality in human action composed of three layers of causality: the **interpretative layer,** the **contradictory layer** and the **agentive layer** (Table 4.1). The first layer refers to an individual as a rational decision maker, in which actions are taken as the outcome of the interpretation of what is happening in the world. This layer is based on the actor's interpretations of the rules, the meaning of his or her activity and logic. Causality in this layer is not only affected by the environment (understood as physical objects) but also by the actor's activities, interpretations and logics. A typical explanation in this layer is: if x, then y. The second layer, the actions of individuals, is affected by the existence of multiple contradictory motives embedded in their activities. According to Engeström (2006, 2007), this layer is what makes actors seem irrational and unpredictable, even though these actions may be explained by the contradictory situations faced by the actors. In the third layer, the agentive layer, actors are seen as agents who intentionally transform their activities. In this layer, actors make use of cultural artefacts to control their activities. The main difference between actions in this layer and the other two is that here the actor does not simply respond passively by interpreting rules (as in the interpretative layer) or take unpredictable and random actions (as in the contradictory layer), but takes intentional actions aimed to change and control his or her activities.

Table 4.1 Three layers of causality in human action (adapted from Engeström, 2006, 2007)

Interpretative layer	An actor	Takes actions based on rules, the meaning of the activity and logic	If x, then y
Contradictory layer	An actor as a participant in collective activities	Takes actions driven by contradictory motives	Searching for a resolution through unpredictable actions
Agentive layer	An actor as a potential individual and collective agent	Takes intentional transformative actions	Inventing and using artefacts to control the action from the outside

Vygotsky studied the cultural mediation of individual action. As a theoretical unit of analysis, this model is problematic as it isolates an individual action from its social context (Engeström, 1987). This limitation was overcome by A. N. Leontyev (1981) by making a differentiation between an individual action and collective activity. This differentiation becomes clear in his example of the 'primeval collective hunt' (Leontyev, 1981, p. 210-213).

> *When a member of a group performs his labour activity he also does it to satisfy one of his needs. A Beater, for example, taking part in a primeval collective hunt, was stimulated by a need for food or, perhaps, a need for clothing, which the skin of the dead animal would meet for him. At what, however, was his activity directly aimed? It may have been directed, for example, at frightening a herd of animals and sending them toward other hunters, hiding in ambush. That, properly speaking, is what should be the result of the activity of this man. And the activity of this individual member of the hunt ends with that. The rest is completed by the other members.*

As Leontyev (1981) argues the action of frightening the herd may not be understood if analysed separately from the collective activity that it is part of. Actually the action of frightening a group of animals, if seen in isolation, seems to conflict with the object of catching the animals. But how is it possible that the need-fulfilling object does not direct individuals' actions? According to Leontyev, this division between the objectives of individuals' actions and the object of the joint activity emerges as a consequence of the division of labour. The product of the whole process meets individuals' needs, even though the individual may not perform the final action (killing the prey) which may directly lead to the possession of the object of the given need.

The distinction between action and collective activity

The differentiation between action and collective activity can be historically traced through the increasing division of labour in human production. The division of labour has led to the separation of individuals' actions from the collective activity carried out to satisfy a human need. Due to this separation, individuals' actions do not directly satisfy their own needs. The satisfaction of needs is mediated through a social process of distribution. The needs of the worker become satisfied by a share of the products of their collective activity. This distribution of the share is regulated through relationships which are specific to each historical form of production.

The distinction between action and activity is of crucial importance for understanding how actions emerge and what they are directed towards. It is also one important difference between activity theory and other action-oriented approaches. Usually, the cognitive approaches focus on the action level, overlooking the difference, highlighted by Leontyev, between the *societal motive and meaning* of a joint activity and individuals' *personal sense and motivation* to take part in the activity. These approaches usually use the concept of a goal to understand what drives people's actions. According to Leontyev (Leont'ev, 1978), actions are indeed directed towards goals. However, only the object and motive of the joint activity, not the objectives of actions, can explain why an action arises. The divergence of the motivational function of labour into two functions, the objectives of individuals' actions and the object and societal motive of a collective activity, is a product of the historical development of the division of labour. In other words, the division of labour separates the objectives of actions from the motive of the collective activity. This separation has created a dialectical relationship; activities cannot be understood without actions, and actions cannot be understood without activity:

> *Human activity does not exist except in the form of action or a chain of actions. (Leont'ev, 1978, p. 64 (Leontyev))*

In Leontyev's hunting example, not only was the labour divided, but the prey was also shared among the hunters so that the beater's action would indirectly satisfy his needs. In collective activity, the problem of the division of labour is connected to the question of the sharing of the outcome. The immediate need fulfilment of primitive man is transformed through the division of labour into two interrelated processes, individuals' actions and collective activities that create objects that meet needs that exist in society. The connection between individuals' actions and societal activities reflect social rather than biological realities (Leontyev, 1981). The concept of **societal meaning** is related to the societal usefulness of a certain object, while the **sense** of something to a person is related to how that thing is related to the person's motive. Let me clarify using an example of a man working in a bakery. The societal meaning of bread-making activity is to produce bread, which can be used for food and the satisfaction of hunger. The worker may also be working in the bakery to satisfy his need for food, clothing, housing and so on, but the object of his action, the bread, is not necessarily the motive for his actions. In a simplistic way, in this example the societal meaning of bread-making is to feed people, while the sense for the worker may be different, for example, to obtain money to buy a house, to travel and so on.

The sense is always the sense of something (Leontyev, 1981, p. 229) in relation to a motive. The sense expresses the relation between the motive and the goal. The sense is the reflection of the subject on what is that stimulates him to act to achieve something (Leont'ev, 1978, p. 91). It is through the sense that the subject's attitude to an objective phenomenon is expressed. In this study, the sense is directly related to the actors' personal relationship and attitude towards the biogas.

4.2.1 Object as the motive of a collective activity

According to Leontyev (Leont'ev, 1978; Leontyev, 1981), what defines an activity and differentiates one activity from another is the object of the joint activity towards which individuals' actions are directed. The concept of the object of activity was introduced for the first time by A. N. Leontyev (Leont'ev, 1978) to explain the development of human consciousness (for recent reviews of different perspectives on the object, see Stetsenko, 1995; Kaptelinin & Miettinen, 2005; Miettinen, 2005).

Leontyev (Leont'ev, 1978), in his book *Activity, Consciousness and Personality,* sharply criticised the traditional way of understanding human activity as a relationship between man and an opposing society. According to him, such a dualistic way of understanding activity overlooks the point that society does not simply consist of external conditions to which man accommodates his activities, but it is the social conditions in themselves that carry the motives and goals of his activity and the means of production. In other words, it is society that produces the activity of individuals and forms it.

Based on the work of Marx (1867/1976), Leontyev (Leont'ev, 1978) introduced the concept of **objective activity**, or object-oriented activity. In his activity man sets objects of nature into mutual interaction as either tools or as objects to be transformed with the help of a tool to meet his needs. The basic assumption is that an activity is always directed to an object. There is no activity without an object. In order to study a certain activity, we first have to identify the object that directs the subject's actions. In an activity theoretical approach, humans are seen as engaged in several activities, which are distinguished from each other by the objects towards which they are oriented (Leont'ev, 1978, p. 62). The concept of the object of activity in cultural-historical activity theory is based on four principles. The first is that the object of an activity is its true motive, and the reason for its existence is related to a need that exists in society (Leont'ev, 1978, p. 62). The second principle is that the object is twofold, epistemic (ideal) and objective (material). The third principle is that the object is in constant change. Contrary to an action whose objective is anchored to a place and time, the object of an activity is more sustained and open. The activity of building houses does not stop when one house is built but continues and the experiences gained in building one house can open new perspectives on building better houses or building houses more economically (Leont'ev, 1978, p. 62). The fourth principle is that the object can only be achieved collectively. In modern societies objects cannot be produced individually, but individuals participate in joint collective activities. Leontyev (Leont'ev, 1978, p. 51) proposes that activity has to be understood in its social relations, from 'the life of society'.

Regarding the motivational aspect of objects, in contrast to other motivational theories that see motive as biologically given (for example, Maslow, 1954), the activity theoretical conceptualisation of motive is that needs themselves are also socially produced. Among humans, needs are not purely biological but evolve in human activities, and are also mediated by objects that are defined culturally in the course of history (Leont'ev, 1978). Human motives emerge through the appropriation, use and development of objects and artefacts in collective human activities. Thus, people become involved in collective activities to produce objects that can satisfy human needs that also emerge when carrying out and developing activities (Miettinen, 2005). The theory separates the process of meeting societal needs through collective activity and individual need fulfilment. An individual's need, for example, for housing is met when he or she obtains one, but the societal need for houses requires that the basis of construction activities continues to exist and provide the motive for construction activities.

The object of an activity is thus both ideal and material as well as imagined and perceived. The difference between an object (a thing as such) and the object of an activity is that the latter is the starting point and raw material of the process of transformation. As Miettinen (1998) explains, the concept of the object of an activity transcends the duality between subject and object as well as the opposition between constructivism and realism. The object of an activity includes 'raw material' to be transformed and a vision, an outcome or a product (or service). The transformation is not only mental and discursive, but it is also objectified in a hybrid system composed of human and physical as well as biological elements (Miettinen, 1998, p. 424).

Another characteristic of objects is that they are constantly changing. The change takes place not only in the object's material aspect but also in its ideal one, which includes the conceptualisation of a thing, knowledge of that thing and the methods for producing it. According to Engeström (1987), there are inner contradictions in objects of activity because the same object is part of several systems such as the system, of its production and the system of its use. Inner contradictions within the object lead to its constant change and evolvement. In the capitalist mode of production, objects are produced as commodities to be exchanged in the market. A commodity can only have exchange value if it has use value in some human activities, that is, satisfies a need. Commodities produced for exchange in the markets do not satisfy the producer's need directly, but provide him or her with the means for obtaining other commodities that may have use value for him or her. This duality of commodities constantly generates contradictory objectives and tensions between producers and consumers, and is the main source of the change and development of objects of activities.

Because objects of activities are socially constructed in the history of the activity, they are, on one hand, given to individuals in a pre-existing form, and on the other hand, interpreted and reconstructed by the acting individuals. The ideal aspect of the object, that is, knowledge about the object and its meanings, is understood and defined differently in different times and by different actors in different, contesting ways. A good example is the object of sustainable swine production. Both the material object and the ideas on its profitability and sustainability can be given different meanings. In this study, I understand the object of an activity as a thing that is being collectively produced to satisfy certain some needs in society. However, in a market economy, most production is not carried out for the producer's own consumption but in order to exchange the products for money on the market. Farmers may produce biogas for their own consumption or to sell it on the market to obtain money to buy other commodities that would satisfy their needs.

Objects can have many properties with the capacity to satisfy the different needs of different actors. Some objects require the collaboration of stakeholders from several different activities. Usually, each actor has a different interest in the object that is being produced. The sustainability of an activity depends on how much the object can satisfy the expectations of the actors involved over time. Moreover, awareness of the interests of the different actors involved in the activity may increase the probability of a sustainable collaboration.

Whether biogas is an object of activity or a tool is an empirical question that requires empirical analysis. The concept of object is used in all the empirical chapters of this study, particularly in Chapter 7, where I analyse the meaning and sense of biogas (and other sub-products) to farmers and the Sadia food processing company. The concepts are especially useful to understand their motivation to get involved in BP for sustainability. These concepts are further elaborated on and operationalised in Chapter 5, when I present the analytical concepts used.

4.2.2 The basic structure of a human activity

Y. Engeström (1987) has developed Leontyev's (1981) theory of activity by modelling the basic mediational relationships in systems of human activity. This model depicts the three culturally mediated, intertwined processes of production, distribution, and exchange that are present in all joint activities and together determine the consumption that takes place in the activity. In this model, Engeström (1987) expands the individual mediational triangle of subject-artefact-object, incorporating social organisational mediators, such as rules, division of labour and community (Figure 4.2). Engeström (1987) proposes that the why of individual actions can only be understood if the object of the joint activity and the relationships of subject, object and tool with the elements at the bottom of the triangular model are taken into consideration. The **community** refers to those who take part in realising the object, the **rules** refer to explicit norms and conventions that constrain action within the activity system, and the **division of labour** refers to the division of tasks among the individuals of the community. The components of the activity system are constantly being constructed, renewed and transformed as a consequence of the development of contradictions. This process of renewing and transforming the mediation in the relationships of interaction in the activity by creating or adopting new mediation artefacts is called **remediation** (Lektorsky, 2009).

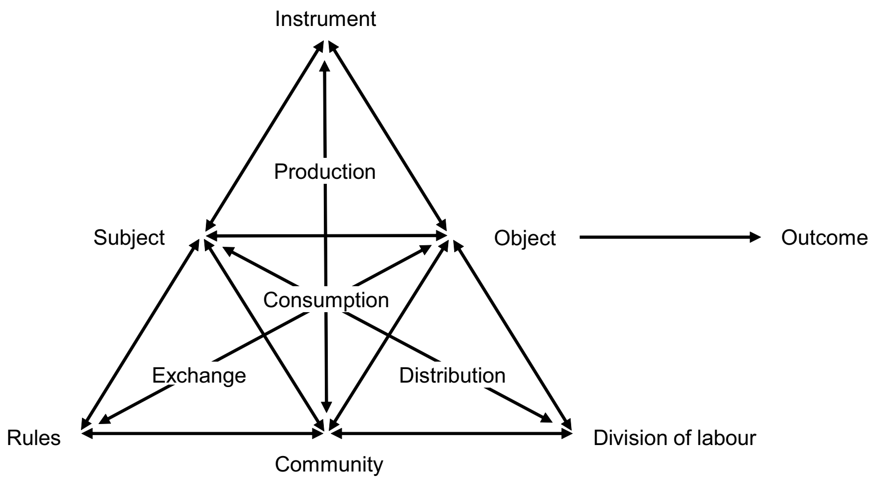

Figure 4.2 The model of an activity system (Engeström, 1987, p.78)

Wartofsky (1979, p. 201) provides a useful differentiation between artefacts that helps us to make sense of the different kinds of mediating functions of artefacts in an activity. According to him, **primary artefacts** are those directly used in production, such as tools, modes of social organisation and bodily skills that enable the use of tools. **Secondary artefacts** are symbolic representations of actions, which include models of forms of actions, design and prescriptions that are created with the purpose of reserving and transmitting skills and use of the primary artefacts. Secondary artefacts allow the collection and accumulation of experience, and the visualisation of an activity, allowing reflection on it. Thus, they are crucial for reflection and learning. **Tertiary artefacts** do not directly represent current practice, but represent tools, rules and actions freely constructed in the imagination (simulation) that are peculiarly different from the tools, rules and actions in use. These new artefacts help actors to create alternatives for the potential change of their actual practices. While secondary artefacts are used to solve problems and improve the production process, tertiary artefacts are used to envision new principles for their activities as well as to design new secondary artefacts.

4.3 Changes in production, organisation and learning

4.3.1 Socialisation and new forms of production

According to Marx (1867/1976), human activity is never independent from other activities. The product of human activity is at the same time the product of a previous labour process and the means of production in a later process. Therefore, products are the result and an essential condition of human activities. This aspect connects activities in space and time. An activity requires means of production produced by other people or in another place and time. Therefore, in practice we may conclude that every activity is connected to a countless number of other activities.

According to Adler (2007), the socialisation of the forces of production embraces the socialisation of objective (material means of production) and subjective forces of production (human capabilities). **Subjective socialisation** can be seen in the increased complexity of knowledge, which in turn, reflects the increased complexity of tasks and technologies. The **socialisation of objective forces of production** can be understood as the increasing interdependence between differentiated and specialised branches of activity, forming an increasingly interdependent whole. Objective socialisation can be either consciously planned or the result of "the invisible hand of the market". Through socialisation, society's productivity is increased by the development of specialised materials, equipment and know-how and the capacity to integrate them on a global scale. Moreover, the socialisation process also involves the development of techniques for increasing the cooperation between interdependent operations, which represents a step forward towards more rational, conscious planning and management of large-scale operations (Adler, 2007).

According to Adler (2007), the search for profit (conceptualised by Marx as surplus value) is what promotes and inhibits the process of socialisation. The competition between firms makes them the most important promoters of socialisation. To increase or sustain the levels of profitability, they consciously or unconciously have to develop or implement new means of production, e.g., technologies, new forms of organisations, and know-how. In doing so, markets expand, integrating production, distribution, exchange and communication on a global scale (Adler, 2007, p. 1324). Nevertheless, this process of socialisation that leads to the expansion of capital also leads to the reduction of the value of a product, resulting in a decrease in the rate of profit in the long term and the need to intensify the process of socialisation.

The process of socialisation of forces of production transforms subjectivities and forms of production, organisation agency and learning (Virkkunen, 2006). Victor and Boynton (1998) supply an interesting historical framework for understanding the transformations in production. They claim that in order to maximise profits (the valorisation process), a company has to develop its production along "the right path", which means a general sequence of historical types of work from craft to mass customisation. This process requires transforming work organisations, knowledge, management and information systems. They identify five types of production: craft, mass production, process enhancement, mass customisation and co-configuration. Each type of production requires qualitatively different elements (Victor & Boynton, 1998).

Craft production is characterised by the production of unique and innovative products that make an impression on customers. Mass production is characterised by the production of cheap and standardised commodities with the use of a standardised process. Process enhancement is characterised by the production of high quality products. Mass customisation is characterised by the production of tailored and affordable products and services made to order. Co-configuration is characterised by the continuous collaborative reconfiguration of the combination of products and services that connects production chains. Co-configuration production is characterised by a) a product that can be continuously adapted to changing conditions and customer needs, b) a collaborative system in which the value is not produced in the interaction and collaboration between the supplier and customer, c) the client who reconfigures the product him- or herself, and d) continuous customisation that constantly changes the product to customers' (Victor & Boynton, 1998).

In the co-configuration type of production, customers as well as other interdependent producers form a network which collaboratively puts together a complex system or a set of products and services, which has a long life cycle (Engeström, 2004). Co-configuration requires a flexible organisation which combines activities with different but complementary resources.

4.3.2 Forms of organisation

Many studies have been conducted in an attempt to define the of relationships between organisations. Recently, Adler and Heckscher (2006, p. 18-21) proposed three forms of organisation: the market, the hierarchical and collaborative communities. By the **market** comunity, they mean organisations that rely predominantly on price mechanisms to coordinate competing and anonymous suppliers and buyers, by a **hierarchical** community, they mean forms of organisation that use predominantly authority to create and coordinate a horizontal and vertical division of labour, while the **collaborative** community relies on values and norms. Engeström (2006) points out that the strength of hierarchies is their ability to secure the standardisation needed in traditional mass production, but they are limited due to their rigidity. On the other hand, market organisations are strong for their flexibility, but they are limited by their excessive competitiveness, which tends to exclude collaboration and reciprocity. Such a limitation seems to be the case when the object of work is an environmental solution, in which benefits are difficult to be "commodified". The collaborative community is an alternative form, in which companies collaborate in a larger constellation of companies. It is important to notice that these three basic forms of coordination always exist in parallel, so that all real forms are hybrids of them. One may be predominant, however. In other words, in real life, networks are expected to be a mixture of a hierarchical, market and collaborative community (Adler & Heckscher, 2006).

Network of functionally interdependent activities

According to Engeström (1987), activity systems are never isolated, but are always affecting and being affected by other activities. One way of modelling is by choosing one activity system as central, and then looking at all the 'neighbouring activities' related to this central activity system. Y. Engeström (1987) classified these neighbouring activities into four groups: **object activities,** which are composed of all activities where the immediately appearing objects and outcomes of the central activity are embedded; **instrument-producing activities,** which include all those activities that produce the key instruments for the central activity; **subject-producing activities;** which involve activities such as education and schooling of the subject of the central activity; and **rule-producing activities,** which include activities such as administration and legislation (Figure 4.3).

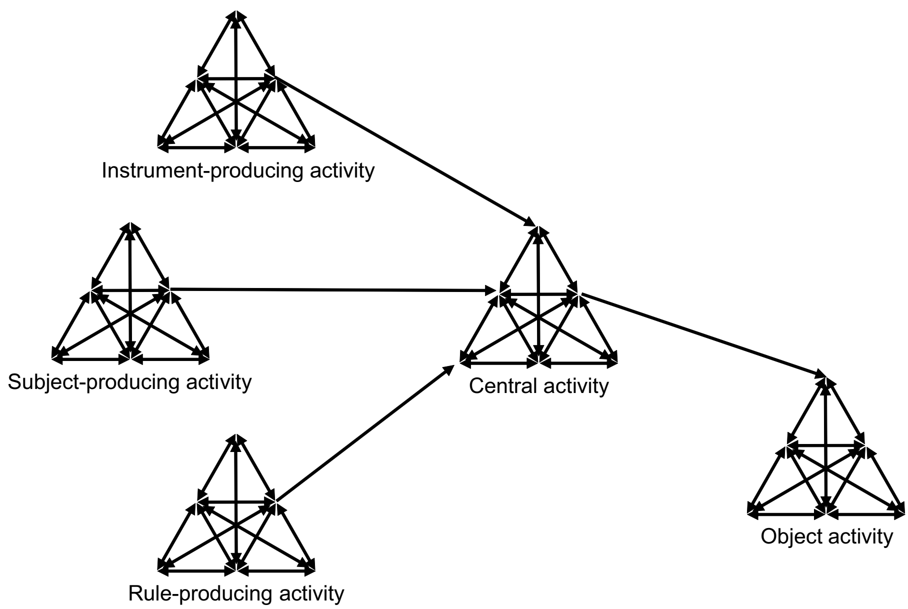

Figure 4.3 Network of functionally interlinked activities (Engeström, 1987, p. 89)

Networks of co-production

The second form of modelling networks of activity systems described by Engeström (2001) is the model of co-production or co-configuration. In this model, there are two activity systems co-producing a partially shared object as a minimum unit of analysis. The activities are directed towards different objects, but in this model, objects overlap, allowing collaboration to take place. Such collaboration is possible because of a shared object (Figure 4.4).

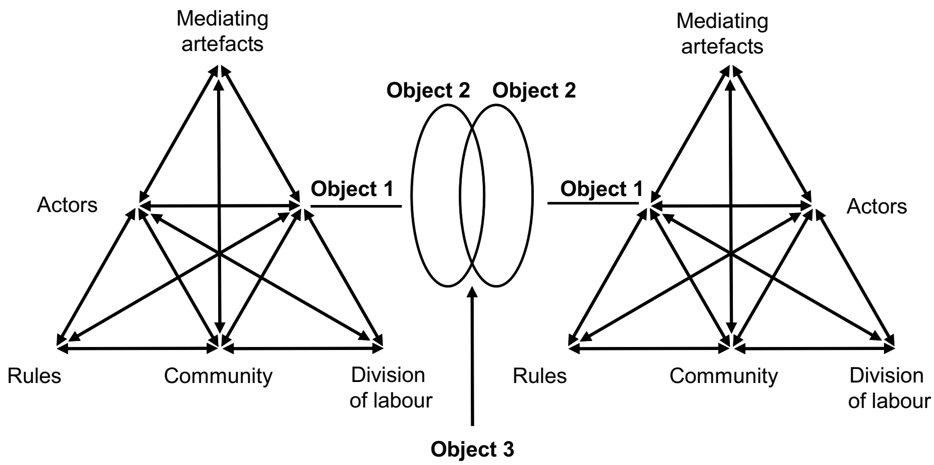

Figure 4.4 Model of two activity systems with a partially shared object

The intensification of the division of human activities into ever more specialised and interdependent activities makes it necessary to take networks of activities rather than isolated activities as the minimum unit of analysis (Engeström, 2001). By considering just one activity, we take the risk of having just a partial picture of the object that is being produced, abstracting a large range of other activities that are equally important. In this study, I define a **network of activities** as a group of activities that are interdependent in the production of a certain product (not necessarily a commodity).

4.4 Expansive learning

Victor and Boynton (1998) argue that each historical type of production required different types of knowledge and, consequently, different types of learning (see also Pihlaja, 2005). Y. Engeström (1987, 1999, 2001, 2004 and 2005; see Engeström & Sannino, 2010 for a recent review of studies) has developed a theory of this kind of learning, which he calls expansive learning, which consists of overcoming an inner contradiction in the previous form of activity through an expansion of the object of the activity. Expansive learning refers to situations in which people collectively create a new object and new motive for their activity in order to overcome a contradiction which is leading to a crisis in the activity, and create new tools and social organisation around this new object. Engeström and Sannino (2010) point out that expansive learning implies the design and implementation of a new model of activity, which involves the construction or remediation of all the elements within an activity system.

Expansive learning is a long process of the remediation and transformation of the collective activity. Each step in the process leads to a new inner contradiction in the activity, the overcoming of which is a new learning challenge for the practitioners. The remediation and expansion of the object require a mode of comprehending the inner contradictions of the system and of finding possibilities for further developing it. To grasp its essence, the subject has to trace and reproduce historically the logic of its development. This is possible by analysing its historical formation and the emergence and resolution of its inner contradictions. By reflecting on the logic of the development of the system, the subject forms an initial idea of the concept, which starts as an abstract explanation of the system, a 'germ cell', which is gradually enriched and transformed into a concrete system. Learning involves not only the formation of theoretical concepts, but also their materialisation. In other words, in this process, concepts and ideas are enriched, obtaining a better understanding of the system. Learning involves and is supported by the formation and use of different kinds of cultural artefacts, such as models, concepts and theories, that help the subject comprehend and construct the system theoretically and in practice.

As pointed out by Il'enkov (1977), internal contradictions are expressed in external ones. Engeström (1987) discerns between four levels or layers of contradictions: primary, secondary, tertiary and quaternary contradictions. The latter three levels are external expressions or manifestations of the primary contradiction. According to Engeström, the double nature of commodities is present in all corners of the triangular structure of an activity.

Contradictions are a key concept in expansive learning. They may have several meanings. In the theory of expansive learning, they are understood as historically evolving tensions that can be detected and dealt with in real activity systems. Contradictions are considered to be the driving force of transformation. Internal contradictions are what make the object a moving, motivating and future generating target. Expansive learning requires that the learner is aware of and engaged with the inner contradictions (Engeström & Sannino, 2010). Disturbances, dilemmas and conflicts are not the same as contradictions, but are rather the manifestation of contradictions. Contradictions can be understood through a historical analysis of the changes and challenges affecting the activity. Disturbances are considered to be the expression of tensions between and within activity systems. In activity theory disturbances are understood as deviations from the normal course of events determined by the script in a work process. They are problems that can be visualised in place and time (Engeström & Mazzocco, 1996).

Engeström (1987) points out the existence of basic inner contradictions in human activity, such as contradictions between the individual and the collective, and between dependent and independent production. Although basic contradictions cannot be permanently resolved, they may take different forms in different activities and times. Each activity experiences and manages contradictions in different ways. In the capitalist system commodities have a dual value; they have exchange and use value. Use value is the usefulness of a thing, given by its properties that allow satisfying human needs.

These two aspects of a commodity are in contradiction as they are both mutually exclusive and mutually dependent. Engeström (1987) calls this contradiction a primary contradiction, which is a contradiction within each element of the activity system. The contradiction between exchange and use value may be understood in the following way. In capitalism, production should not be understood as synonymous with the labour process. In a capitalist society, production is a unity of the labour process and the process of value creation. Although the product of an activity has a use value (i.e., a useful product), within the capitalist mode of production, obtaining a use value is not the objective of a capitalist. A use value is produced only because it is necessary to obtain exchange value. The objective of a capitalist is above all a) to produce a product with use value that also has exchange value and that can be sold as a commodity, and b) to produce a commodity that has a higher value than the cost of producing it. The final objective is not only the production of use value, but a commodity, and not only a commodity but value, not and only value but surplus value (e.g., profit).

Engeström (1987) proposes an ideal model of the **expansive learning cycle** (Figure 4.5). There are different types of interconnected cycles of expansive learning: macro, meso and miniature cycles. Macro cycles of expansive learning refer to the expansion of a whole activity system. In order to expand these activities, other intermediary activities are needed, which are the meso cycles. Meso cycles refer to change in one part of the activity system. Meso cycles take the form of transitory and temporary activities, or processes, directed to support the expansion of the main productive activities. Miniature cycles refer to learning actions with a time span of half a day or a couple of hours.

The cycle of expansive learning proposes that the emergence of a new, more expanded object starts within an already consolidated activity which starts to experience problems. This phase is characterised by a situation of dissatisfaction with the existing situation, a state of indeterminacy, arrest, a crisis or an urgent need to do something. This phase is called the **need state**. In this phase the contradictions appear in their basic form, as primary contradictions. Again, it is important to recall that in each activity contradictions appear in different forms. During this phase, the actors start to discuss and challenge the purpose of their activity (their object) and the current way of achieving it, e.g., methods and technologies. There is a need to change but not yet urgent pressure for change, as it is still possible to leave the situation as it is (Engeström, 1987).

The second phase is characterised by the aggravation of the problems already experienced in the previous phase. Emerging disturbances start threatening the achievement of desirable outcomes. This phase is called a **double bind**. At this point, the contradiction begins to produce misfits and tensions between the elements of the activity system, which are called secondary contradictions. People participating in the activity feel that it is not possible to continue doing things in the current way, but they do not yet know what should be done to solve the problems (Engeström, 1987).

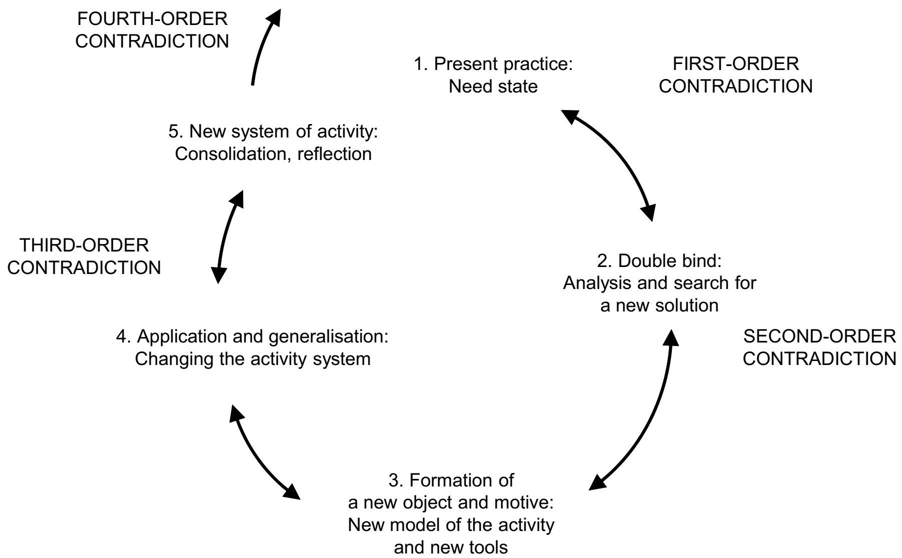

Figure 4.5 Theoretical cycle of expansive learning (modified from Engeström, 1987)

The aggravation of the problems leads to a search for solutions. These solutions may or may not include a more expanded object. They may be simply adjustments in the elements of the activity system, such as a new technology or a new way of doing something. If the crisis is severe enough, people may challenge the whole system, including the purpose of the whole activity (the object). If people challenge and change the object/purpose of the activity, and redesign it in a more expansive form, the cycle is called an expanded cycle. This phase is called **object** or **motive construction**. In this phase the community designs a new activity in which the object is more expanded (broader and including more desirable characteristics than the previous one).

Once the solution is modelled, the idealised activity can be implemented. This phase is called **application** or **generalisation (implementation)**. In this phase, the community starts to materialise the plans and makes the first attempts to begin production of the idealised object. Misfits between the elements of the new more expanded activity and elements of the old activity start to emerge (tertiary contradictions). These misfits may be caused either by insufficient development of the new elements (which are not adapted to the real conditions because the actors could not fully predict the whole reality) or by some incompatibility between the new and the old. This type of contradiction usually emerges during the application and generalisation phase of a new activity (Engeström, 1987).

As the new activity starts to take shape, and the new object begins to be implemented and produced, it is very likely that the new activity may collide with other neighbouring activities which still follow the old logic of production. Thus, before being able to consolidate, the new activity has to solve these tensions with the neighbouring activities. These tensions are the quaternary contradictions. If the activity manages to resolve these tensions, it evolves to a phase of **consolidation**. As Engeström and Sannino (2010) suggest, the cycle of expansive learning is not a universal formula of phases or stages. In everyday life, it would be likely to find a process that follows this ideal-typical model.

4.5 The zone of proximal development

The first formulation of the concept of the **zone of proximal development** (ZPD) was done by Vygotsky (1978), who defines it as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under guidance or in collaboration with more capable peers". In order to solve the problem, people make use of cultural artefacts, which accumulate historical human knowledge. By using these tools, people become more independent of the immediate context and open up new future possibilities of development, making these people pro-active agents rather than simple reactors (Meshcheryakov, 2007).

Engeström (1987) redefined the concept of the ZPD at the level of collective activity. According to Engeström (1987), the ZPD "is the distance between the present everyday actions of the individuals and the historically new form of the societal activity that can be collectively generated as a solution to the double bind potentially embedded in the everyday actions". The main idea of Vygotsky's (1978) and Engeström's (1987) concept is that the ZPD is the distance between the present and the future predicted situation in which a problem is resolved. In Vygotsky (1978), a problem is resolved through collaboration with other peers, with the use of more culturally advanced tools. In Engeström (1987), the problem, seen as a contradiction, is resolved collectively in collective activity; not only new tools but a new object and new social relations are needed.

The main idea in Engeström's (1987) concept is that a problem that is not solved on the lower systemic level (action) is solvable on the next higher level (activity). The same idea could be applied to problems that cannot be solved within an activity system; thus, they would have to be solved at the next systematic level, the level of the network of the activity system. As Engeström (2000) emphasises, the word 'zone' refers to the fact that the solution to a contradiction cannot be defined as a goal, fixed-end point or state, but as an area with many possibilities in which the present contradictions are resolved. Thus, the ZPD is a set of future possibilities that could solve the present contradiction. Such solutions may require more advanced tools, collaboration within an activity or even collaboration between several activity systems.

One way to identify the zone of proximal development is through an analysis of the development of the activity in general (the concept or model of production) and a specific analysis of the object under investigation, a specific case. The former shows the developmental dimensions and historical tendencies, while the latter shows the contradictions that are faced in practice. The analysis of historical contradictions presents a hypothesis of the actual developmental phase of an activity and the current contradictions. Once there is a clear picture of the actual contradictions of a system, one can try to propose a zone in which these contradictions could be solved, the zone of proximal development. An analysis of the development of concepts and an analysis of current practices can help to reveal the characteristics that future activity should have to solve the contradictions. In this study, the concept of the ZPD unites the findings of all the empirical chapters.

The concept of a **learning challenge** is an intermediary concept between contradiction and expansive actions to help to further formulate concrete actions for developing a system. Learning challenges originally refer to the further concretisation of contradictions, or what must be done to solve problems (Seppänen, 2004). The concept of a learning challenge is a conceptual tool for moving from an abstract analysis of systemic contradictions either at the levels of a network of activity systems or an activity system towards more concrete actions. Such contradictions can be solved in many different ways. As Seppänen (2004) points out, contradictions as such do not reveal, the "good ways" of solving them. Learning challenges go a step further by showing the developmental direction that may solve them. Therefore, the concept of a learning challenge includes an understanding about what is a preferable and good direction in which to move forward. Learning challenges have to be locally defined and provide information about the developmental direction for solving contradictions.

In her study, Seppänen (2004) analysed the learning challenges in organic farming at the level of actions of specific farmers. In this study, there is no particular key actor who can learn separately or learn certain actions that would resolve the contradictions and allow the system to develop. The resolution of the contradictions involved in the network of activitiy systems require that several actors learn together about each other's activities and transform their own activities. In other words, one person alone would not be able to solve the contradictions; rather, the solution has to be constructed in collaboration. Collaborative learning here has a special meaning. It does not mean that all the actors involved in the network have to dialogue and collaborate simultaneously, but refers to groups or combinations of individuals who are experimenting together in searching for new solutions in well-defined experimentation through constant communication. Thus, the innovativeness of this study is not in the proposition that collaboration is needed in order to change the production towards environmental sustainability. The idea that collaboration is needed for developing work is already well known. The innovativeness of this study is in how and what concrete actions should be taken to change the production towards environmental sustainability.

Thus, I adapt the concept of learning challenges to the challenge of collaborative learning. In the study, the concept of a learning challenge operates on the three levels: the network of activity systems, activity system and actions. Expansion implies a dynamic of moving forward and backwards on these three levels. In order to change the actions, we have to change the activities, which may require a new network of activities. In order to concretise these network-level solutions, changes at the activity and action levels are needed.

5 THE RESEARCH PROCESS AND METHOD

5.1 The research problem

In this study, I am particularly interested in the challenges of learning with regard to sustainable swine production. The system of biogas production (BPfS) in the 3S Programme is used as a case example for exploring the challenges, possibilities and obstacles of learning in the use of BP as a way to increase the environmental sustainability of production. The aim is to contribute to the discussion about the possibilities of the development of systems of BPfS.

In the study I will develop a hypothesis concerning the central challenges and possibilities of the development of systems of BPfS in three phases. First, I will construct a) an idealised model of the historically evolved concepts of BP for sustainability through an analysis of the development of forms of BP for sustainability, and b) a hypothesis of the current central contradictions within and between the activity systems involved in BP for sustainability in the case study. I will then test and enrich this hypothesis through two actual empirical analyses: an analysis of the general meanings that the actors attach to BP and the actors' senses in taking part in the system, and an analysis of the disturbance processes in the implementation and operation of the biogas production system in the case study.

In the following, I will present the research questions (RQs), the methodology, the data and the methods of analysis. The RQs aim to open a window to concrete ways of facilitating learning and the development of networks, such as the network of BP in the 3S Programme, by clarifying the roots of the challenges and proposing concrete ways of solving them. A summary of the research questions, the methodology and the analytical and theoretical concepts are presented in Table 5.1.

RQ1 – What are the main dimensions in the historical development of concepts of BP for sustainability?

This question aims at identifying the possible directions of development of the BP for sustainability based on the findings from the historical and actual empirical analysis. To answer this question, I will use a historical typology of BP concepts that is based on the historical analysis of BP concepts as an intermediate conceptual tool. This typology will be used to analyse the possibilities of overcoming the current inner contradictions in the 3S Programme.

RQ2 – How has the object/purpose of BP for sustainability emerged and developed in the 3S Programme?

The first task is to grasp the how and why of the emergence of the BPfS. For this, an **historical analysis** of BPfS is needed that covers the emergence of the idea of producing biogas until its implementation and its actual current state. The historical events that were related to the emergence of this specific network should be reviewed in detail. The aim of this question is to understand the environmental problem that BP was intended to solve, what alternatives existed and what challenges emerged during the implementation of the project. I mainly use the concepts of object, activity system and contradiction to grasp the dynamic of change that has lead to the problem that BP was initially intended to solve. The method of data analysis is based on the theoretical interpretation of a sequence of events. The research data used to answer this question is derived from documents and interviews with key informants (engineers, coordinators and farmers).

RQ3 – What are the senses of taking part in BP of the swine producers and representatives of the Sadia food processing company?

The aim of this question is to grasp the concrete motivations and expectations of the actors involved. I want to understand how biogas enters into these two activities and explore the content of the object (material and ideal) of collaboration in the network. This requires exploring not only people's discourses about the meaning of BP, but also grasping their personal relationship to it: how they, for instance, use or expect to use the products of BPfS in their own activities. I will identify the factors that are directing their BP-related actions (or inaction). The data used to answer this question are composed of observations, interviews with the actors and documents.

RQ4 – How were the observed disturbances, ruptures and innovations related to the structure of the network of the activity systems involved in the BP for sustainability in the 3S Programme?

This question aims to explain how the disturbances observed during my field visits can be explained. As discussed in Chapter 1, there were many possible explanations for the disturbances according to who explained them. In order to deal with this challenge, I analysed the process of disturbances at the level of the network of activity systems. This process is depicted through the concepts of disturbance, rupture, innovation and asynchrony. To answer this question, I use observational data from video- and audio-recorded data, field work notes and photos as well as discursive data in which people try to explain the observed disturbances, e.g., interviews and conversations between the actors.

RQ5 – What are the main learning challenges for developing a sustainable system of BP in the 3S Programme?

The interpretation of contradictions within and between activity systems in the BP network, and within and between specific elements of the activity systems forms one component of the learning challenges. The other component of the learning challenges is constructed from an analysis of the zone of proximal development of the network of BP and the specific possibilities for further development. The answer to this question is gained through a theoretical elaboration of the empirical findings that answer RQ1 and RQ2.

Table 5.1 Summary of the Research

RQ*	**Data**	**Theoretical unit of analysis**	**Unit of data**	**Analytical concepts**	**Key theoretical concepts**	**Chapter**
RQ1	Empirical studies on BP	On-farm BP systems		The concepts of BP	Developmental dimensions	Ch. 6: The analysis of BP concepts
RQ2	Historical data and interviews	The network of activity systems involved in BP in the 3S Program	Historical events, periods and phases	Historical events	Activity system, object of activity, inner contradiction and the concepts of BP	Ch. 6: The historical analysis
RQ3	Interviews, documents and observations	Two activity systems (farming and Sadia food production)	Episodes	Current and expected use	Sense and object	Ch. 7: The analysis of meaning and sense
RQ4	Video- and audio-recorded visits, interviews and conversations	The network of activity systems involved in BP in the 3S Programme	Episodes	Disturbances, ruptures, innovations and asynchronies	Activity system and contradictions	Ch. 7: The analysis of disturbances
RQ5	Findings from the empirical chapters	The network of activity systems involved in BPfS			The zone of proximal development (ZPD) and learning challenges	Ch. 8: The ZPD of BP

* Research Questions:

(1) What are the main dimensions in the historical development of concepts of BP for sustainability?
(2) How has the object/purpose of BP for sustainability emerged and developed in the 3S Programme?
(3) What are the senses of taking part in BP of the swine producers and representatives of the Sadia food processing company?
(4) How were the observed disturbances, ruptures and innovations related to the structure of the network of activity systems involved in the BP for sustainability in the 3S Programme?
(5) What were the main learning challenges for developing a sustainable system of BP in the 3S Programme?

5.2 Developmental work research methodology

When studying complex and evolving systems, one has to deal with two planes, those related to the **functioning** and to the **development** of the system (Blauberg et al., 1977, p. 232). An analysis of the functioning of the system implies first that the system can be broken down into the parts that form its structure, and that each part has substantial properties. However, a structure is more than just static parts but is formed by the dynamic functional relationships between the parts. To understand a system, it is thus necessary to understand the dynamics of the functional interactions between the elements that compose it. This emphasis on the dynamics of the system requires taking the concept of historical time[9] into account. To understand the dynamics and the functioning of a structure, the concept of development is used. The term "development" in this study is not just understood as a sequence of stages of a certain system but rather as a change in the structure of the system (Blauberg et al., 1977). The analysis of development requires analysing the structural variation in the system.

Blauberg et al. (1977, p. 233) suggest three types of tasks for analysing an evolving system: (1) analysis of its history irrespective of its structure, (2) analysis of the structure of the object regardless of its history, and (3) structural and genetic analysis of the object, which means explaining the structure of the object through its history and its history through its structure. The tasks are schematised in Figure 5.1.

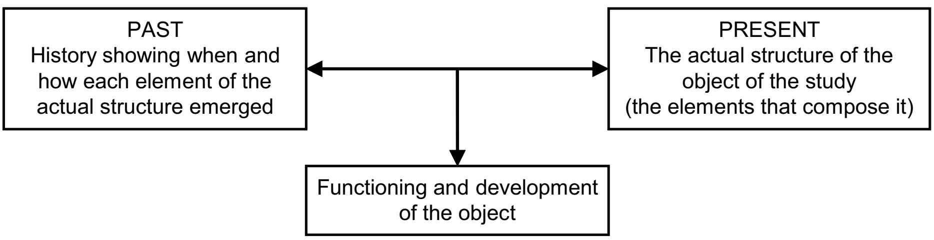

Figure 5.1 Development and functioning as a relationship between history and structure (Blauberg et al., 1977)

To understand complex systems, we need a methodology that combines both the analysis of the structure and its functioning. For this purpose, I adopt the methodology of developmental work research (DWR), which takes into consideration the

[9] Historical time is correlated with a "change in the structure of the object, in the forms of its interaction with the environment and its modes of vital activity" (Blauberg et al., 1977, p. 238).

analysis of these two aspects (Engeström, 1987, 1999, 2005). This methodology is especially useful in the study because it offers methodological tools that help the researcher to identify a network in a way that the findings and conclusions obtained are comparable with other studies, and generalisations can be made. The concept of object is not only a theoretical tool but also a crucial methodological tool. An activity theoretical study of BP implies taking seriously both the local actions of actors as well as the collective activity under study. Moreover, it implies seeing the activity as culturally mediated by artefacts that are socially constructed and historically changing.

In Figure 5.2, the methodological cycle of DWR is shown. First, there is a phenomenology and delineation of the activity system aimed at a) gaining a preliminary insight into the nature of its discourse and problems as experienced by those involved in the activity, and b) delineating the activity system under investigation. In practice, this insight is necessary to define the research questions of the study. It usually requires a preliminary data collection or previous contact with the phenomenon by the researher.

Second, there is an analysis of the activity that is divided into three sub-steps: a) the object-historical analysis, b) the theory-historical analysis and c) the actual empirical analysis. The theory-historical analysis aims at identifying the models and concepts that an activity system uses or has been using in any of its developmental phases. The basic idea of the theory-historical analysis is to establish the developmental dimensions and examine realistic new forms of production. The outcome of this analysis is a hypothetical zone of proximal development (ZPD) at the level of general concepts. Moreover, the theoretical history gives us concepts for analysing the actual concrete BPfS system. The hypothetical model obtained from the theory-historical analysis will be further developed based on the findings obtained from the object-historical analysis.

The object-historical analysis is the analysis of a real object, which is rarely a pure model, but usually combines elements of different concepts. Such a combination may lead to incompatibility, misfits and tensions in everyday activities. The object-historical analysis aims to uncover the **contradictions** that give rise to the transitions from one developmental phase to another. The main difference between the theoretical-history and the object history is that the theoretical history refers to general cultural models which typically do not have contradictions.

The third step is the formation of the new instruments. The participants of the activity system under investigation are pushed into formulating qualitatively new models to solve the double bind. After the implementation of the new instruments, it is very likely that tertiary contradictions may appear. This means that the participants of the activity system face intense conflicts between the old and the new ways of doing and thinking.

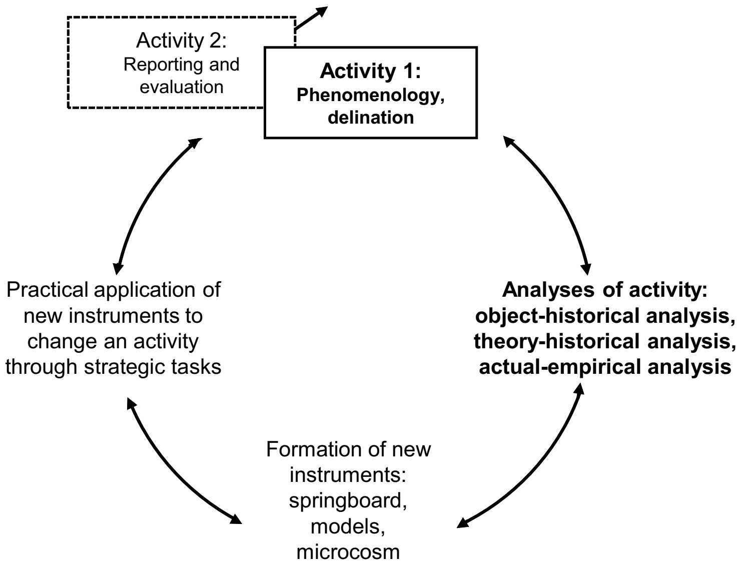

Figure 5.2 **The methodological cycle of developmental work research (adapted from Engeström, 1987)**

The fourth step is to register and support the tertiary contradictions between the new instrument and the old activity. For example, a tertiary contradiction appears between the BP and the old way of treating the slurry. The researcher's task is not only to register and support the events that transpire as a result, but also to trace and analyse the solutions to the conflicts produced by the participants in their daily actions. This task may also demand ethnographic data collection methods. Finally the outcome of the expansive research is reported and assessed.

In this study, I focus on the first two steps. The phenomenology is explored in Chapter 2, where I make a brief ethnographic study of BP in which I delineate the object of my study. Step two is analysed in Chapters 6, and 7. The actual-empirical analysis is conducted in Chapter 7. In the first part of Chapter 7, I explore the different senses of biogas for two of the actors involved: the farmers and the food processing company. In the second part of Chapter 7, I analyse the disturbances and investigate how the hypothetical contradictions are manifested and resolved in situated practices. Based on the findings from the historical analysis of the object and from the actual-object analysis, the ZPD of BPfS in the 3S Programme is constructed.

Although I have not conducted an intervention in its traditional sense, I have presented my findings to Sadia staff (engineers, a coordinator and the Sadia financial director). The findings obtained in this research will be important for a future intervention in the food processing company as well as serve as reference material for interventions in other cases. At the end of the study, I explore for possibilities for the development of BP.

I see the change and development of an activity system and a network of activity systems as a process in which actions and events change the structure of the activity. A process is understood as a coherent sequence of events that describe how things change over time. In the process approach, change and development are explained as the result of the order in which the events unfold and of particular conjunctions of events and contextual conditions (Poole et al. 2000).

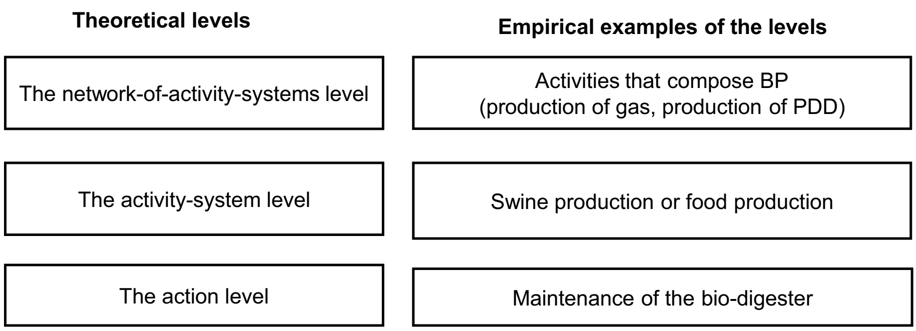

Figure 5.3 Levels of the units of analysis used in the study

Systems such as BP for sustainability have artefacts that are shared by a large number of heterogeneous activities. To investigate and promote the development of such environmental solutions as collective objects, it is necessary to have a unit of analysis that takes into consideration the network of activities involved in its production. In this study, I adopt three basic levels of analysis*:* the **network of activity systems,** the **activity system** and **actions** (Figure 5.3). By the network of activities, I mean the group of activities involved in the production of a certain object. This includes those activities that create the problem, provide the tools and funds, and utilise its results.

5.3 Sets of data

In the study, I use a range of data and data collection methods to gain an understanding of the object and to increase the validity and reliability of the qualitative research. The methods of data collection were analysing documents, shadowing stakeholders, conducting semi-structured and informal interviews, audio- and video-recording field visits, making field notes and taking photographs. The data collection was divided into three main sets: a) set 1 from December 2006, b) set 2 from May 2007 and c) set 3 from May 2008. The three sets were rather homogeneous, being composed of interviews, informal conversations, photographs, field work notes and audio- and video-recorded conversations between engineers and farmers. The first set of preliminary data (December 2006) aimed at identifying the cases of the study, establishing contacts with key actor, and providing a brief overview of the activities involved in BP. The second set of data (May 2007) aimed at obtaining deeper and more complete information about the history of the programme, its challenges and the different meanings and senses of the programme for Sadia, the SI and the farmers. The third set of data (May 2008) aimed mainly at observing the actual disturbance processes.

5.3.1 Documents, field notes and photographs

I have documents collected during my visit to the Sadia offices in Sao Paulo and Concordia and obtained from the Internet, which were either from official websites of the institutions or from other sources. They include project documentation, letters, guidelines, checklists, reports, presentations, online news articles and newspapers, scientific articles from research institutes, and articles in magazines specialised in swine production.

The collected documents were separated into three groups: reporting, operational and explanatory documents. The **reporting documents** are those that describe what have happened or were hampeing, such as news or field reports from technicians (see Appendix 5.1 for an example of a reporting document). The **operational documents** refer to those used as tools for explaining how tasks should be conducted, such as guidelines, norms or design documents, and the **empirical documents** are scientific studies. In practice this differentiation is not very clear because documents can have multiple characteristics, for example, they can report and also include a study. Moreover, it is possible to argue that all documents are operational because they have a meaning and function to someone. Nevertheless, it is still worth differentiating between them, as they may be used differently and provide different kinds of data and knowledge.

Another set of data was composed of the field notes and photographs taken during the visits to the farms in 2006, 2007 and 2008 (Appendix 5.2). During these visits I wrote down things that caught my attention, or information that I could not audio- or video-record.

5.3.2 Audio- and video-recorded interviews and informal conversations

Some of the interactions between the actors and me were also recorded and used as sources of data. These are mainly in two forms: semi-structured interviews and informal conversations. Both of these took place indoors and during field visits. The **semi-structured** interviews were conducted with key participants, such as farmers, managers, consultants and engineers from Sadia and the SI. Most of the interviews were scheduled and followed some sort of framework or key points to be asked, such as questions on history, challenges and meanings. Thus, they were more or less directed by the researcher. I asked open, informal and unstructured questions: What are the main challenges in BP? What are you doing or what could be done to solve them? In contrast, the **informal conversations** were less structured, and the interviewee was able to define the topic of the conversation. Some informal conversations were audio-recorded, while others were written down in the form of field notes during or after the field visit. Those that were audio-recorded were fully transcribed. On average, interviews lasted one to two hours and informal conversations between 15 to 30 minutes. The interviews with technicians were much more informal and took place in the car, in the field or in the office.

5.3.3 Interviews and conversations from the sets of data

I started the data collection in December 2006 (Appendix 5.3), when I conducted two semi-structured interviews with three engineers. The aim of these interviews was to collect data about the history and challenges of BP. In addition, I had informal conversations with three farmers while we (the engineers and I) visited their farms. As for my selection critirea, I chose to visit farmers with different levels of motivation and levels of implementation of the bio-digester. Mr Fabio was considered highly motivated and innovative and already had an installed bio-digester. Mr Frei was a small farmer, a "standard" farmer (not highly motivated), and Mr Laerte did not have a bio-digester, even though he was highly interested in having one. His farm was considered too small to have a bio-digester.

In the data set of May 2007, I conducted 22 interviews and informal conversations with actors such as farmers, engineers, experts, a coordinator, managers, a consultant and experts in carbon credits. In May 2008, I conducted six indoor face to face interviews, in which one interview was with one SI engineer and his colleague, three were with farmers, one was with the manager of Sadia's industrial swine production unit, and one was with his advisor. The data were audio- and/or video-recorded and fully transcribed.

5.3.4 Audio- and video-recorded field work interactions

By field work interactions, I mean conversations between farmers and engineers, and informal conversations with farmers which took place while I was following their work (Appendix 5.4). There are important differences between these interactions and the interviews. Here, I discuss six main differences between indoor interviews and field visits and their importance in analysing disturbances (Table 5.2). The first difference is related to who was present during the data collection. The interviews are characterised by the presence of the researcher plus an interviewee who was answering questions, while in the field work the interaction includes the presence of a third party. In the field work interactions, there were farmers, at least one engineer, the researcher and other actors (other researchers or an engineer from an outsourcing company).

Table 5.2 The main differences between interviews and interactions

	Indoor interviews	**Field work interactions**
People present	Interviewer and interviewee	Interviewer and other actors (e.g., farmers, engineers)
Topic selection	Questions raised by the interviewer	Topic chosen by the actors
Place	Indoors	*In situ*
When the disturbances took place	Past, present and future	Past, present and future
The presence of material artefacts	No	Yes
Content	Mainly speech	Speech and actions

The second difference is related to who selected the topic of the conversation. As previously mentioned, in the interviews, the topic was selected or mostly influenced by the researcher, while in the interactions the influence of the researcher on the topic was less. Information on which actor has initiated a certain topic is a useful data for analysis.

The third difference is about the place in which the data were collected. As already mentioned, while interviews usually took place in spaces such as offices and/or farmers' homes, the field visits usually took place *in situ*, where the BP devices were. This difference in the physical context leads to significant qualitative differences in the data, which will be discussed below.

The fourth difference is when the actions and events discussed have occurred. Usually, the interviews described actions and events that occurred in the past, present and future. However, in the interactions sometimes the actors talked about events that took place in the past and might happen in the future, and the richest data are about events that were taking place at the time of the visit.

The fifth difference is in relation to the presence of material artefacts during the data collection. In contrast to the interviews, during the interactions material artefacts were present, which can greatly affect the topic and the quality of the actors' discourses. Finally, the last, and perhaps the most important difference is what the actors were doing during the visit. While the interviews are mainly composed of speech, the interactions are composed of speech and the physical transformation of things. I am mainly interested in the discursive content of the actions.

During the data collection of May 2007, I followed the work of Sadia's advisors and the SI technicians and engineers. During these visits, I audio- and video-recorded their conversations. The names of the farmers present in the interactions are not shown for several reasons.

In 2008, I visited a total of eight farms, of which seven had a bio-digester installed. The data from the field visits are composed of interviews and interactions between the farmers and the people present during the visit. The participants discussed several topics, including the disturbances occuring in the BP system. The criteria of selection of the visited farms and the purpose of the visits varied. The first three farms were purposefully selected by the researcher and the SI engineer with the specific aim of collecting data for this study. I mentioned to the engineer that I wanted to visit at least three farms, one from a farmer considered a “good” farmer, one considered as “problematic” and one he considered to be “average”. The selection of the good farmer was easy, Mr Paulo. This farmer was one of the longest standing suppliers of Sadia, and the engineer Reginaldo had been cooperating with him since 2007 during the development of the technology for burning the biogas. I also knew Paulo already from the field work data collection that I have done in 2007, so I was the one who suggested Paulo. The selection of the “bad” farmer was not an easy task. The engineer was looking for a farmer who was problematic, but at the same time, would welcome my visit. As he had nobody in mind, he went to ask advice from his colleagues from Sadia, the swine production advisors. One of his colleagues recommended Mr Omar, a small swine producer, as a “bad” farmer. A “bad” farmer to Sadia’s swine production advisors was one who did not have good indexes (low efficiency in the feed conversion of the piglets, high mortality rates) and resisted to following the advisors’ recommendations. The selection of the third farm was rather random; we simply selected the closest farmer to Mr Omar, which happened to be Mr Marcio.

The purpose of the last four visits was different. They were part of the everyday work of SI engineer named Iara. We first visited Mr José’s farm. The aim of this specific visit was to check the reconstruction of a bio-digester, a routine that was called the “finalisation of construction”. The other three visits, the farms of Antonio, Manuel and Ugo, were part of a field visit together with the SI engineer and researchers from an agricultural research institute called Embrapa. The purpose of this visit was to find potential farms for implementing an experiment that was aimed at identifying alternative and complementary technologies to BP (the digestion of the manure) so that small farms could also have a of manure treatment system and to be able to test a more efficient and cheaper system.

5.4 Data used in each empirical analysis

5.4.1 Data used in the historical analysis

The historical analysis combines two kinds of data: **interviews** with key information and **documents**. When combined, the two sources of data complemented each other, enriching the validity and reliability of the study. The interviews provided the advantage of showing the “big picture” of the sequence of events and the outcomes, which helped to identify the most important events (Poole et al., 2000). However, this process is biased. People forget events that could be relevant. Moreover, people cannot remember with accuracy the dates of the events. To overcome this weakness, I used documents. Archival data have several advantages such as that they take much less time to be collected and detail events that people may have forgotten (Poole et al., 2000).

The period between the 1980s and the end of 1990s was mainly covered through empirical studies which presented the history of swine production and its related environmental consequences in the region (e.g., Miranda, 2005). The period between 1999 until 2003 was mainly based on documents. These were found through Internet search programmes combining Sadia and keywords such as swine manure management, environmental certificates, bio-digester and biogas. The main source of documents was the website of the company, which have an archive of internal news since 2003 and annual reports since 1998. Other Internet pages that provided useful data on news and document design were also used. The events from the periods of 2003 and 2007 are based on all the other sources mentioned above as well as interviews with two engineers, a manager and a consultant, the data from which were confirmed through documents. From this period a more rich availability of documents exist, such as power point presentations and descriptions of the programme, which help confirm the accuracy of the observations on events (Figure 5.4). The events after 2003 are considered to be critical whenever they are considered important by a stakeholder.

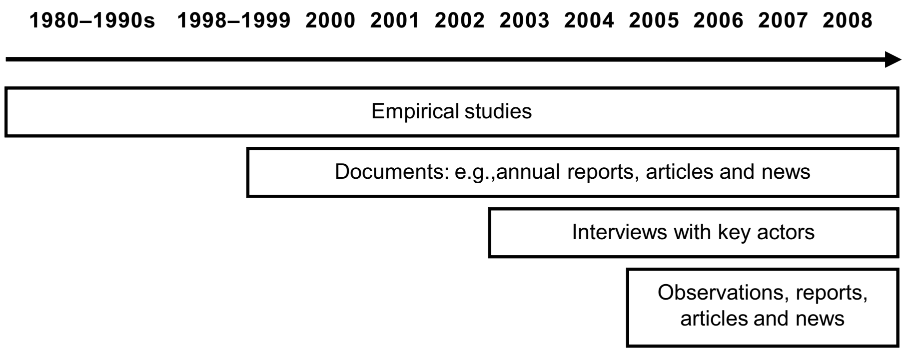

Figure 5.4 Data for historical analysis

In addition to audio-recorded interviews and documents, I also asked the informants to complete a time line with the events that they considered the most important. This helped me reconstruct the history.

5.4.2 Data used in the analysis of meaning and sense

The data used in the analysis of meaning and sense are composed mainly of informal interviews with managers from the SI and farmers. During the interviews, I asked the actors to give their opinion about the importance, advantages and usefulness of biogas on the farm. In doing so, I wanted to understand how BP figured in their everyday life. The interviews are not exhaustive; therefore, there are probably many issues that were not mentioned by the interviewees for several reasons. The main usefulness of the interviews was in constructing a general list of the aspects that were relevant to the cooperation in BP. I rely on the content of the interviews to represent the points of view of the stakeholders. The interviews with farmers were conducted while I followed the work of Sadia and the SI advisors. There are nine interviews, seven with farmers and two with managers of the SI.

5.4.3 Data used in the analysis of disturbances

The data used in the analysis of disturbances can be divided into three types: observed data, reported data (statements that people made before, during or after the field visits) and hypothetical data. The **observed data** were those in which I witnessed what was going on. This data includes field notes, photographs, operating documents such as the functional documents used by the actors in their everyday work (guidelines, design reports and plans) and video-recorded field visits, in which I observed the practices in the everyday work of the actors. One example of observed data would be if I saw a farmer touching the flare. The **reported data** were composed of those in which other people reported what had happened (historical events and actions). These consist of interviews, informal conversations, audio- and video-recorded interactions between actors, and reporting documents such as news and reports made by technicians. One example of reported data would be a report saying that a farmer had touched the flare, or if someone told me in an interview that a farmer had touched the flare. The **hypothetical data** were composed of explanations by the actors of what had happened. These are composed of interviews, informal conversations and documents (e.g., news and studies). Thus, they are interpretations and explanations given by people. One example of hypothetical data would be an explanation given by someone of why the farmer touched the flare. These different kinds of data are used in the three empirical chapters.

The idea of observed and reported data presented above comes close to what van Maanen (1979) calls operational and presentational data. He defines **operational data** as data that *"document the running stream of spontaneous conversations and activities engaged in and observed by the ethnographer while in the field"* (van Maanen, 1979, p. 542). **Presentational data** concern those appearances that informants strive to maintain (or enhance) in the eyes of field workers, outsiders and strangers. In short, operational data deal with "observed activity" (behaviour *per se*), while presentational data deal with what the informant says about these activities. Van Maanen (1979) gives an example of "street justice" from his ethnographic work with patrolmen. He classifies two kinds of data: what the patrolmen say about street justice (presentational data) and what he observes of it (operational data): *"I had to see the implementation of 'street justice' first hand and compare my direct observations with accounts provided to me by others."*

The concepts of presentational and operational data are useful in making sense of the interview data used in this study. The interviews can be characterised as presentational data, as they are mainly the interpretations of engineers and farmers about what was happening in the BPfS system. However, what I call field work interactions goes beyond van Maanen's (1979) distinction between operational and presentational data because in these visits both kinds of data were present at the same time. Field work interactions are operational data because they can be used as observations of the actual behaviour of farmers and engineers while they discussed their everyday problems and tried to fix their problems in the field. Moreover, they are presentational data because while actions were being taken, the actors discussed and explained to each other, for example, why a combustion system was failing. They talked about events from the past and from the future.

The combination of operational and presentational data in one set of data is not very common in ethnographic studies. Usually, the operational and the presentational data are collected separately in space and time. In other words, there are "pure" operational data and "pure" presentational data. As van Maanen (1979) himself recognises, such a separation has the disadvantage of making further generalisation difficult. In my mind, this difficulty is minimised when both operational and presentational data are collected together in time and space.

Moreover, such field work interaction situations have an even more important advantage. They generate a good quality of knowledge about disturbances in the work. This type of data supersedes "pure" presentational data because in field work interactions there is the physical presence of artefacts and actors and the physical space in which the disturbances are taking place. This enriches the quality of the presentational data. It reduces the purposeful appearance effect caused by the researcher's presence. Although the actors (e.g., farmers and engineers) were aware of the presence of the researcher and tried to direct the discourse to what they wanted the researcher to hear, this direction had to be divided among the actors present in the conversation. For example, in an interaction with a farmer and an engineer, they both had to present an appearance to each other, not only to the researcher. Moreover, the presence of another actor made it harder for the informants to lie or manipulate the information discussed, since the other actors present might also know about the topic. When another actor enters into the conversation, the researcher has the option of changing his or her role from topic giver to topic observer. In the interactions, the researcher has the option of not participating in the conversation, which reduces his or her influence on the topic chosen in the interaction. The choice of the topic made by the actors can be used later as additional data in the analysis. Third, the interpretations given during the interactions are more detailed because of the presence of material artefacts.

Similarly, field work interactions situation also supersede "pure" operational data. In addition to the researcher observation of what is occuring and what actors are doing, the presence of another actor enriches the actions by inserting a discourse about what has occured. For example, while fixing a failure in the combustion system, the engineer discussed possible causes of the failure with the farmers.

I suggest that interaction situations should be used to analyse disturbances at work when a) the point of view of the actors present in the interaction is relevant to understanding the phenomenon, b) the actors are co-responsible for the disturbances, and c) the activity under study is relatively new, and there is no clear interpretation of the causes of the disturbances.

5.5 Method of historical analysis

5.5.1 Analytical concepts

The concept of BP

I start with a historical analysis of the **concepts of BP**. By the concept of BP, I refer to the logic that connects the different elements of the BP system into a functioning whole. The logic can be either the idea or the plan of how to construct a feasible BP system, or an idealised presentation of the logic of operation of an empirically existing BP system. It can also be seen as a relatively stable phase in the development of the system. In this sense the cycle of expansive learning (Figure 4.5, Chapter 4) can be understood as a process of development from one BP concept to another.

Historical event

For analysing the historical development of a BP system, I use the concept of a **historical event**. Historical event analysis has been used in other studies to investigate the evolution of BP (Negro & Hekkert, 2008). Here, I adapt Poole et al.'s (2000, p. 40) concept of event to actions that transform the structure of an activity system. Sewell Jr. (1996, p. 842) defines historical events as *"occurrences that have momentous consequences in history"*. As he suggests, events are conceived as sequences of occurrences that result in transformations of structures (Sewell Jr., 1996, p. 843). The analysis of a sequence of events should not take every event into consideration, but only those that change the relationships between elements of the system.

The concept of a historical event proposed by Sewell Jr. (1996) is rather similar to the concept of critical events. Toiviainen (2003) defines critical events as those events that result in a change in the structure of an activity. This leads us to the question: what concept of structure should we use? According to Sewell Jr. (1996), a concept of structure must be able (1) to recognise the agency of social actors, (2) to build the possibility of change into the concept of structure, and (3) to overcome the divide between semiotic and material visions of structure. To form his concept of structure, Sewell (1996) uses Giddens's theory of structuration in which structures are regarded as a process rather than a steady state.

In this study, I use the cultural historical activity theory approach (Chapter 4) to understand structures. This approach is compatible with Sewell's idea that structure and process are dialectally connected: the structure forms the process and the process affects the structure. An activity is always a process of producing an object that directs and motivates the subjects' actions. As suggested in Chapter 4, the structure of an activity can be depicted with the help of the general model of an activity system (Figure 4.2, Chapter 4).

Periods and phases

In order to grasp qualitative changes in the course of development, the concept of a period is needed. A period is a "piece" of history in which something essentially new develops that can change the direction of development. A period is commonly understood as a time in which the principle and the direction of development is the same, and the period changes when the direction changes. In such a definition, it is necessary to deal with the concept of direction(s) of development.

Here it is important to make a differentiation between historical and developmental periods. All periods are historical, but not all historical periods are developmental. Something may change, but it may not necessarily be a development. Development, here, means overcoming an essential inner contradiction of a specific system under study. Development is related to a value or a preferable direction to be followed. For example, if the swine production changes towards lower productivity, environmental degradation and unemployment, this is not be considered as development, as these characteristics are not desirable. In this study, I am not interested in all types of periods, but specifically those in which there is a development of the object under study.

Periods always refer to time. A period is a stream of historical events that follow a certain meaningful characteristic of their own. In this study, periods are related to the object/purpose of an activity or network of activities. A developmental **period** is understood here as a developmental cycle, an interval of time during which the object of the activity changes. A new period starts when a previously stabilised object of activity starts to be destabilised and ends in the stabilisation of a new object of the activity. The creation of the new object of the activity is the middle point of a period. In this interpretation, a period can be a cycle of expansive development of an activity, but it can also be a narrowing cycle.

A developmental period is divided into phases according to changes in the nature of the dynamics of the change process. A phase is a process or a piece of the development with a certain characteristic. When the model of expansive development is used to define periods, phases are defined on the basis of the nature of the inner contradictions in the system that created the change dynamics in a certain phase.

In this study, I am interested only in those periods in which expansive development possibly takes place. In the case study of the 3S Programme and the swine production farms, it is not self-evident that expansive development is taking place. Thus, one of the expected findings of the analysis is to assess whether the changes within the period are expansive or not.

5.5.2 The steps in the historical analysis

The historical analysis is the second of three steps in the DWR methodology. This step includes two types of historical analysis: the object-historical analysis and the theory-historical analysis. The **object-historical analysis** aims to identify the previous developmental phases of the activity by following the object in the history of the activity, while the **theoretical-historical analysis** aims at analysing the different tools (theories, models, methods, artefacts) that have been used in the history of the activity.

Analysis of the development of the concepts of BP

The analysis of the concepts of BP starts by identifying the common characteristics of the models of BP according to the purpose of BP and the way that the gas is produced (1, Figure 5.5). This led me to some basic models (2). I interpreted each model of BP with the model of an activity system and identified the basic idea or principle of each one by comparing the models (3). This led me to a series of dimensions, some of which overlapped. I tested these dimensions with the actual described models of BP to see how useful the dimensions were for classifying the models. The result was a two-by-two tabulation with the main developmental dimension (4).

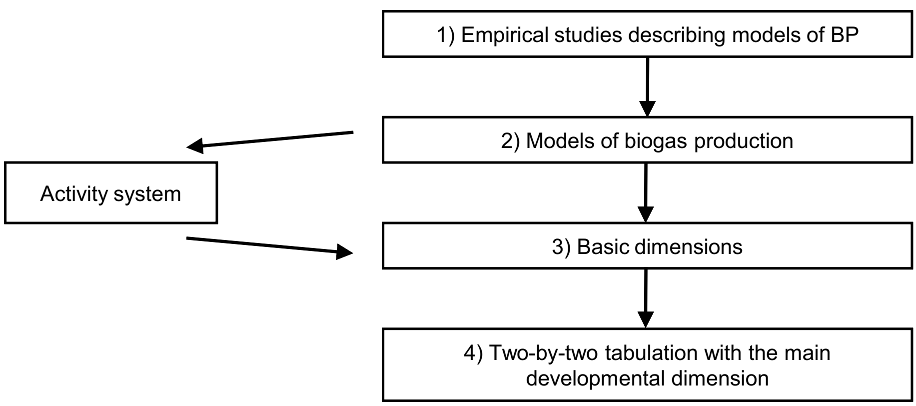

Figure 5.5 Steps of the method of analysis of the development of the concepts of BP

Object-historical analysis

The first step in the analysis was to collect all the events that I could find in the data, from documents, interviews and studies. Some of the events were repeated in the different types of data. In some cases, in interviews for example, the informant gave me a very broad range of time for the events such as a year or a half yeaar. By cross-checking the events with other sources of data (documents, for instance), I could refine the dates and define them more precisely as months or days. The events were organised in chronological order and entered in a database.

Based on the events of the list, I constructed my own narrative of the history, aimed at obtaining a more logical history of events. I constructed two narratives, one for the swine production and BP in the 3S Programme in general, and the other for swine production and BP in the farm of Mr Paulo. In the analysis, I focused on the narrative of BP and use the narrative of swine production to concretise it.

Once I had the narrative ready, I divided the sequence of events into hypothetical periods, according to the meaning of the object of the activity that was being described, for example, swine production, environmental pollution or the swine manure management system. The identification of periods was done so that the two narratives were interpreted with the analytical concepts, such as historical events. The identification of the historical events was facilitated by the diagrams drawn by the informants. Moreover, in order to identify the historical events, I went back to the interview data to check which events were stressed by the informants as relevant and how many informants mentioned them. These events helped me construct the hypothetical periods. A new period started when an event changed the meaning of an object. The result of this step is a hypothesis of periods. I had two sequences of hypothetical periods, one for the 3S Programme in general and one for the swine production and swine manure management on the farm of Mr Paulo.

The hypotheses of periods are interpreted using the model of an activity system and the concept of contradiction. The results are pictures of the network of activity systems and their respective contradictions in specific sets of time. The hypothetical periods are interpreted with the cycle of expansive learning. The result of this step is the developmental cycle of BP in the 3S Programme.

To sum up, the object-historical analysis is composed of four basic steps: (1) the identification of events in the raw data, (2) the organisation of the list of events in chronological order, (3) a written meta-narrative of the events, which a kind of logical sequence of events, and (4) the reconstruction of the developmental phases (Figure 5.6).

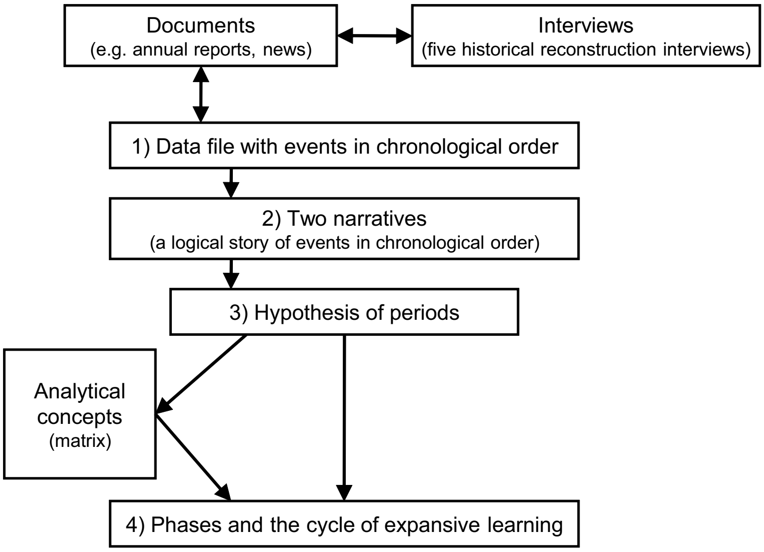

Figure 5.6 Steps of the method of object-historical analysis

5.6 The method of analysis of meaning and sense

5.6.1 Analytical concepts used in the analysis of meaning and sense

In this study, societal meaning is the societal significance of BP, which is defined through its objective role in society in meeting different societal needs. Sense is the specific, subjective meaning of BP for an actor, how the actor sees and interprets his or her relation to BP in view of his or her own activities, motives and interests as well as the specific objectives that he or she attaches to BP from the point of view of his or her activity. Societal meaning refers to the general societal importance of something, while the sense is related to how that thing is related to motives (Leontyev, 1978, 1981).

5.6.2 The steps in the analysis of meaning and sense

The method of analysis was created in the course of the study (Figure 5.7). The analysis started by listening to the interviews and later continued by reading the respective transcripts. To narrow the data, I first divided the data into episodes according to the topics. I selected only the pieces of discourse in which the actors talked about the importance, advantages or use of biogas. I used key words to identify the pieces of data that were of interest. I was particularly interested in the content of the answers of the actors to my questions of the importance/advantage/good side of BP. In the analysis, I noticed that people refered to importance either to their own activity or to other's activity, which were separated respectively in two groups: a) people's perception of its societal meaning and b) uses within the activity. When the subject related the usefulness with himself (his farm or company), I considered the usefulness as a sense. The presence of first and third person pronouns (e.g., I, us, our, my) helped differentiate the usefulness of the activity the subject under analysis. I separated uses of BP in two groups: a) actual and b) expected use.

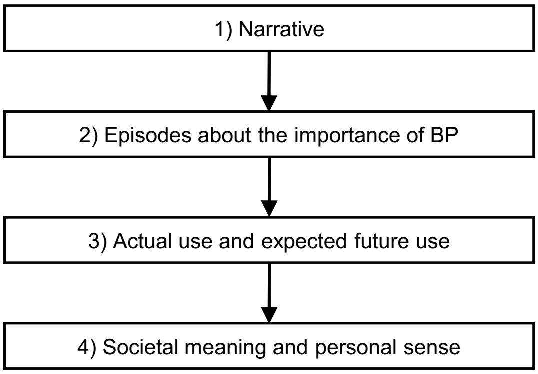

Figure 5.7 Steps of the method of analysis of societal meaning and personal sense

5.7 Method of analysis of disturbances

5.7.1 Analytical concepts used in the analysis of disturbances

Disturbances imply the existence of a "normal" situation, which is defined by plans, explicit rules or tacit assumed traditions, while ruptures are understood as blocks, or breaks in the inter-subjective understanding and flow of information between two or more participants of the activity (Engeström, 1992, p. 19). These concepts have been mainly used in identifying disturbances in the discursive interaction in a work process. In this study, I adapt these concepts to make them a tool for analysing problems in the production process. I maintain the general idea of disturbance as an interruption of the flow of work, or a break in the logical process of producing an output.

Scripts, disturbances and ruptures are mutually describing concepts. As already mentioned, disturbances depend on a script that describes how things should be operating and operated. A script is a special kind of schema. In psychology schema is a term used to refer to knowledge structures in which the parts relate to one another, or how things are believed to work. Schemas are not complete and ready but leave less essential elements to be filled in as needed according to the circumstances (Cole, 1996, p. 125). Scripts, as well as schemas, serve as guides for actions. People enter into interaction with ready scripts about how things should work, but in the flow of events these scripts are negotiated and refined. Shared scripts are necessary to facilitate coordination (Cole, 1996).

I mainly use five analytical concepts: disturbances, ruptures, innovations, asynchronies and the disturbance process. In this study, by **disturbance**, I mean a visible, undesirable and unexpected event that is taking place in the process of producing biogas. A disturbance has undesirable consequences, which are directly related to a specific space and time. Thus, they can be observed by the actors. A disturbance is an event that was not expected by anybody, or a blockage of actions. In a technological system, it can be seen as the observable malfunctioning of a machine that endangers the attainment of the expected outcome. An example of a disturbance is the malfunctioning of the combustion system. This disturbance was observable: the gas was not burning, which was undesirable (because the gas was expected to burn). Below, I present an Excerpt (5.1) in which the farmer Ugo, visiting researchers from Embrapa and a field work engineer from the Sadia Institute (SI) discuss a problem with the flare. The ignition was dislocated, and the spark was given outside the correct place. In this example, the disturbance is the failure of the flare, caused by the dislocation of the ignitor.

Excerpt 5.1

> ***Visitor 2:*** *The flare is not triggering?*
> ***Farmer:*** *No, has a problem. Then, I turned it off. It is ... The ignition is not ...*
> ***Visitor 1:*** *How long has it been installed there, the flare?*
> ***Farmer:*** *The flare it is, I think it is already six months that it has been here...*
> ***Field work engineer 1:*** *It has been longer, it has been longer.*
> ***Farmer:*** *But?*
> ***Field work engineer 1****: During the night there was no problem, was there?*
> ***Farmer:*** *No. It just started. It is giving an ignition almost like this [showing with the hands] before the place. The spark is coming outside.*
> ***Field work engineer 1****: Ah, it is a problem of the ...*
> ***Farmer:*** *Then, I turned it off, because it ...*
> ***Field work engineer*** *1: It is this kind of ignition.*
> ***Farmer:*** *Yes*
> *(Field visit to Ugo farm, May 2008)*

As I started to analyse the data, I felt it was necessary to expand the concept of disturbances to capture also events which were not yet causing an interruption in the production process, but which had the potential to do so if they persisted. Thus, when I speak of disturbances, I am also referring to **potential disturbances**, which are undesirable events that have the potential to cause disturbances in the future if they are not solved in time. An example of a potential disturbance was rust. The presence of rust did not interrupt the process of the production and burning of the gas, but depending on where it was located, to it could lead to bigger problems. The rusting of the metal junctions that anchored the balloon to the beams, for instance, could lead to leakage, which would mean that some gas would not be burned.

The disturbances analysed are for the most part those that I was able to observe during the field work visit in May 2008. However, to have a more complete picture of the process of the formation of the observed disturbances, I also use data from interviews taken in other periods of time (December 2006 and May 2007). The disturbances that were reported by the actors are called **reported disturbances**.

Ruptures and the script of operations

A **rupture** is a discoordination of actions, or a lack of an expected action that has caused or has the potential to cause future disturbances. A lack of action is something that can be observed and therefore is rather objective. A rupture is a break in a chain of actions which may be caused by a break in the flow of communication, a miscommunication or misunderstandings. Below, in Excerpt 5.2 I present an example of a rupture that I was able to observe during a field visit. The rupture is that the farmer had not removed a branch beside the bio-digester, a task that he was expected to do. This rupture did not cause a disturbance during the visit, but could cause a potential disturbance in the future, such as a tear in the canvas, which would lead to gas leakage.

Excerpt 5.2

> ***Reginaldo[10]:*** *Mr Paulo, the most careful guy, let the branch grow in this way. What a shame!*
> ***Paulo:*** *But it is just to remove it.*
> ***Reginaldo:*** *What a shame. Look this branch! It is horrible.*
> ***Paulo:*** *Ah, this?*
> ***Reginaldo:*** *Look at this branch.*
> ***Paulo:*** *But I have already broken off this several times, it is hard to remove. [Mr Paulo tries to remove it with his hands]*
> ***Reginaldo:*** *Oh my God! Get a knife and remove it.*
> ***Paulo:*** *No, I want to see if I can remove it. You can't do it. I 've broken it off twice.*
> ***Reginaldo****: It is amazing.*
> ***Paulo:*** *Let's break it off again. I will really break it down.*
> *(Field visit to Mr Paulo's farm, May 2008)*

[10] The names of the actors have been changed for confidentiality.

In activity theory, disturbances and ruptures are understood as deviations from the script. In the 3S Programme, there was not only one script saying how operations should be run, but there were several scripts which were either materialised or remained as unconscious assumptions. These scripts were also expressed in the form of the expectations of different actors, plans and agreements. In this study, I use a variation of a script, which I call the **script of operations**. By the script of daily operations, I mean those operations that are needed to optimise the production of a certain object. In BP, some examples of these operations are mixing the slurry accumulated at the bottom of the bio-digester weekly or keeping the area around the bio-digester clear (free of branches).

The asynchrony of change

Asynchrony is another concept used to classify the causes of disturbances. In activity theoretical studies, asynchronies are understood as a gap between concepts (Launis & Pihlaja, 2007). In this study, asynchrony has a different meaning. An **asynchrony** is understood as a situation in which part of the elements of the activity has been changed but the other part has not, making the use of the elements impossible. An asynchrony may be experienced as a delay, or a lack of a planned action. An asynchrony is very much related to the temporal dimension in which actions are taken. In other words, it takes place when a planned action is not taken and some parts of the system fall behind, causing disturbances. In contrast to ruptures, asynchronies are a lack of action in relation to plans of implementation rather than routines or operations.

An asynchrony may take place either because of changes in the conditions of an activity or imperfect planning (a gap between the reality and the expected). In the first case, the subject plans the implementation of a chain of actions, but the conditions in which these actions would be taken change, and some of the actions are not taken. In the second case, there is imperfect planning, and the subject was not able to predict certain conditions or the need for certain actions.

It is possible to say there are always asynchronies when something new is implemented. They are typical of the phase of application, but they can be avoided or minimised by having a good implementation plan. An example from this study may be a delay in installing a flare, which causes the emergence of misfits and disturbances. According to the implementation plan, the combustion system was planned to be installed simultaneously with the bio-digester.

A plan of implementation is a predetermined and sequential set of actions which are considered to be necessary to achieve a certain objective. The concepts of a script of operations and a plan of implementation are interlinked. Asynchronies related to the plan of implementation can disturb the script of operations. Moreover, both the plan of implementation of actions and the script of operation and expectations are related to how the actors see the object and the outcome of the activity. Disturbances, ruptures and asynchronies may arise from competing scripts and plans.

Innovations

Another concept closely linked to the concepts of disturbance and ruptures is the concept of innovation. Engeström (1992, p. 19) defines innovations as "*situations and action sequences where actors attempt to go beyond the standard procedure in order to achieve something more than the routine outcome*". In this study, an **innovation** is understood as an intentional, unexpected action aimed to produce something that goes beyond what is established in the script. An innovation can be seen as a new technical device, such as a new security valve, or a new way of doing things to solve a problem or to improve a process which deviates from the script (e.g., a farmer installs equipment to heat a chicken warehouse). An innovation is temporally connected with disturbances and ruptures. Innovations may be created to solve disturbances and ruptures. On the other hand, innovations may cause disturbances and ruptures, since people may not know how to deal with them.

The disturbance process

The three concepts presented above are temporally related, forming a chain. Disturbances, ruptures and innovations cause each other. Someone may implement an innovation, and others may not understand it (a rupture), which can lead to a disturbance; then people manage these disturbances by creating innovations and so on. In the analysis, I try to depict this chain of actions. The chain of disturbances, ruptures and innovations which lead to the emergence of a certain disturbance, is called here the **disturbance process**.

5.7.2 The steps in the analysis of disturbances

In the analysis I use data about disturbances, ruptures and innovations. The different kinds of data from the different sets of data provided different types of knowledge. The observed data provided the **observed disturbances, ruptures and innovations**. I used the audio- and video-recorded field visits from May 2008 as the primary source of data for identifying the actual disturbances, ruptures and innovations. The reported data (interviews, informal conversation, reporting documents) provided knowledge about the chain of past disturbances, ruptures and innovations that were related to the actual observed ones. The hypothetical data, which were the explanations given by people about why things were happening, provided me hypotheses of what could have happened (Appendix 5.5).

Here a differentiation should be made regarding the disturbances, ruptures and innovations, and the data concerning them. The data can either be in the form of observed undesirable events or explanations, in which people told me what had happened and why. While the data regarding explanations could be considered subjective and contested, the actual ruptures are not. The actual disturbances, ruptures and innovations refer to objective events in the field. In the explanations, it is not always clear which disturbances people were speaking about, which means that it is possible to have different explanations for the same rupture. To deal with this problem, I tried to find as much evidence as possible about whether the ruptures mentioned in the explanations had taken place or not.

First, I identified the disturbances, ruptures and innovations that took place during the field visit in May 2008. At this stage, I was interested in those disturbances that were taking place during the field visits. I started by reading through the transcribed field visit. To identify the disturbances, I had some knowledge in advance on how the technological system was supposed to be working. This knowledge was obtained through operational documents (guidelines or the project design), as well as through interviews with engineers and farmers. These documents stated what the actors were supposed to do and how the technological equipment was supposed to be operating. Moreover, I only considered as disturbances the events observed and mentioned by the people present during the field visit (e.g., farmers, the SI's engineers). When reading the transcripts, I searched for disturbances, ruptures and innovations. Once identified, the disturbances were classified according to which part of the equipment they were related to, while the ruptures were related to what kind of disturbance they have the possibility to generate.

After the disturbances had been identified, I collected explanations and evidence about them. These explanations were given either during the field visits or in other circumstances, such as during a visit to another farm or during a conversation in the office. The explanations were either specifically about the disturbances and ruptures observed during the field work or about the kind of disturbance in general. Such reported disturbances, ruptures and innovations are introduced in their disturbance processes.

Once a list of disturbances and ruptures that took place during the field visit was drawn up, I selected some disturbances for further describing their process of formation. I selected those for which I had sufficient explanations and evidence. Then, I wrote a logical chain of actions (or lack of them) that lead to the disturbances. This chain of actions of a disturbance is what I call here a disturbance process. The disturbance process was modelled using the network of activity systems. The disturbances, ruptures and innovations were located in the model for each disturbance process. Symbols were used to represent disturbances, ruptures and innovations, and these will be presented in Chapter 8. The process of disturbances was then contrasted with the historical contradiction obtained from Chapter 6. Figure 5.8 summarises the method for the analysis of disturbances.

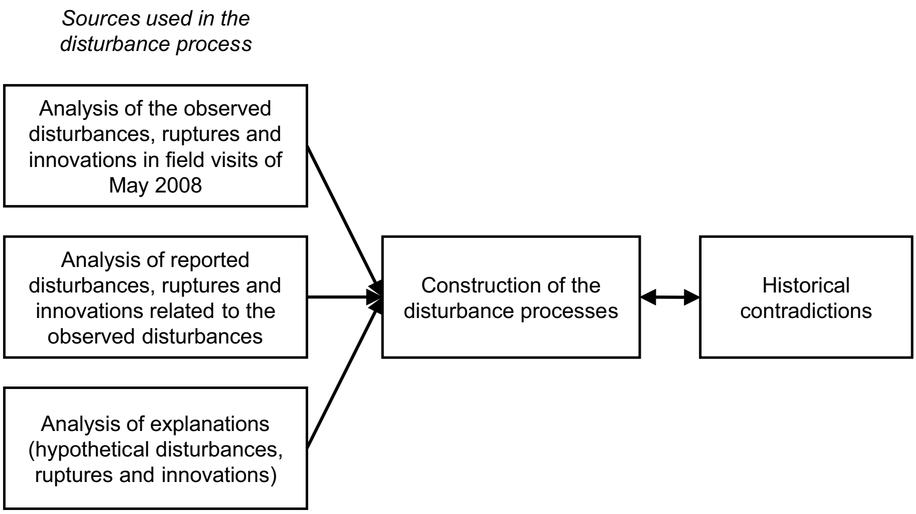

Figure 5.8 The scheme of analysis

6 HISTORICAL ANALYSIS OF THE EMERGENCE AND DEVELOPMENT OF BPFS IN THE SADIA CHAIN OF FOOD PRODUCTION

6.1 Nature and purpose of the historical analysis

This chapter has two purposes: a) to develop a model of types of BP for sustainability (BP) concepts, which evolved historically around the world, and b) to develop hypotheses concerning the inner contradictions in Sadia's food production chain, which led to the emergence and development of BP, the current[11] developmental phase and the current contradictions within and between the activities involved. These purposes imply studying local change and development: a) how has the object of the activity emerged ? b) what kind of contradictions preceded and followed the emergence of the object? c) how have other elements of the activity system changed. I shall start by presenting an analysis of different concepts of BP, followed by an analysis of BP in the specific case of the Sadia chain of food production.

6.2 Analysis of the development of swine manure-related BP concepts

Biogas has been known about for a long time. According to Chinese literature, the first registration of intentional biogas production may already have occurred between 2,000 and 3,000 BC (He, 2010; U.S Environmental Protection Agency, 2010). Several registrations of BP can be found in the early 16th century in Persia, and throughout the 19th century in Europe. However, it was only after the petrol crisis in 1973 that biogas spread commercially as a potential solution for treating swine manure, and as an alternative source of energy. In this period several projects promoting BP emerged around the world. My analysis starts from this "wave" of BP projects in the 1970s (a more complete history of BP (anaerobic digestion) can be found in Marchaim, 1992; Castañón, 2002; He, 2010; GTZ, 2011).

The intention of this theoretical-historical analysis is to identify the different historically evolved BP concepts, to define the central lines of development, and to create a hypothesis concerning the zone of proximal development of the 3S Programme. The analysis will identify and model the main BP concepts that have evolved in different countries over the last 40 years. Unlike previous studies, in which the production concepts have been classified on the basis of the technology used (such as whether the biogas is covered by a fixed-dome or a balloon), I have

[11] The last data collection was in May 2008.

classified the concepts on the basis of the object and purpose of BP, as well as on the structure of the activity system created to carry out the production. By concept I refer to the logic of operation of BP systems. I will describe the concepts as historical ideal types of BP.

6.2.1 The historical development of BP concepts related to swine manure

Small-scale, on-farm BP for local energy consumption

During the 1970s the price of petrol increased from $3.35 in January 1970 to $32.50 by the end of the decade (Hammes & Wills, 2005). The increase in energy prices led to the initiation of several programmes promoting alternative sources of energy such as BP. The first projects of BP from swine manure concerned small-scale, on-farm production in which the outputs were used on-farm. During this period, special emphasis was given to biogas as a source of energy, for example, for heating stables or producing electricity, and to the use of the remaining slurry as a bio-fertiliser in agricultural fields. This small-scale energy-oriented concept of BP was applied in both industrialised countries such as the Netherlands, Denmark (Raven, 2005) and Germany (Negro & Hekkert, 2008), and developing countries such as Brazil (Gaspar, 2003; Kunz et al., 2004).

Most of these projects were conducted by governmental agencies responsible for designing the technology, and sometimes for also constructing the bio-digesters. When the price of petrol fell, most of the projects were abandoned in Western countries. Several reasons, such as the inadequacy of the technology, too much emphasis on energy and lack of assistance have been pointed out to explain the failures of some of these projects (Raven, 2005). However, this concept of BP remained viable and expanded in many countries around the world, including China and India (UNAPCAEM, 2007). Now, more than eight million bio-digesters have been installed in rural China and 12 million in India (UNAPCAEM, 2007). Recently, this BP concept has been applied again in some Western countries as well. In Austria and Germany, for instance the number of decentralised on-farm BP plants has increased rapidly owing to new subsides for renewable bio-energy approved by the government (Walla & Schneeberger, 2005; Negro & Hekkert, 2008).

The basic characteristic of the concept may be summarised as follows: 1) the object and purpose is to produce energy for local use from the local swine manure within a farm; 2) both the produced gas and the processed manure are used on the farms; 3) farmers carry out the production and use of biogas as well as the maintenance of the BP system. I call this concept **BP from local manure for local energy needs.**

Centralised commercial waste processing through BP

The early 1980s saw a wave of constructing centralised manure processing plants in Western countries. The main idea behind this wave was to increase the scale of production to reduce unit costs (economies of scale). According to this concept, biogas shifts from mainly being energy source to becoming a technology for waste treatment (or to solve environmental problems related to swine manure). The manure is collected from many farms to be processed in large BP plants. In Denmark, most of the centralised BP plants are owned by an association of farmers and heat consumers. In normal situations, the owners neither profit nor withdraw profits from biogas companies, but rather they use them to save costs in manure handling and fertiliser purchases (Nielsen & Hjort-Gregersen, 2002). Specialised organizations with specialised competencies often operate these plants. Thus the responsibility of production and utilisation is transferred from farmers to a commercial organisation. The organisation takes the risks, decides which technologies to use, and how to use or sell the biogas, while farmers supply the raw material to the centralised plants. In this concept the object is broader than BP alone, and includes manure processing and production of fertiliser granules (Raven, 2005).

This concept of BP is today carried out in many European countries, including the Netherlands, Denmark (Raven, 2005) and Finland (Pereira-Querol et al., 2010) as well as in developing countries such as India (Rao et al., 2010). In Europe, these plants usually combine different types of waste and produce a variety of products that can be traded in the markets. In India, this concept has resulted in communitarian BP plants focused on the production of energy as well as on the living conditions of small and poor farmers (NPBD, 2002). I call this model **centralised commercial waste processing through BP**.

BP for carbon credits (BPCC) as a profitable business

At the beginning of this century, the creation of Clean Development Mechanism (CDM) from the Kyoto Protocol, and the approval of methodologies based on the reduction of GHG emissions from swine waste management systems, allowed the emergence of a new wave of BP projects (Salomon & Lora, 2005; Yapp, 2005). BP became a way of creating tradeable carbon credits (Certified Emission Reductions; see Banuri & Gupta, 2000). I call this concept **BP for carbon credits – BPCC** (now and onwards).

One of the early projects based on this concept of BP was conducted by Agricola Super Limitada (Agrosuper) in Chile (UNAPCAEM, 2007). The company developed the technology, and proposed a methodology to the Executive Board of the UNFCCC for applying for carbon credits. The methodology, called AM0006, opened up a new opportunity for using BP from swine manure to create tradeable carbon credits. In Brazil, the first contracts for production of BPCC were presented in 2003, when two units called Fazenda Agua Limpa and Granja Becker were constructed. AgCert International developed the AM0016 methodology, becoming the one of the main actors in producing carbon credits in the agricultural sector in 2007 (UNAPCAEM, 2007). The AgCert business model is based on the Build, Operation, Own and Transfer (BOOT) model. According to this, the project sponsor (in this case AgCert) finances, constructs and operates the swine manure treatment system. In return, the sponsor has the right to generate revenue from the facility for a specific period. After the concession period, the facility is transferred at no cost to the franchising farmers.

In 2007, BPCC projects were mostly large projects following the BOOT business model. In practice, a specialised organisation identifies large farms, writes project design documents, secures money in the market, installs the bio-digesters and the other technologies needed, and then applies for carbon credits. Farmers sign a contract agreeing to produce the gas, and give the rights to carbon credits to the specialised company. The main purpose of BP within this model is profit-making. The sponsor company, therefore, has to select the largest farms available in order to create economies of scale, which, in turn, means lower unit costs and higher profits. Moreover, the company usually combines 6 to 15 farms in one "carbon project" (PDD) to reduce the transition costs. BPCC projects, however, are not necessarily all large projects. Recently, new methodologies have been approved to allow small farms to be included. Nevertheless, a relatively large scale of production is needed to obtain economies of scale and to maximise revenues. This concept, referred to as **BPCC as a profitable business** concept, is based on the idea of mass production of carbon credits. It is characterised by a centralised administration and decentralised production, in which the focus is on making a profit by producing a few standardised commodities to be commercialised in the market (carbon credits and electricity). Figure 6.1 shows the time of emergence of each concept. The concepts are summarised in Table 6.1.

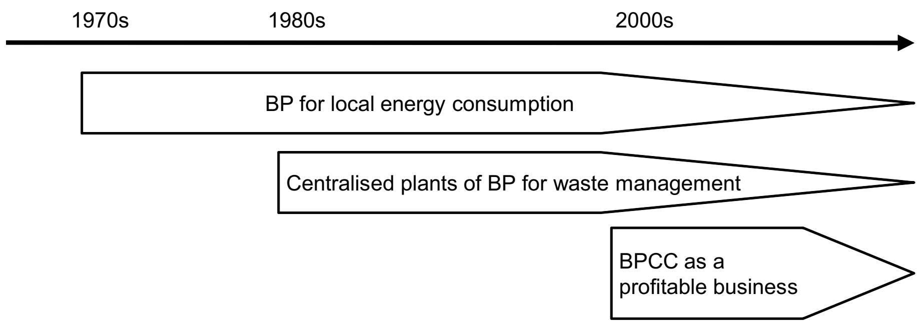

Figure 6.1 Temporal development of concepts of BP

Table 6.1 The historical succession of concepts of BP for sustainability

Elements of the activity system	On-farm scale plants	Centralised biogas plants	BPCC for large farms
Subject	Farmer	Specialised commercial organisation	Specialised commercial organisation
Object	Biogas for on-site use (e.g., heating chicken houses, electricity, bio-fertiliser)	Manure and waste processing (e.g.,service of waste treatment, selling electricity, bio-fertiliser)	Production of tradeable carbon credits from the manure of large farms
Outcome	Cheap alternative energy	Gas, electricity, fertiliser for the markets	Carbon credits for profit
Tools	Technologies for small-scale BP	Large-scale production technologies	Knowledge about CDM projects, technologies adapted for large-scale production, BOOT model (Build, operate, own and transfer)
Community	Farmers, state project	Commercial organisation or non-profitable association with its suppliers (e.g.,farmers) and customers	Project building organisation and franchising organisation
Division of labour	Each farmer produces and maintains the bio-digesters separately	Functional specialisation	Project building versus production
Rules	Energy production for one's own use	Business competition on the markets, legislation on bio-energy and waste treatment	UNFCCC methodologies, market competition, national environmental legislation, and franchising business

6.2.2 Dimensions in the historical development of the BP concepts

The development of the BP concepts exhibits two main dimensions. The first one is a historical movement from BP from local raw material and immediate local use to BP for markets to gain exchange value. This dimension may be interpreted as the change from BP for one's own use to BP for market exchange, and is connected to the transition from small-scale to large-scale production. New BP projects, therefore, are constantly searching for more products and services to make BP economically viable (for example, heat and electricity production). This suggests another dimension of movement from single purpose to multipurpose, synergic BP, in which several use values or sources of exchange value are created in the same process. The dimensions identified above are similar to concepts of biogas proposed by Blokhina et al. (2010), in which they propose four concepts of BP mainly differentiated by the level of centralisation of production and consumption of biogas and heat.

In the first BP projects the plants were owned and managed by farmers, while the most recent BPCC projects follow the BOOT model, in which the plants are owned and managed by a specialised commercial organisation. Initially, this started from the separation of the roles of the owner of the bio-digester, the manager (decision-maker), the maintainer and the operator, suggesting a movement of historical development from decentralised towards centralised ownership of biogas plants, with one organisation owning and managing many plants. The administration can be a group of representatives of a community, an association of producers, or a private company. In a centralised administration, the producer is not responsible for searching and implementing the technologies to be used, nor how the biogas should be used and commercialised.

Hypothesis of the developmental dimensions

By combining these two dimensions, I arrived at a model of historical ideal types of BP for sustainability (Figure 6.2). It contains two dimensions: integration of production and societal integration with markets. Although the integration of production is related to the dimension of societal integration of BP through market exchange, they are considered separate dimensions because the correlation is not necessary. For example, not all small plants are or may be oriented to local use of biogas.

The framework is not a tool for classification of empirical cases, but an idealisation of the concepts of BP. The concepts of BP are ideal types, mental abstractions of the basic principle of operation, that is, how the system functions. Thus, I do not intent to use the framework to classify all the BP plants existing in the world, and I probably cannot fully explain the BP in the Sadia chain of food production either. However, the framework is a starting point that offers a basic conceptual tool to be used in the empirical chapters. The framework proposes the developmental possibilities of BP. Field 1 represents a unit of BP which is self-sufficient. The strength (or competitive advantage) of the concept in field 3 is the high level of standardisation and bureaucracy, which allows economies by dividing fixed costs through units of production. The direction of the arrow represents newer concepts. The newest concept would be the concept in field 4, the strength of which is flexible networks of activities supporting each other. To my knowledge, this concept does not yet exist, but is under construction (UNAPCAEM, 2007).

Both field 2 and field 4 are models of integrated production, meaning that biogas is integrated with other activities. In field 2, BP is integrated with other activities on the farm, such as using biogas for cooking, or for heating chicken houses. In field 2, integration occurs with activities outside the farm. In this field, integration is achieved through a network of interdependent activities. In field 4, BP is not an independent activity as in field 3; it is rather an activity integrated with other activities; its meaning and function are defined in terms of integration.

The matrix suggests that field 4, BP for market and multiple purposes, is historically more developed than the other models, since it is more likely to satisfy the needs of the actors involved. The idea of BP for multiple purposes is supported by several studies (Nielsen & Hjort-Gregersen, 2002; Blokhina et al., 2010).

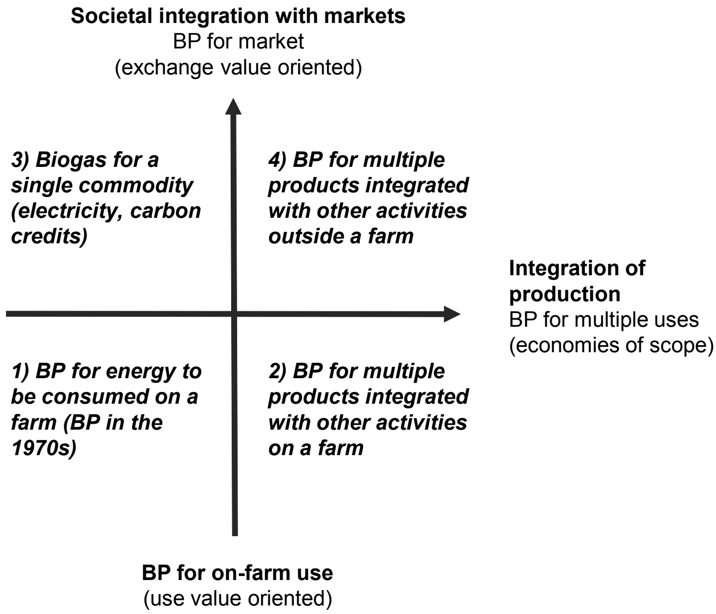

Figure 6.2 General representation of the historical development of BP concepts

A concrete case of BP in Finland

To illustrate the use of the framework, in the following I will briefly review a recent study conducted by Pereira-Querol and colleagues (2010), which nicely illustrates the evolution of the concepts presented above. We analysed a case of emergence and development of BP in Finland, and showed how the meaning of BP has evolved. The concept created in the Finnish case was a centralised plant in which the raw material used for the production of biogas came from many farms, and was characterised as large-scale production with centralised administration. The decision to centralise the production and adopt a specialised organisation for administrating the BP was based on economies of scale. At the beginning of the project, the main purpose of BP was to treat the swine manure produced by the swine production farms, to adapt the farms to environmental legislation, and thus allow further expansion of the farms. However, as biogas production started, new sources of raw material, especially industrial and domestic waste, were added to keep the operation economically viable. The treatment of these new sources of waste proved to be profitable. Later, the plant also started using electricity and selling it to the local network. Nowadays, the plans are to further develop economies of scope by also selling biogas as fuel (for example, for cars and trucks) and bio-fertiliser. In the Finnish case, the evolution of BP fits with the model presented above, starting in the upper part of the framework and moving towards the right: more products and integration with other activities. The case is a good example of increasing societal integration of BP through market exchange, large-scale production, centralised administration and multiple products.

BP in the Finnish case could be characterised as integration through a network of activities, and would be located in field 4.

What are the contradictions that create a tendency for BP to move from field 1 to field 2 or 3 and from field 2 and 3 to field 4? In the BP model in field 1, BP is mainly used for one or two purposes, such as cooking and bio-fertiliser. In this respect, BP is useful but the costs of investment and maintenance are considerable. This model is viable when the technologies of bio-digestion as well as the technology for using the gas are simple and cheap. However, as the technology of bio-digestion and biogas use becomes more sophisticated (such as use for electricity) and the scale increases, the costs of investment and maintenance increase as well. Such sophistication may be necessary, for example, because of reasons of safety or reduction of environmental pollution caused by leakage. Thus, the investment and maintenance costs create a tendency to move either to production for the market, in which commodities are traded (field 2), or towards a greater variety of uses (field 3).

The concept of BP for sustainability in field 2 of Figure 6.2 achieves economic viability by commercialising biogas products in the market (carbon credits or electricity) and achieving in this way economies of scale. The commoditisation of biogas requires rather sophisticated and expensive technologies, which include for measuring, treating and burning the gas. In order to be economically viable a certain specialisation and scale of production have to be achieved. Commoditisation may have the advantage of paying back the investment and maintenance costs, and even generating extra income to producers. However, this model has important limitations. The concept requires relatively costly investments that exclude the smallest and poorest farmers, who either do not produce large enough amounts of the gas to gain economies of scale or cannot afford to produce a standardised quality product.

BP in field 3 maximises the social and environmental benefits because BP is used to produce as many products as possible; the bio-fertiliser is used to produce maize used for the swine, the biogas IS used for heat for the animals, and so on. This model is usually considered the most environmentally sustainable as there is a recycling of nutrients on the farm. On the other hand, it may be difficult to pay investment and maintenance costs that may be required to produce and use the gas. This model depends on direct or indirect subsidies from other activities, and the dependency on external services and equipment creates a tendency to move towards the market.

6.3 Development of the BP system in the Sadia chain of food production

In the followimng I will present two narratives of the development of BP in the Sadia chain of food production: one from the perspective of the Sadia staff and the other from the perspective of a swine producer. Both narratives start with background information about swine production before the emergence of the BP system. The first narrative gives a general overview of swine production in the south-west region of Santa Catarina (SC) during the 1980s, showing how concentration of swine production further aggravated environemtal problems. Both of the narratives end with the actual data obtained from interviews and observations conducted in May 2008 (see Chapter 5 for details on the method used for constructing the narrative and data analysis). Suffice it to say here that I relied mainly on other studies and a document to reconstruct the history from the 1980s to end of the '90s. For the period 1998–2003, I relied on documents such as news and annual reports, while the period 2003–2008 is supplemented by interviews with multiple key actors in addition to documents. The next section presents the history of swine production on a selected farm, followed by an analysis of the two narratives with the help of the activity system model, the concept of contradictions and the model of the cycle of expansive learning.

6.3.1 NARRATIVE 1: The emergence and development of the 3S Programme

The crisis in swine manure management in the south-west region of SC and increasing pressure to become environmentally responsible (1980s – 1998)

As already mentioned in Chapter 1, since the late 1980s swine production in Brazil has suffered important structural changes brought about by changes in agricultural policies. These changes have intensified the process of concentrating swine production in areas around food industries as well as the specialisation of farmers. In addition, specialised swine producers have given up their agricultural activities. These major structural changes have led to the production of economies of scale and to the reduction of production costs, making swine production more internationally competitive. On the other hand, concentration and specialisation have led to an increase in water pollution (Miranda, 2005; Palhares & Calijuri, 2006). At the end of the 1980s the first reports about the increasing contamination of the local water resources in the region began to appear. The media spread news about the breakage of manure-storing tanks, which had led to the death of fish and, in some cases, to the interruption of the water supply to urban areas. Studies were conducted associating the pollution of water resources with other sanitary problems such as blackflies infestations (Guivant & Miranda, 2005).

In 1993, several gatherings were organised in the south-west of Santa Catarina to discuss the environmental problems brought about by swine production (2). The outcome of these initiatives was the elaboration of a programme for the expansion of swine production and the treatment of swine manure. In the late 1990s, consumers and financial investors became increasing concerned about the social and environmental impacts of the activities of companies (Padilha et al., 2006).

Consumers started to prefer environmentally and socially friendly products, and several concepts of more socially and environmentally friendly food production emerged to satisfy this demand, such as organic food and fair trade. This concern also became relevant among investors, who felt that environmental and social problems should be avoided because they represented financial risks. Shareholders started to value the market shares of those companies that took their social and environmental responsibility seriously. The Dow Jones Index of Sustainability was created in 1999, followed by the Index of Corporate Sustainability in the BOVESPA Stock Market in Sao Paulo, Brazil. "Environmental" and "social" are cited in the annual reports of the Sadia company since at least 1998.

Another sign of increasing concern about the environment was the growing number of awards given to companies for their good ecological performance. Sadia received several awards during 1998 and 1999 for numerous environmental projects, among them the installation of a swine manure treatment system on one of its own swine farms in Faxinal dos Guedes. Guivant & Miranda (1999) drew attention to this contradictory situation in which the food industry was receiving more and more awards for environmental projects within their own units, while the environmental situation on the farms of their outsourced suppliers remained poor.

Developing the idea of anaerobic digestion (BP) for treating swine manure in Sadia's own farms (1998–2003)

In May 1999, Sadia announced an experimental project of swine manure waste treatment on its own swine farms in Faxinal dos Guedes (SC). Before the implementation of the project, the manure treatment system used in Sadia's own units was anaerobic lagoons. Although this technology complied with Brazilian environmental legislation, it had many disadvantages: it demanded a huge spatial area, the accumulated sludge was difficult to remove, a great deal of nitrogen was lost (Document, 06/2004), and it emitted odour. The new project consisted of a series of processes and installations of swine manure treatment to assure the quality of water required by the environmental legislation. The aim of the project was to reduce the risk of contamination from swine manure management. The treatment system was composed of four tanks, two anaerobic, one mixed, and one aerated (Sadia's magazine: *Revista Integração*, 1999; cited by Guivant & Miranda, 2005). The system was created to fit the conditions of outsourced farmers, using simple and inexpensive equipment. In their annual report of 2001, Sadia presented an experimental project in Toledo (Paraná State) to test BP as a potential alternative solution to the economic and environmental problems. The treatment system was called an integrated bio-system. Sadia implemented the experimental swine manure waste treatment system on its own farm, and used it to test the technology with outsourced farmers as well. The system, however, was not yet implemented.

Aggravation of the environmental problem, the signing of TAC, and the increasing need to become sustainable (2001–2004)

The discussion about the environmental problem in the region was frozen for about five years (1996–2001). On 30 October, 2001 a meeting proposing a Term for Adjusting Behaviour – TAC (Termo de Ajustamento de Coducta) was organised. In the meeting it was established that several actors such as representatives of the municipalities in the south-west of Santa Catarina, the farmers and the food industry, would elaborate a term to adjust the farms in the region to the environmental legislation (Pillon et al., 2003). In 2002 a preliminary term of adjustment was signed, which led to an assessment of the conditions on the swine farms. The assessment pointed out that only 8.3% of the farms had environmental licenses and 78% had some sort of environmental inadequacy, such as under-dimensioned of storage tanks or lack of agricultural field for applying the slurry. In July 2003, the discussion turned to the question of who should take responsibility for paying the costs of adjusting the farms. The fact was that swine farms were not in a position to assume such costs since they were still recovering from a financial crisis. The new argument suggested by representatives of the farmers was that the costs should be divided between the State, the farmers and the food industry.

On 29 June, 2004, the TAC was signed between several representatives of the swine producers, including Sadia and its outsourced suppliers, in the western part of SC State. The stakeholders agreed to take action to adjust the farms of their outsourced swine suppliers from the south-west region of Santa Catarina to the environmental legislation (see Palhares, 2006 for information on the history of the environmental legislation in the region). In practice the TAC was an agreement in which the food processing companies agreed to support farmers in adjusting to the environmental legislation, and to buy pigs only from those with environmental licenses. Among other measures, farmers would have to change their swine manure treatment. One of the roles of TAC was to show, clarify and operationalise the environmental legislation. This meant showing exactly what was required and forbidden.

By requesting farmers to have licenses to supply pigs, the food companies were essential to the application of the TAC. Moreover, the environmental licenses were also essential to keep account of who had adjusted to the environmental legislation. The TAC clearly established that in order to obtain the environmental license, farmers had to follow basic norms regarding a) distances from river and roads, b) minimum preservation areas, and c) minimum practices of managing and distributing the swine manure.

In 2003, parallel to the environmental problem, Sadia's former director of marketing and sales was invited to join an international learning platform called Sustainable Food Laboratory (Food Lab) (Document, 01/06/2004), aimed at bringing together entrepreneurs seeking a change towards sustainability. The purpose of the Food Lab was to understand the problems in Sadia's food chain production. The director joined because sustainability was seen as a trend and more knowledge was needed. In May 2004, a representative from Sadia replaced the director in the Food Lab. As this person explained, the intervention helped bring the concept of sustainability to the attention of the top administration of the company, and increase concern about the sustainability of the company. The company wanted to become economically, socially and environmentally sustainable.

The TAC required that farmers to adapt their farms to the environmental legislation to be able to obtain environmental licenses in the future. For Sadia, the TAC started to threat the supply of swine to the food processing company. Moreover, the whole environmental and social impact of swine production could also harm the image of the company, and consequently devalue the brand value of Sadia.

The emergence of the carbon project in Sadia's own farms (2003–2004)

At the beginning of 2003, the Chief Financial Officer from Sadia, a member of the executive board, heard about the Kyoto Treaty and had the idea of obtaining carbon credits from the company's forests. The forests were already used as a source of firewood for the boilers of the food processing units. The initial idea was to use the mechanism of the Kyoto Treaty to increase the company's areas of Eucalyptus forests as efficiently as possible (Interview, 22 December 2006). To assess the possibilities, in the first half of 2003, Sadia contracted a consultant company (called here Company Sigma) to diagnose and elaborate a project design for obtaining carbon credits. In March 2004, the consultant company issued a report in which it was pointed out that only three of the twenty projects identified were considered viable for applying for carbon credits. These were projects to produce biogas for treating swine manure (Interviews 22 December 2006 and 16 May 2007). At this stage, the significance of swine manure treatment changed from a mere technology for solving the environmental problem to an opportunity to generate extra income for the company. The Sadia Sustainability Team was created to design and implement the project (Document, PDD1). The technology regarding the bio-digester and burning of the gas was purchased on the market from a company called Sansui. Sadia engineers called the model "engenheriado" (engineering), referring to the fact that the installation required the supervision of engineers. As the Project Design Document (PDD) was elaborated, the team perceived several economic and environmental benefits from producing biogas for carbon credits. The project was presented to the Sadia executive board whose members were surprised by the large number of potential tonnes generated in the project (242,000 tonnes in 10 years). The executive board decided to implement the project and expand it to all 24 of Sadia's units of sow production, which initiated a second set of 'carbon projects', the PDD2 (Presentation, 30 May 2005*)*. In October 2003 the carbon credit project began operations at Sadia (News, 4 March 2008).

The three projects were based on the installation of non-heated anaerobic digesters that captured and flared GHG. These projects were based on methodologies AM0006 and AM0016, characterised as on-farm BP for carbon credits in large-scale farms.

To sum up, during this period, the purpose of waste management on Sadia's own farm changed from a means to adjust Sadia's own farm to environmental legislation, to a way to obtain extra income. The event that marked this transition was the assessment of opportunities to apply for carbon credits within the company. The company discovered that only BP projects could be used for applying for carbon credits. The technologies adopted, as well as the methodology to be applied, were suitable for large farms.

The design of the 3S Programme (2004–2005)

During the first half of 2004, the Sadia Sustainability Team realised that the carbon project could also be used as a potential instrument for adapting the farms of their outsourced swine producers to environmental legislation, and it could be an opportunity for improving sustainability of the whole swine production chain. They perceived that the carbon project could be extended to the whole production chain to help achieve completely sustainable waste management and solve environmental problems that were hampering the productive capacity on some farms due to the difficulty of obtaining environmental licenses (Interview with Katia, May 2007).

In early 2004, parallel to the ongoing plans for the carbon project on Sadia's own farm, a Canadian company specialising in the production of carbon credits from swine waste management contacted Sadia's outsourced farmers and proposed the installation of bio-digesters. According to Sadia's Institute coordinator, Sadia did not like this intervention because the business model of the Canadian company selected only the large farms, excluding the smallest and poorest farmers. Moreover, the Sadia also did not agree with the contractual terms that reduced to a minimum the economic benefits that farmers could obtain in the project. Thus, the Sadia staff recommended to their suppliers holding negotiations with the Canadian company, and announced their intention to develop the carbon project for Sadia's outsourced farms. The TAC was signed, reinforcing the need for adapting the farms of Sadia's outsourced swine producers. In September, two committees were created at Sadia: a Strategic Committee of Sustainability, and an Executive Committee of Sustainability. The latter became responsible for coordinating the 3S Programme and for the Sadia Institute (SI).

In the first half of 2004, the Sadia Sustainability Team proposed the idea to the top administration of the company. The Directorate was divided on whether the programme should be implemented or not. Those directors against the idea argued that Sadia should focus on food production rather than carbon credits among outsourced farmers. Finally, the president of the company took the decision of expanding the carbon project to outsourced farmers. To clarify the idea, Sadia started to design the programme (from now on called the 3S Programme) (Document, May 2007), and signed a new contract with the consultant for supporting the design of the 3S Programme and writing the PDD2. During 2004, the 3S Programme, its guidelines and governance model were completed.

Several challenges emerged during the design of the 3S Program. The first challenge was related to the legal structure of the company. A mediating institution was needed for implementing the infrastructure, commercialising the carbon credits, and then transferring the money to farmers. To solve the problem, Sadia founded the **Sadia Institute – SI**, an independent non-profit organisation in December 2004 (Document, May 2005). Another challenge was related to technology. The bio-digesters available in the market at that time were too expensive to be implemented on small farms (fewer than 1,000 animals per farm), which corresponded to 80 to 90% of the farmers. Sadia engineers developed a cheaper model, easy to install. This new bio-digester for small farms was called the Vietnamese model. As the name suggests, it was adapted from a model developed in Vietnam (Interview with Alberto Silva, December 2006).

In March 2005, once the project was ready, the Sadia Sustainability Team began training Sadia field work technicians for the 3S Programme. Before engaging farmers, it was necessary to evaluate of the economic, social and environmental conditions among the farmers. 20 October, the SI borrowed R$65.5 million (US$ 36.11 million) from the Brazilian Developmental Bank (BNDES) for starting the implementation of the programme (Document MQ, News 6 January 2007).

Implementation of the 3S Programme (2005–2006)

At the end of 2005, the team started to present the programme and the contracts to the farmers. Once the farmers signed the contract, the bio-digesters were installed on their farms. As the installation proceeded, problems with the Vietnamese bio-digester began to arise. These included tears in the canvas and leakage from joints. The problems were so frequent that the engineers decided to stop the installation process and redesign the bio-digester.

On 2 February 2006, the Executive Board of Sadia approved the Sadia PDD1, opening the way to the 3S Programme. It was the first CDM project approved in a Brazilian food company (Document MQ, News 6 January 2007). This positive experience reinforced the idea of the 3S Programme. At the beginning of 2006, a new bio-digester was developed and proposed by the same company that had sold the bio-digester to the carbon project of the PDD1 (the first three projects on Sadia's own farms). This new bio-digester was cheaper and better adapted to the farming conditions (Interview with Silva, December 2006). An outsourced company was hired to conduct the installations, and in March 2006 they began installing the new model of bio-digesters (Document "Obras Executadas" 2006, Figure 6.3).

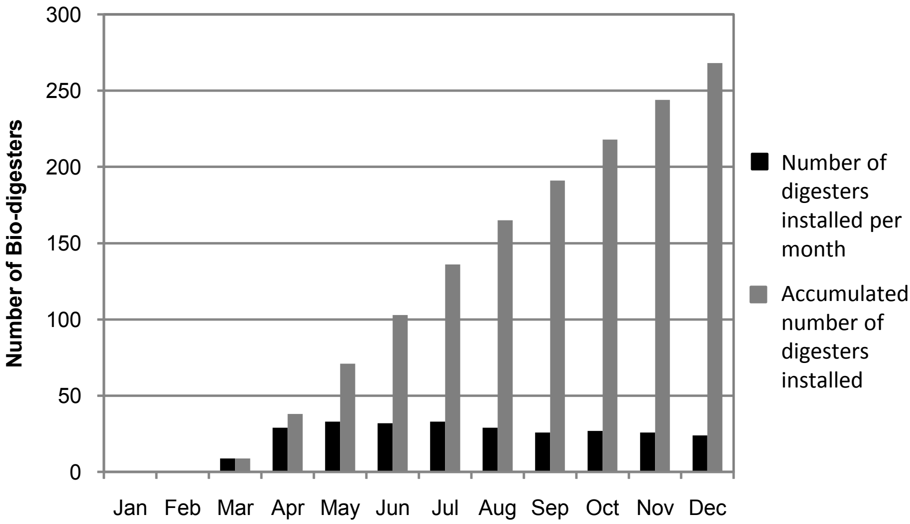

Figure 6.3 Number of bio-digesters installed in Concordia unit, SC State in 2006 (Operational document, "Relation of installations during 2006", May 2007)

On 12 May 2006, the Executive Board of the CDM agreed to put methodologies AM0006 and AM0016 on hold. The decision was affected by recommendations given by the Meth Panel's rising concern about the difficulty of validating and monitoring projects based on these methodologies, as they did not guarantee the production of data about the amounts of gas produced and burnt. As Sadia's project coordinator explained, this event had a huge impact on the project. In practice, the new methodology required the implementation of new monitoring equipment, which almost doubled implementation costs and reduced the number of farmers that could benefit from the programme. Before continuing the bio-digester implementation new cheaper combustion technologies (flare and measurers) would have to be found and adapted to the conditions of Sadia's outsourced farmers.

On 25 May 2006, Sadia and the SI sold 2.5 million tonnes of carbon credits to the European Carbon Fund (Document News 9, 26 May 2006). In June the same year, Sadia decided to setup its own managerial structure to manage the 3S Programme and break the contract with the consultant company (Interview with consultant, May 2007). According to the coordinator of the programme there were mainly two reasons for that. First, the consultant company was demanding participation in the commercialisation of the carbon credits, which would impair the viability of the programme. Second, the consultant company sold the idea of the programme to Sadia's main competitor, which reduced its credibity (Interview with Katia, May 2007). Sadia decided to continue without any consultancy, and hired a coordinator and field work technicians to monitor the implementation of the bio-digesters.

Throughout the year 2006, as the implementation of the bio-digesters proceeded, some problems started to emerge in the field: a delay in answering the requests for maintenance from the outsourced company that was installing the bio-digesters; inappropriate use of biogas; lack of maintenance of the bio-digesters; farmers' lack of training in how to operate the bio-digesters; and Sadia field technicians were not assuming the task of checking the bio-digester (Report of September 2006 from the field workers of the SI).

As the coordinator of the programme explained, when the bio-digesters began to be installed in large numbers, new operational tasks were demanded at the local level (such as presenting and signing the contracts with farmers, and monitoring the installation of the bio-digesters). The managers of the SI requested the cooperation of Sadia's industrial department, but the production sector initially resisted including the bio-digesters in their everyday routine, since they were not part of the goals established by its directorate. After negotiations between the institute's staff and the industrial Directorate, it was agreed that one of the advisors' tasks would be to present the contracts and check the bio-digesters during their farm visits. As reported by the SI field work engineer, however, this was not taking place in practice.

In December 2006 one problem was that the outsourced farmers were not doing the maintenance as expected, which was causing problems such as the obstruction of digesters and perforation of the plastic covers. This required training the outsourced farmers as well as monitoring and solving practical problems. According to the technicians, this might have been related to the fact that the farmers' main motivation was to use the biogas as an energy source instead of simply reducing GHG emissions. The engineers and coordinators felt that a lack of instruction also played a role. To deal with this problem, the engineers started drawing up guidelines on how to operate the digesters.

Adjusting the programme to a change in UNFCCC Methodology (2006–2007)

On 15 December 2006, the CDM-UNFCCC Executive Board launched a consolidated methodology, the ACM0010, aimed at replacing methodologies AM0006 and AM0016. As stated in the meeting report, the main change regarded the procedure for estimating flare efficiency. The methodology approved refered to the Methodological Tool (Annex 13 from the Executive board EB28) to determine project emissions from methane flaring (Document Meeting Report EB28).

According to the new methodology, only 50% of the burnt gas from an open flare would be counted. To the 3S Program to remain viable, the SI had to adopt closed flares and a complex measuring system, instead of open flares, as initially planned. The new methodology required measuring the efficiency of the flare, temperature of combustion, composition and flow of biogas. This meant the incorporation of highly complex electronic devices, which were too expensive. In practice the new methodology made the implementation of bio-digesters on small farms uneconomical. This required urgent changes and decision making in the programme.

The coordinator of the programme alerted the Sadia administration about the changes and the risks that the new methodology could bring to Sadia and the SI. To deal with the changes, in December 2006, the managerial structure of sustainability moved from the marketing and sales department to the department of institutional and juridical relations. This change aimed at giving more power to the coordinator to take decisions and influence other production activities within Sadia.

In January 2007, a meeting was organised to define the operational management of the 3S Programme (Document, RS News 3, 4 March 2008). The responsibility of the new operational manager was to develop the bio-digester and other equipment, identify suppliers, and elaborate the PDD. To do this, the institute would hire one coordinator, one technician per region and one specialist for the elaboration of PDDs (Interview with Katia, May 2007). Early that year, the SI staff organised a meeting with the Sadia Executive Board to deal with new methodological and operational challenges. The programme coordinator was seen to be unable to conduct operational tasks, and a rearrangement of operational tasks was necessary. A new combustion system was also being developed jointly between Sadia, the equipment manufacturers and farmers. Sadia engineers asked the manufacturers to install their equipment on some farms, where they could be adapted to Sadia's needs (small farms) and tested for their performance, durability and so on. Farmers participated by making their bio-digesters avaliable for conducting the tests. In May 2007, the combustion system was selected and new equipment purchased. The installation started in June and continued at least until May 2008.

Since 2007, Sadia engineers have been testing technologies for using biogas on the farms. The basic strategy for developing the technologies was to ask manufacturers to install their technologies and to test them. Another important strategy was to allow some innovative farmers (such as Mr Fabio) to test different equipment, which could then be shown to other farms. Another strategy was to collaborate with other research institutes such as universities.

The SI also proposed a new methodology for UNFCCC that would reduce the costs of certification. Such methodology would allow new farmers to be constantly included in the project without the need to elaborate and submit new projects.

In May 2008, Sadia aimed to further develop the technology of bio-digestion in order to improve the efficiency of the process and reduce the volumes of the end slurry. This development was being done in collaboration with the Embrapa (Brazilian national agricultural research institute). The idea was to test new technologies which would complement BP for reducing the volume of end slurry.

To deal with everyday problems and needed decisions that emerged during the implementation of the 3S Program, a platform called "check meeting" was created. The check meetings were periodic and aimed at discussing and taking decisions about actions needed to make the programme to go forward: for example, the need to hire new staff and the need for maintenance. The meeting was composed of representatives of the Sadia Institute and different departments at Sadia, such as operational management of the 3S Programme, and the coordinator and directors from the financial, supply and industrial departments. These meetings were internal and confidential and only Sadia staff could participate.

When the combustion system was installed at the farms, some problems became evident. Farmers were requested to purchase a new measuring system and use a certified technology in order to use the biogas. In 2008, there was still no certified technology, and the measuring system was too expensive, so some farmers started to organise opposition to this rule. They threatened to disobey the rule and to use the gas. In order to deal with the "resistance" of farmers, the SI coordinator planned the formation of a platform for dialogue, with a committee of representatives of farmers to start the dialogue and to find solutions to the resistance. The committee was formed at the beginning of 2008, but the platform (meetings) had not yet been orgined when I collected my last data in May 2008.

According to an interview with the operational engineer in the 3S Programme, there were two basic alternative plans for the future: carbon credits and biogas use. In the first option, BP would be used mainly to produce carbon credits so that the money could be used to improve farming in general. In the latter, BP would be used in swine production and other farming activities. I shall discuss this in Chapter 8 along with the ZPD of BP in the Sadia food production chain.

6.3.2 NARRATIVE 2: The history of swine production and swine manure management at Mr Paulo's farm

For a change of perspective, I will analyse the development of swine production and manure management at one farm. The analysis aims at establishing when and how the relationship between the BP system and farming system was established, that is, how the farm became part of the BP system. Although the analysed farm differed regarding the exact number of animals and activities on the farm, Mr Paulo's farm was similar regarding the pattern of development: increase in production, closer integration with the food industry, technologies used and challenges faced (see Guivant & Miranda, 2005). This case is also an example of how swine manure management has changed. The data are based on face-to-face interviews conducted in 2007 and 2008. The periods are divided according to the meaning of swine manure, and how it was dealt with on the farm.

Swine manure for agricultural fields and thrown in the river (early 1980s to 2001)

Mr Paulo started producing swine almost 30 years ago. At that time, he had 30 to 35 hogs under a production system that is nowadays called "complete cycle". He was responsible for the whole process from the reproduction of the sows to delivering hogs to the slaughterhouse. In this production system, the farmer owned not only the infrastructure and labour, but also all the raw materials and inputs used in the production. He was responsible for producing the swine food and medicine himself. In Mr Paulo's case, the food was initially produced on the farm. He planted, harvested and prepared the food for the animals, which involved almost anything available at the farm: maize, cassava, vegetables and grass. Food production demanded fertile soils which in turn demanded huge amounts of fertiliser obtained from swine manure.

As the farmer explained, 25 years ago, there was no storage of the manure; part of it was collected for use in the agricultural fields and part was disposed of directly into the river, which was an accepted practice at the time (from 1979 to 1996). During that period, since most of the food was produced on the farm, the manure was significant as fertiliser to keep the soil fertile and the productive. A slight change in swine manure management happened in 1996. That year, Mr Paulo built a rustic open tank of stones and cement for storing the manure. According to the farmers, the reason for building the tank was that the demand for manure in the agricultural fields was not constant; instead, demand peaked during the planting season. Thus, the manure had to be collected and stored for use when needed. The main significance of the storage was to allow the manure to accumulate for the periods of high demand. As the farmer pointed out, since the tank was installed, manure was no longer released into the river (for more information about open tanks see Kunz et al., 2005).

Swine manure stored and distributed in fields (2001 and 2006)

Between 2001 and 2002, Paulo was asked by Sadia to change the production system from a "complete cycle" to a breeding system (see Chapter 2 for an explanation). In short, this meant specialising in piglets' production, which required a special infrastructure that included a new and larger open tank for storing manure. In addition, he also increased the production capacity from 100 to over 250 sows, which also led to a demand for a larger labour force. The labour problem became even worse when two of Mr Paulo's three sons migrated to the town to work as advisory technicians. It also affected maize production. The farmer had to choose between continuing the production of swine food on the farm or purchasing it from the market, and specialing in piglet production. Because of the low price of maize, it was cheaper to buy it from other regions rather than produce it.

The fact that the manure could not be thrown into the river and it was no longer needed for producing swine food changed the significance of swine manure. It became a cost for the farm, because it had to be stored, transported and distributed in the fields. Even though the open tank was expanded, it was not a satisfactory treatment system because it produced low quality slurry. During this period environmental licenses became a requirement for producing swine. Mr Paulo's farm was not totally in accordance with the environmental law in regard to at least two points: the storage tank capacity was too low, and the warehouse where the pigs were produced was too close to the road. To adjust to the environmental legislation in order to obtain environmental license, he had to expand the storage capacity of his previous open tank.

In 2005, he dealt with the problem of lack of labour by stoping maize production and buying it from the market. Moreover, he installed a system of automatic feeding. Despite these changes, at least up to 2007, the labour force was still insufficient.

Bio-digesters for biogas and for the "environment" (2005 to 2008)

In 2005, Mr Paulo was invited by Sadia's advisors to participate in a meeting organised by Sadia to present the 3S Programme to farmers. There, the advantages of joining the programme and its functioning were explained. Mr Paulo, as well as the majority of attending farmers, were interested in joining the programme and immediately signed a recruiting list for interested farmers. The reasons for joining the 3S Programme were that farmers: a) could increase the capacity of slurry storage without increasing costs (the bio-digester); b) could potentially use the biogas in the future; c) would receive money from the carbon credits; and d) would reduce the impact that swine production had on the environment. In 2006, the bio-digester construction began. In 2007, the SI engineers asked Mr Paulo to test a new combustion system that would be used to measure the biogas produced and burnt. He remembered that both, the staff from Sadia and from the manufacture company that was testing the combustion system asked for some space beside the digester for testing potential equipment for burning the biogas. He agreed to collaborate, and allowed them to install the equipment for testing. At the end of that year, the equipment was dismantled and new equipment was installed in 2008.

By joining the programme and having a bio-digester, Mr Paulo managed, at least temporarily, to solve the problem of lack of space for storing swine manure. This particular solution was one of the reasons for joining the 3S Programme. Manure retention capacity doubled, which accorded with the legislation. Furthermore, the final slurry from the bio-digester was of better quality, which facilitated its loading and distribution in the field. Although this slightly reduced the cost of distribution of the manure, the cost of disposing of the slurry was still significantly high. Mr Paulo still had to pay between R$ 300 and R$ 400 (US$ 222) every 60 days for removing the slurry from the tanks and distributing it in the fields.

In 2007, Mr Paulo received an offer from Sadia to change his commercial contract from breeding (UPL) to the comodato-breeding system. In practice, this meant receiving a fixed amount of money for the piglets. The system had the advantage of reducing risks and releasing labour force because instead of preparing the food himself it would be supplied by the Sadia food processing company. Moreover, in the same year, one of Mr Paulo's sons returned to the farm, increasing considerably the availability of labour. Thus, both the return of his son and the change in the production system allowed him to solve the labour problem. Owing to the increase in the labour force available, he decided to expand the swine production capacity from approximately 250 to 550 sows, almost doubling the piglet production capacity. Such expansion in production was possible thanks to the existence of the bio-digesters, which gave him extra capacity for storing manure. However, the environmental organisation FATMA required still other measures, such as building more open tanks and covering the previous one. Again, this involved extra costs to Mr Paulo (infrastructure as well as transportation and distribution of the end slurry, which at that time was carried out by an outsourced organisation.

Mr Paulo desired to use the biogas for heating the piglets during the winter, but the equipment was too expensive, and he was worried that during the winter the production of biogas would not suffice.

6.4 Analysis of the role of BP in the expansive development towards sustainable swine production

In this section, I will analyse the role of BP in the expansive development of the object of swine production in the network of Sadia's outsourced farms. The concepts used will be historical event, periods, cycle and phases of expansive development as presented in Section 5.5 in Chapter 5.

6.4.1 Activity systems analysed and analytic concepts used in the analysis

The primary activity systems analysed here are Sadia's activity of swine-based food production and the swine production activity on Paulo's farm. I also analyse the 3S Programme, which I consider here as a transitory activity system created in order to realise the planned change in the object of swine production and to produce biogas for selling carbon credits. This transitory activity system involved both Sadia and the outsourced farms in BP.

The first step in my analysis was to identify the main historical events related to BP in the two narratives. The main events are presented in two historical lines, one concerning the activity system of the Sadia food production chain and the transitory activity system of the 3S Programme, and the other concerning the activity of swine production on Mr Paulo's farm. As mentioned in Chapter 5, these events were selected because of the importance the interviewed informants attached to them.

As the second step of my analysis, I classified the events according to the changes that they produced in the structure of the activity systems (Appendix 6.1 and 6.2). Because I am analysing the role of BP in the production activities and the object of the 3S Programme, I have only selected those events that contributed to the formation of or changes in BP within the 3S Programme. To do this, I used the analytical concept of **historical event** (see Section 5.5 in Chapter 5 for a definition of the concept). To identify phases and periods (Section 5.5 in Chapter 5), I used a matrix with the elements of the activity system, and I analysed how the main events changed or created the elements of the structure of the respective activity systems.

Appendices 6.1 and 6.2 present the elements of the activity system that were changed by the main historical events in the 3S Programme and on Mr Paulo's farm. The theoretical interpretation of some changes is rather obvious and relatively incontestable, while others are not. I further discuss those interpretations that I found contestable in the text when the cycle of expansive learning is presented.

6.4.2 Analysis of cycles of expansive learning

In this study, the identification of historical periods is used as a starting point for analysing the progress of expansive learning. The analysis of expansive learning is carried out with the help of the model of the cycle and phases of expansive learning (see Figure 4.5 in Chapter 4). I have used remarkable qualitative changes in the object of the activity as the criterion of change in the historical period, and major change in some of the elements of the activity as the criterion of change of phase. Not all events and changes that take place in these contribute to the expansive development of the activity. Therefore, as the next step I will interpret the changes from the point of view of the progression of expansive learning and development. The starting point of a new cycle of development is not the formation of a new object but the questioning and destabilisation of the current object. The change of object takes place in the middle of the expansive cycle.

To identify the periods of biogas production for sustainability (BPfS) in Sadia's outsourced farms, I focused on those historical events that created and changed the object of BP. My interpretation was that the object emerged in the 3S Programme in 2004 when the Sadia Sustainability Team discovered that they could use BP for adjusting the farms of Sadia's outsourced farmers to the environmental legislation. However, the formulation of the new object (3S Programme) did not occur when the cycle of expansive learning started. It already started during the aggravation of environmental and social problems faced by the outsourced farmers. The formation of the problem is part of the **object/purpose** of BP. Without such a problem there probably would have been no need for BP. Of course, many solutions were tried, but here the analysis focuses on BP in the 3S Programme.

Table 6.2 illustrates the events that formed the transitory activity system of the 3S Programme classified according to which element of the activity system the event changed the most (columns). The events are arranged in a time line from past to present. The purpose of this table is to identify the period in which BPCC emerged.

Table 6.2 Changes in the activity system of the Sadia swine production chain in chronological order

Time	Object	Tools	Subject	Commu-nity	Rules	Division of labour
1980	Increase in the concentration of production and specialisa-tion of farms					
1993	Regional discussions on pollution from swine produc-tion					
2001		Experiment with BP as a way to solve the problem				
2003	BP for carbon credits as extra income	Report sho-wing the possibility of using biogas for carbon credits	Hiring of a con-sultant compa-ny to analyse the possibilities of obtaining carbon credits; formation of Sadia sustain-ability team	UNFCCC, consultant and Sadia	UNFCCC met-hodology on hold	Consultant company responsible for PDD
2004	Farms of outsourced far-mers needed to adjust to environmental legislation, Sadia's top administrati-on decide to support the 3S Programme	SST's idea of using BPCC for adjusting farms was approved by Sadia's management	Hiring of a consultant to help to design the program-me. Establish-ment of Sadia Institute		Signing of TAC	Establishment of the SI
2005		Design of Viet-namese model bio-digester, design of the 3S Programme		3S Programme presented to Sadia fieldwork technicians		
Spring 2006		Manufacturer proposes a new model of digester, First bio-diges-ters installed	Fieldwork technician hired to moni-tor the instal-lation	Company was hired to install the digesters. Meetings to present 3S Programme to farmers	UNFCCC met-hodology on hold. Farmers sign the cont-ract	
Autumn 2006			Sadia Institute hired a coordi-nator	Sadia broke its contract with consultant	New UNCCC methodology launched	Sadia hired a coordinator
2007	SI sells carbon credits to ECF	New combus-tion system tested.	Environmental manager beca-me responsible for the 3S Programme	Manufacturer of the com-bustion system hired		Meeting to re-organise SI
2008		Redesign of the flare; new flare approved by Sadia engi-neers, Installation of the new flares				

Table 6.3 presents the events that led to the integration of BP as part of the swine production activity on Mr Paulo's farm. They are classified according to which element of the activity system the event changed the most (columns) and arranged in a time line from past to present.

Table 6.3 Changes in the activity system of Mr Paulo's farm in chronological order

Time	Object	Tools	Subject	Community	Rules	Division of labour
1980	Starts pig production, complete cycle		The farmer	Start supplying swine to Sadia industry		
1996		Builds open tank				
2001	Specialises in piglets					
2005	Stops producing swine food					
Spring 2006		Participates in a meeting about the 3S Programme		Sadia joins 3S Programme		
Autumn 2006		Bio-digester installed.				
2007	Decides to double production, and to change to the comodato system	Starts constructing new tanks and warehouses		Son comes home	Obtains new environmental licence	
2008		New combustion system installed				

I shall interpret Tables 6.2 and 6.3 using the model of the cycle of expansive learning. The idea of the historical analysis is to identify the nature of the contradiction present in the current developmental phase of the Sadia food chain's activity system and in the activity system of Mr Paulo's farm.

6.4.3 Expansive learning of Sadia's swine production chain with the use of BPfS in the 3S Programme

Phase I – Recognition of the environmental impacts of swine production (1980s – 1998); Need state.

The need that later led to BP started to evolve in the 1980s and early 1990s as the concentration of swine production and specialisation of farms led to increasing pollution of water resources in the south-west region of Santa Catarina. The aggravation of the environmental problems caused by swine production was recognised both by the inhabitants and the Sadia Company. Sadia saw the environmental degradation as a threat to the expansion of swine production while increases in swine production would inturn lead to more environmental degradation. In the late 1990s Sadia's management aimed to make Sadia a more sustainable company and to show investors and consumers that it was a responsible company, but it did not know how to do this. The annual reports of the company show that attempts were made to develop solutions and programmes that could satisfy the need to improve environmental sustainability of the production; the attempts did not, however, lead to a solution. We can say that at the end of the 1990s, Sadia's swine-based food production was in a need state.

Phase II – Double bind: The aggravation of the environmental problem and the signing of TAC (1998–2004)

In 2001, a meeting organised by legislators again rasied the topic of environmental impacts of swine production, and negotiations between different stakeholders started the process of adjusting the swine farms to the environmental legislation. In this new discussion, the food industry (including Sadia) became co-responsible for the problem. In June 2004 an agreement called TAC was signed among representatives of various companies and sectors with the aim of adapting the swine farms to the environmental legislation. Moreover, pressure from the market and investors to improve sustainability increased. At the beginning of the century a series of new events (such as participation of Sadia staff in the Food Lab, and development of new sustainability indexes) stimulated the desire to become a sustainable company.

The TAC and the market were forces from outside, and acted as new rules in the activity of swine and food production. These new rules were societal responses to the contradiction described above, between specialisation, intensification and concentration of production and its environmental impact. These new rules required minimum standards regarding the management of swine manure, location of the warehouse, natural conservation area and so forth. In 2004, most of Sadia's outsourced farms were not adjusted to the requirements of the legislation. In Sadia's activity of food production, the change of rules created a contradiction between the new rules and the current object of its activity (the unsustainable swine production used in the food industry). On the farm, the new rules created a contradiction between the rules and the tools in the activity system, the infrastructure of the farm (such as under-dimensioned open tanks, insufficient agricultural area for distributing the slurry). This can be seen as increasing inadequacy of the tools from the point of view of the changing environmental demands of the legislation.

In regard to the cycle of expansive learning, the situation faced by Sadia at the end of 2004 can be seen as a **double-bind**: it was not possible for Sadia to continue in the old way, but it was also not possible for it to immediately comply with the new rules. The emerging market rules for sustainability and socio-environmental responsibility, and rules such as TAC made it impossible for Sadia to maintain the old way of operating and prompted it to search for a new way.

Phase III – Construction of the new object/motive: The design of the 3S Programme (2004–2005)

In 2004, the Sadia Sustainability Team found a new object, BP and carbon credits, as a potential financial and technological instrument for adjusting the outsourced farms. It could potentially resolve, or help to resolve, the contradiction in its food production chain related to the inadequacy of outsourced farms to comply with the environmental legislation. The idea was presented to the top administration of the company and approved. As the team started to model the project, they discovered that it could benefit environmental sustainability of swine production as a whole. Including waste management and carbon credits through BP in the object of swine production on the outsourced farms would expand the object of their activity. Starting the **S**adia **S**ustainable **S**wine Production Program, 3S Programme in short, Sadia expanded the object of its own activity by taking responsibility for the development of the production systems on the outsourced farms. BP would be an instrument for achieving sustainable swine production.

The design of the programme involved hiring a consultant, developing new technologies that adapted to small-scale farms, collecting information about farmers, training technicians and so forth. Finally, engineers developed and tested a cheaper version of a bio-digester that would be adapted to small-scale farms and allowed its installation on all the 3,500 outsourced farms. This is a phase of construction of the new object: more sustainable swine production in which BP was an instrument for making it happens.

Phase IV – Application and generalisation: The establishment of the Sadia Institute (2004–2006)

The creation of the Sadia Institute (SI) can be seen as an action to concretise Sadia's new model based on expanded responsibility of the outsourced farms. The fact the SI was a legally independent non-profit organisation and had hired some employees (engineers and technicians) may give the impression that it was a completely new activity. However, the formation of a new legal body may not necessarily result in a new independent activity. As explained in Chapter 4, activities differ from each other on the basis of the object. I argue that the creation of the SI reflects the expansion of the object of Sadia in the internal division of labour in the company. It was legally necessary to establish the SI to carry out the expansion of the object in practice by designing and implementing the 3S Programme, as these tasks were legally beyond the mandate of Sadia's existing organisation.

I interpret the 3S Programme carried out by the SI as a transitory activity system, the object of which was to design and implement the BP system within the network of the outsourced farms as well as to support the development of the farms. This transitory activity was not a completely independent new activity system, but rather an activity within Sadia's organisation: a) it was partially financed by the Sadia company (donations and loans backed by Sadia); b) it was located within the Sadia organisation and used its infrastructure (offices, telephones); and c) the staff working in the management and coordination of the SI programmes and projects were employed and paid by the Sadia, and were "borrowed" as volunteers for the SI (there were, however, employees hired for the implementation of such projects). Moreover, it was not guaranteed (at least up to the latest data collection in May 2008) that the project would be approved by UNFCCC and that the carbon credits would be obtained. Even if the project was approved it had a predetermined ten year term of operation.

In terms of the cycle of expansive learning, establishing the SI may be seen as a historical event marking the beginning of the phase of **application and generalisation (implementation)** of Sadia's new concept of sustainable swine production.

Following the establishment of the SI, several other actions were taken to construct new structures in the swine production activity. These included: obtaining loans, signing of contracts, introducing the programme to the farmers, hiring companies, installing of the bio-digester and so on. Each of these elements had to be designed, implemented and consolidated. In themselves, they can be seen as smaller cycles of expansive learning. Even, for example, the construction and implementation of the bio-digester involved its own community of engineers and companies, division of labour, and tools. This still is, from the view point of activity theory, a chain of actions rather than an activity, as the objectives were based on the process of expanding the object of Sadia's swine production. I consider them as mini-cycles that are part of the phase of application of the model of sustainable swine production in the broader cycle of expansive development of Sadia's activity. I understand the phase of application as composed of multiple and temporary mini-cycles, which are actions lasting for a short time.

During the implementation of the modelled elements of the activity, problems emerged. A good example was the resistance of Sadia's technicians to take on the tasks of monitoring and controlling the bio-digesters. As the installation of the bio-digesters proceeded, new tasks materialised requiring new field work operations. The SI requested the help of the Sadia industrial department, but the staff resisted assuming the tasks of the programme because the bio-digesters were not considered to be part of their goals. Although agreements were made with the top administration, this resistance persisted at the operational level throughout the implementation of the programme. The resistance of Sadia technicians is a good example of disturbances caused by the contradiction between the old object (cheap swine) and the new more expanded object, which also included reducing the environmental impact of swine production through BPfS.

During the Implementation of the new activity, the UNFCCC methodology changed, which also changed the characteristics of the farms that could participate. One way of interpreting the event could be to see the exclusion of small farms as a movement backwards in the cycle towards the reconstruction of the object. This interpretation may be justified because the event led the subject to re-think the object and reduced the capacity of the programme to help those who needed help the most. Moreover, the event led to the redesign of other elements in the activity system, such as the combustion system and the PDD. Another interpretation would be to understand the event as part of the implementation of the concept of sustainable swine production, since the motive did not change considerably. Thus, it is possible to say that there was no regression in the object/purpose of the activity, and the cycle was in the phase of application of the concept.

Another event that affected the 3S Programme was the broken contract between Sadia and the consultant company. This resulted in a gap in the division of labour, and contributed to the delay in the adaptation of the project to the new UNFCCC rules, as well as to the process of writing the PDD. This caused a contradiction between the available division of labour and the expanded object of swine production. In order to deal with the contradiction a meeting was organised in January 2007. In this meeting, the environmental manager of Sadia was made responsible for the operational management. I interpret this event as the creation of a new subject and division of labour. These are important events that marked a re-start in the implementation of the project. The new manager immediately began searching for new alternative technologies of the combustion system. During the first half of 2007, a new engineer was hired to develop and test a new closed flare and measuring system. Several models were tested, and in May 2007 a set of equipment was selected, and a company was hired to assemble and install the the equipment. The installation started in the second half of the year 2007.

I interpret the design of a new combustion system, and the change in the community and division of labour brought about by broken contract as microcycles within the cycle of expansion of swine production towards environmental sustainability. This interpretation is justified by the fact that although the combustion system and division of labour were important, they were not the main motivation, but rather elements for the expansion of swine production. The lightened in Figure 6.4 arrow represents the contradictions in the new activity on the phase of application.

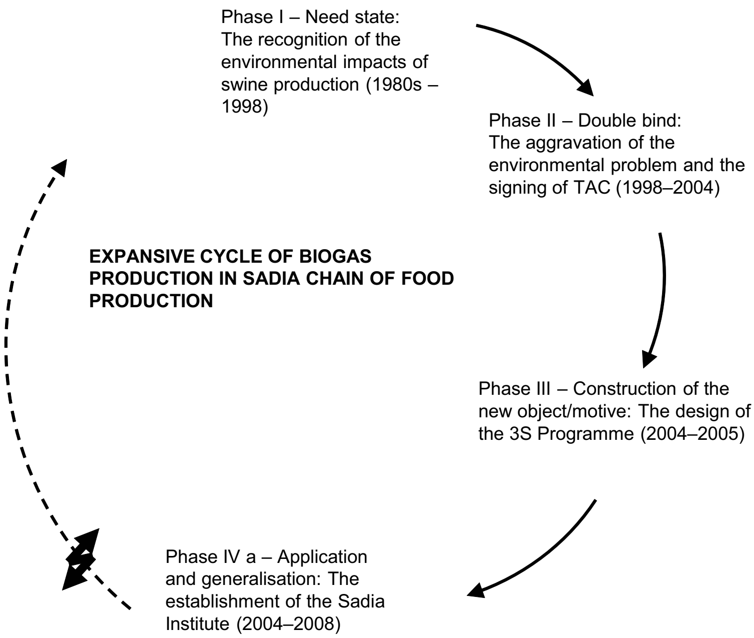

Figure 6.4 Theoretical interpretation of the development of the 3S Programme as four developmental phases

In terms of the cycle of expansive learning, from 2004 until the last data collection in May 2008, the BPCC was under **implementation of the new object**. This is considered here the "current" developmental phase, during which some problems such as the resistance of farmers to a proper operation of the bio-digester remained. The developmental phase of application suggests that these problems are an expression of a contradiction between actions of the old activity of swine production and the new activity of swine production with BPfS. Figure 6.4 represents the cycle of expansion of Sadia's swine production chain.

6.4.4 The expansive cycle of swine production at Paulo's farm

Mr Paulo's farm had gone thourgh several transformations in the last 30 years. His farm is a good example of challenges and trends faced by swine production in the region. From the perspective of swine production, at least two expansive cycles may be identified: a) from "complete cycle swine production" to independent producer of piglets, b) from independent producer of piglets to a comodato (2007 – 2008) (see Section 2.4.1, Chapter 2). During these periods the activity changed qualitatively towards different systems of production: specialisation, increase in scale and further integration with the food industry.

Phase I – Decreasing price of swine (between the 1980s and the 1990s)

From the end of the 1980s until the 1990s, the production capacity on Paulo's farm increased from 35 to 100 animals. This change may be attributed to general changes in the swine production sector in Brazil, such as change in agricultural policies and price of agricultural products. These changes reduced the income of farmers, creating pressure for them to find ways to compensate for this reduction. In this phase, there is a constant need for solutions to increase income but no solutions. I interpret it as a **need state phase**, in which there is a contradiction between the price and use value of the swine.

Phase II – Increase in scale, technological changes and changes in environmental legislation (1990s until 2000)

To deal with the decrease in income, Mr Paulo made several changes in production. He increased the number of animals per area, changed the feeding, infrastructure and so on. These changes helped to alleviate the contradiction. At the end of the 1990s, throwing manure directly into the river was prohibited and it became compulsory to store manure for 120 days before its use in agricultural fields.

I interpret the market pressure to reduce costs and increase scale as rules imposed by the market. In this phase the contradiction between price and use value of the swine intensified leading the activity to a situation of **double bind**, and requiring more radical changes in production.

Phase III, IV and V – Specialisation in piglet production (2001–2006)

In 2001, Mr Paulo decided to increase production from 100 to 250 sows, and specialise in piglet production. The specialisation allowed him to get better prices, and increase the family income. The larger number of sows allowed a reduction in unit costs. The object of the activity changed from pigs to piglets. This period also saw important qualitative changes in the production system. To increase production, Mr Paulo had to obtain an environmental license, what was only possible after constructing a larger open tank. He adjusted the activity to the law and expanded the tank. In this same period, he also stopped producing maize and started buying it from the market. These two events led to a significant change in the function of swine manure: from a fertiliser to an extra cost.

In the light of the cycle of expansive learning, I understand the period between 2001 and 2006 as the **construction of a new object/motive and the application of the new object.** Whether the cycle was an expansion or regression is disputable, depending on the perspective. From Mr Paulo's perspective the new object (piglets) was more expansive as it had more desirable characteristics, such as less work, better prices and lower risks. From the environmental perspective it may be argued that this change is a regression in that it increased the volume of manure without considerably improving its management. However, since I am taking Paulo's perspective, I shall consider it as an expansion.

During the ealy 2000s, farming activity was rather stable. Specialisation in piglet production alleviated, at least temporarily, the contradiction between the decreasing price of pigs and the need to maintain the family income. The new activity of piglet production stabilised and **consolidated**.

Phase VI and VII – Decrease in piglet price and increasing demand for further income; migration of the children (2001–2007)

In the early 2000s the price of piglets started to decrease. Paulo's children grew up, increasing the pressure for a larger income. Because he could not provide a satisfactory income for his children, two of his three sons migrated to the nearby city in search of jobs, the result of which was a disequilibrium in the division of labour. The situation led to a contradiction between the community (the labour force available) and the tasks to be done (division of labour). To deal with the problem Paulo hired an extra worker, and installed an automatic system for preparing the food and distributing it to the warehouse, but the lack of labour remained a problem.

In 2006, Mr Paulo heard about the 3S Programme and decided to join it. His main expectation was to improve the quality of the end slurry, and potentially use the biogas to reduce production costs, particularly those related to energy consumption due to heating during the winter. The bio-digester was an attempt to reduce production costs and improve swine manure management. In 2007 Paulo hired a new worker and one of his sons returned to the farm, increasing the availability of a labour force. This solved the contradiction between the division of labour and availability of a labour force, but increased costs on the farm, putting even more pressure on Paulo to expand production.

In this phase several elements of the activity system changed, including the tools (automation of feeding and swine manure management) and division of labour (hiring a new worker). The bio-digester was also used as a tool to treat the manure and maintain piglet production. Such events did not change the object/motive of the activity; instead they were micro-cycles changing the elements of the activity system. In this case, the biogas helped to minimise the contradictions between management of manure and the low price of swine, though it was still not completely satisfactory. These solutions alleviated but did not solve the contradiction related to the income of the farm and swine manure management.

During 2006 and 2007, the situation on Paulo's farm was characterised as a phase of **double bind**, in which there was a need to increase income but no satisfactory solution.

Phase VIII – Changing the production system to commodato (2007)

In 2007, Mr Paulo was asked by Sadia to change the production system from independent breeder to comodato, which meant a change in the object towards further specialisation. Paulo would no longer own the sows, and would not have to take care of preparing the food and hiring advisory services. All these services and products were delivered by Sadia. Thus, Mr Paulo could specialise in piglet production. He decided to change the system and double the production capacity from 250 to 500 sows. From the point of view of swine production, the specialisation in piglet production may be seen as a new expansive cycle, the formation of a new, more expanded object with more desirable characteristics for him (lower risk and costs). As mentioned, the decision to expand was related to the contradiction in the activity: lower prices and the need to maintain income.

Phase IX – Obtaining the environmental license and construction of the new warehouses (2008): application

In 2008, Paulo took action to concretise the activity of comodato breeding. He signed a contract with Sadia to sell the sows, and used the money to start constructing the warehouse. He had to apply for a new environmental license to increase the volume of production. The bio-digester installed in 2006 had significantly increased the farm capacity for swine manure management, allowing him to obtain the new license. As already argued, the requirement regarding the capacity of swine manure management functioned as a rule in the activity of swine production, which was contradictory to the environmental rule that requested a minimum storage capacity and area to distribute the slurry. During the year, Paulo was struggling to get the environmental license. In the light of the cycle of expansive learning, the construction of the warehouse and signing of the contract are actions from the phase of **application**. The cycle of expansive learning in Mr Paulo's case is shown in Figure 6.5. The lightened arrow represents the contradictions in the activity.

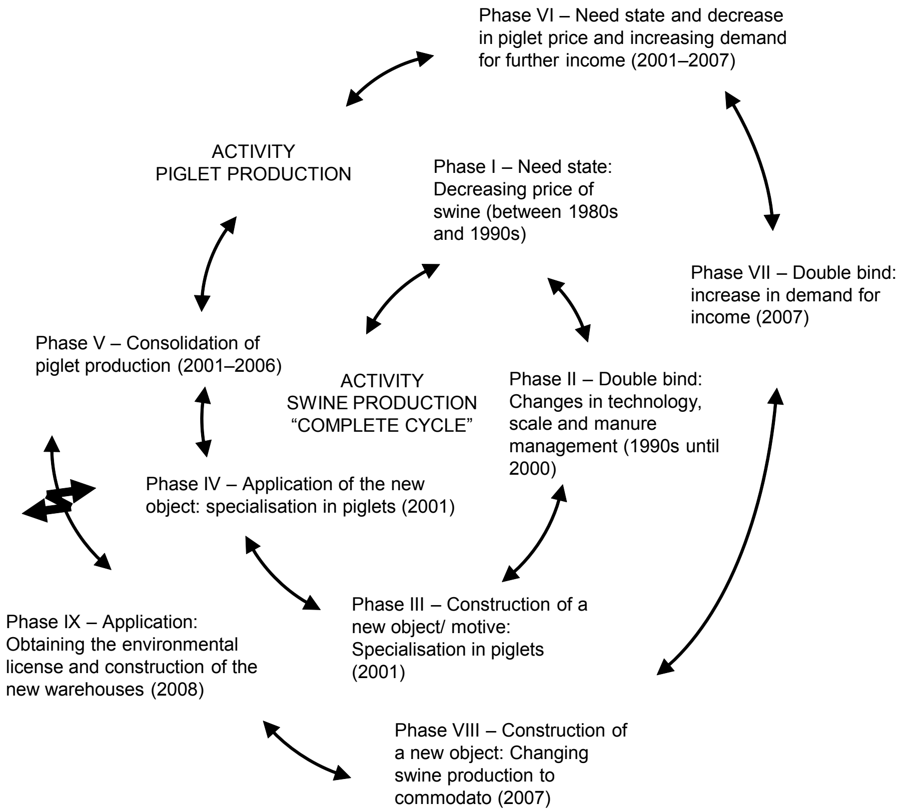

Figure 6.5 Expansive cycle of swine production at Mr Paulo's farm

6.5 Summary of the findings

The result of the analysis of historical development of BP concepts related to swine manure is a two-dimensional matrix. One dimension represents the level of societal integration with the markets, while the other represents the level of functional integration of the products. By combining these two dimensions, four concepts of BP were obtained: BP for energy to be consumed on the farm, BP for multiple products to be consumed on the farm, biogas for a single commodity, and BP for multiple commodities.

Regarding the analysis of the activity of swine production at Mr Paulo's farm, the need for BP already began in the early 1990s as prices for swine continued to decrease. Faced with the contradiction between low prices and the need to maintain income, Paulo increased the scale of production, and specialised in fewer tasks within swine production. In May 2008, Paulo faced a limitation in swine manure management capacity. This limitation is understood as a manifestation of a contradiction between the new object (specialised and large-scale piglet production) and the old unsatisfactory system of manure management. This contradiction was exacerbated by further specialisation, concentration and increase in volume of production. BP entered the picture as a potential tool to improve swine manure management, and to make it possible to continue the process of specialisation and increase in scale. In other words, BP is not a solution to the double-bind, but part of the process of increasing specialisation, which is the new broader object.

Regarding the analysis of the swine-based food production chain, BP was also related to the intensified contradiction between the increase in scale, specialisation and concentration of swine production, and their respective environmental impact. As this contradiction grew, society took measurements to control the problem by creating new rules. Such rules were either market rules, such as consumer and investors' appreciation of companies that were socio-environmentally responsible (later on replaced by the concept of sustainability) or legal rules such as environmental legislation. To resolve this contradiction, Sadia expanded the object of swine production towards environmental sustainabilityby creating the 3S Programme, in which BP played an important role. BP was supposed to reduce the negative social and environmental impacts caused by the swine manure, while farmers could invest in improving their social and environmental living conditions by using money from carbon credits production. The concretisation of the new expanded object required a new division of labour within Sadia, the Sadia Institute, which was formed in order to coordinate and implement the 3S Program, and therefore facilitate the expansion.

From 2004 until the last data collection in May 2008, the activity of sustainable swine production was in the phase of implementation. During the implementation several operational problems and challenges emerged. Managers were having difficulties identifying technologies adapted to small-scale production, writing the PDD and certifying the carbon credits. I hypothesise these current problems as expressions of contradictions between elements of the old production and the new sustainable production

To sum up, in this chapter I have presented hypotheses of the current developmental phase and the role of BPfS in the Sadia food production chain. The analysis shows that integration between BP and swine production is crucial for the expansion of swine production towards environmental sustainability. The next empirical chapters investigate the actual practices of BP. In Chapter 7, I further analyse the question of integration between BP and swine production, and whether or not there was a new more expanded object on the outsourced farms. I expect that some farms integrated BP with other activities while some did not. Moreover, I also analyse whether farmers see the relation between BP and the environmental sustainability of their farm. In theoretical terms, my aim is to assess whether farmers are conscious about the relation between biogas and the actual secondary contradictions. I shall proceed by further analysing the current disturbances, ruptures and innovations to assess whether they are related to the proposed contradictions.

7 ACTUAL EMPIRICAL ANALYSES OF BPfS IN THE SADIA NETWORK OF OUTSOURCED FARMS

This chapter focuses on what actually happens at the grass roots level of the production of biogas. It reports on two actual-empirical analyses of the system of BPfS on Sadia's outsourced farms. The purpose of the analyses is to further understand the contradictions proposed in Chapter 6, their specific content and how they were expressed in everyday actions. First, I analyse the sense of being involved in BP for Sadia outsourced farmers and the Sadia food industry, that is, how farmers and Sadia's staff perceived the relationship of BP with their activity. Second, I analyse the disturbance processes within BPfS.

7.1 Analysis of the sense of being involved in BP for farmers and the Sadia food industry

A common problem experienced during the implementation of BPfS in the Sadia food production chain was that farmers and Sadia technicians were not taking the actions that were considered crucial for achieving sustainable outcomes. One of the explanations given by engineers was farmers' lack of motivation to take care of the BP equipment. In Chapter 6, I hypothesised that these problems were expressions of a tertiary contradiction between the new and old forms of swine production. This section delves more deeply into: the actors' subjective view of the relationship between BP and the activity they are involved in; swine production on the farms and Sadia's food production business. I use the concept of *sense* of being involved in BP to depict this subjective relationship. I have analysed the farmers' and the Sadia staff's sense of the current actual use and the expected future use of BP. According to the analysis in Ch 6, BPfS was supposed to be a tool for solving the contradiction between increasing production and environmental protection. The analysis of the senses of being involved in BP of the actors will test this conclusion and enrich it. The sub-questions to be explored are:

a) How were farmers and Sadia staff using BP in their activities?
b) How did they perceive the importance of BP?
c) What were their future expectations concerning BP?

The analysis uses data from documents and interviews conducted in 2006, 2007 and 2008. The results concern senses of the actual use of BP and expectations of farmers and the food processing company Sadia, followed by an interpretation of the results and the discussion of the above-mentioned questions.

The first step in the analysis was to identify discourses in which participants talked about the importance or usefulness of BP. By reading and listening to the data I found two kinds of discourses: one was about the importance of BP for others; the other was about the importance of BP in one's own activity. The first was a kind of repetition of what they had heard from others. I divided the discourses into these categories using indicators such as whether the person used the first or third person pronouns (I, me, we us) or here, or the third person (they, them) or there. I considered it important to differentiate between these two kinds of discourses regarding the importance of BP because people might acknowledge that BP was important for the society but not act accordingly because they do not see it as important for their activities and purposes.

When farmers and Sadia's staff referred to the importance of BP for others, they seemed to be referring to the benefits or advantages of BP in general for society. These might or might not include the benefits and advantages they saw in their own current or expected future use of BP. Although the perception of the general societal meaning of BP is important in terms of sustainability in general, it does not help us to understand the motives of real people as subjects of specific activities.

7.1.1 Farmers' actual and expected future use of BP

The analysis identified nine main ways farmers used biogas production (Table 7.1). The analysis is based on 11 interviews conducted with farmers while visiting the farms. The uses and expectations of use are here discussed in relation to specific artefacts or sub-products of BP and do not necessarily mean that the use is limited to the specific artefact or sub-product discussed.

The most acknowledged benefit of BP was the improvement in swine manure management. In total, 10 of the 11 interviewed farmers acknowledged the benefit of BP in improving the surrounding conditions of swine manure management, a use that I call **BSMM**, bio-digester for improving swine manure management. The sense of this benefit was rather homogeneous among the farmers. They acknowledged that BP reduced flies and odour. The anaerobic open lagoons produced a smell of putrefied egg, which was considered undesirable; a problem which was aggravated in the summer when the high temperatures increased the emission of methane and other gases. Mr Omar and Mr Fabio mentioned that before BP, the neighbours usually complained about the odour, but with BP there had been no further complains. Mrs Neli mentioned that the slurry without digestion impregnated the hands and would take several days to wear off. Mrs Neli did not yet have a bio-digester, but according to what she had seen from the neighbour's digester, the odour in the ending slurry from the bio-digester was much less offensive. This benefit facilitated handling of the slurry and improved working conditions.

The second most acknowledged benefit of BP was the improvement of the quality of the end slurry as a bio-fertiliser. The nutrients composing the manure were transformed into forms that could be easily absorbed (or become available) by the plants. In other words, BP produced an excellent source of fertiliser. This had at least two senses. For farmers who did not have agricultural fields (7 of 11 farmers), the improvement in the chemical properties of the slurry meant an increase in the demand for the slurry, and a reduction of costs to dispose of the slurry, a benefit that I call **FertCoR**, fertiliser for cost reduction in uploading and distributing the slurry. Usually farmers had to pay a considerable amount of money for having the slurry removed every 60 days. With the improvement of the quality of the slurry, some neighbours came to the farm to pick up the slurry free of cost to use in their agricultural fields as fertiliser. This meant a reduction of operational costs in swine production. The demand for slurry during the planting season was so huge that farmer Lino was thinking of selling slurry in the future as well. Among the farmers who had other agricultural activities, such as maize production or grazing, the bio-fertiliser had the direct sense of a fertiliser, which I refer to as **FertAgr**, fertiliser for reducing costs in other agricultural activities on the farm, as they were used to replacing the chemical fertiliser. This was the case on 2 of the 11 farms. The result is interesting in two respects. It indicates that, depending on the activities on the farm, the same sub-product can have a different sense. For farmers without agricultural activities, it meant simply cost reduction in swine production, while among farmers with agricultural fields it meant a bio-fertiliser, a cost reduction in the other agricultural activity on the farm. The low level of acknowledgement of this second sense of the bio-fertiliser is related to the fact that only a few farmers had a demand for bio-fertiliser On their farms. Most of the producers received the swine food from Sadia, and did not need to produce maize.

The third most acknowledged benefit of BP was the reduction of investment cost in a new open tank (6 of 11). The bio-digester tank was financed through the Sadia Institute and would be paid with carbon credits. Thus, the bio-digester was constructed at almost no cost for farmers. These farmers acknowledged that the bio-digester reduced the need of investing in a new storage tank, increased the storage capacity and allowed further expansion of swine production (**BCor**, bio-digester for reducing investment costs in larger open tanks). Five of the 11 farmers acknowledged the importance of the bio-digester in increasing their capacity for storing slurry (**BStor**), and allowed further increase in the volume of swine production; this was the current case for four of the farmers: Paulo, Francisco, Elmo, and Omar. In Paulo's case, the bio-digester allowed him to obtain an environmental license, which he would not have obtained without the bio-digester because of the already large number of animals. Also for him the bio-digester was a way to increase the volume of production.

Another sense of being involved in BP was to satisfy technicians (3 of 11 farmers). I refer to this sense as **BTec**, bio-digester for satisfying the technician. When asked about the importance of BP, some farmers answered that they had joined the programme because my interpretations is that BP was a way for farmers to maintain their image, as well as a good relationship with Sadia's field work technicians in order to continue swine production or even to receive favours.

Regarding the use of BP as a source of energy, 8 of 11 farmers were interested in using biogas energy either on their own farms or by selling it in the market.

However, only Mr Fabio was already using biogas. This gap between actual use and expectation is interesting, as it shows not only the differences in the installation of the bio-digester among the farms but also the existence of barriers for using biogas energy of biogas such as the unavailability of biogas use technologies. The most important expected use of the gas was on the farms; 5 of 11 farmers were expecting to use the gas as a source of energy on their farms (**GasErg**, biogas for energy to be used in other activities on the farm).

Mr Fabio, the only farmer interviewed using biogas, was using it to heat his chicken warehouse during the winter. On his farm, biogas had replaced the rather expensive natural gas bought from the market. His use of biogas led to a considerable cost reduction during the winter. Mr Fabio constructed the technology needed on the basis of advice given by researchers from Embrapa, a public research centre. Mr Marcio and Mrs Neli were interested in using the gas for heating the chicken warehouses, but they were not yet using it. Mrs Neli's reason was that the bio-digester was not yet ready, while for Marcio the limitation was a lack of technology. He had heard about a possible technology, but was not sure whether it was efficient and reliable. In general, farmers who produced chickens had a strong desire to use biogas because of the significant costs of fuel during the winter. Another intended use of biogas was heat for piglets during the winter. Mr Paulo, for example, estimated that he spent around R$ 360 (US$ 211) per month on electricity for piglets during the winter months (3 to 4 months). He searched for technologies to using biogas instead, but they were too expensive, around R$ 25,000 (US$ 14,700), and the availability of gas during the winter was uncertain. Mr Omar expected to be able to use biogas in the future, but had no idea of how. He expected that Sadia would find a way of using biogas and provide it to the farmers.

The second most important expected use of biogas (3 of 11 farmers) was to sell it outside the farm as a source of energy (**GasMark**, biogas for market as an extra source of income). In 2008, Mr Fabio was installing an electrical generator to supply electricity to the local electrical company. Mr Lino was expecting to sell the gas to a company that was interested in producing electricity for sale. In all three cases, the sense of being involved in BP was to increase farming income. Only Mr Marcio expressed interest in obtaining money from carbon credits as a motive for joining the programme (**CC** biogas for carbon credits).

What does Table 7.1 tell us? First, it tells us that all of the farmers interviewed were using or expecting to use BP. Most of the farmers acknowledged the benefits of BP as a way to manage the manure, though in different ways. Several farmers expected to use biogas. Most of them were expecting to use it on the farm to reduce costs, while others expected to sell it in the market (for example, as electricity) and earn an extra income. Based on these findings, we can say that farmers acknowledged the relationship between BP and their environmental challenges, as well as the reduction of costs in swine production, and the opportunity for extra income that it promissed.

Second, in comparing the actual use with the expectations, two issues can be highlighted. Farmers were already using BP to improve their swine manure management, though in different senses for different farmers. Most of the still unfilled expectations were related to the use of biogas. The gap between actual use and expectation regarding BP as a technology of waste management existed because some bio-digesters had still not been installed during the field work visit. The gap between actual use and expectation regarding biogas use was related to the lack of technology available and uncertainty whether the technology worked, or whether there would be enough gas during the winter.

Table 7.1 List of actual use and expected use of BP by famers

	B Stor	B Tec	B Cor	B SMM	Fert CoR	Fert Agr	Gas-Mark	Gas Erg	CC	A	E
Mr Paulo	A		A	A	A			E		4	1
Mr Francisco	A		A	E	A	A				4	1
Mr Fabio			A	A			E	A		3	1
Mrs Neli		A		E	E			E		3	1
Mr Pedro		A		A	A			E		3	1
Mr Elmo	A			A						2	0
Mr Frei	E			E		E		E		0	4
Mr Ugo		A		A	A					3	0
Mr Lino			A	A	A		E			3	1
Mr Omar	A		A	A				E		3	1
Mr Marcio			A		A		E	E	E	2	3
Actual use	**4**	**3**	**6**	**7**	**6**	**1**	**0**	**1**	**0**		
Expectations	**1**	**0**	**0**	**3**	**1**	**1**	**3**	**6**	**1**		

BStor = Bio-digester for storing manure, and adjusting the farm to the environmental legislation;
BTec = Bio-digester for satisfying Sadia's technicians;
BCor = Bio-digester for reducing investment costs in open tanks;
BSMM = Bio-digester for improving swine manure management (such as odour and flies);
FertCoR = Fertiliser for cost reduction in uploading and distributing the slurry;
FertAgr = Fertiliser for reducing costs in other agricultural activities on the farm;
GasMark = Biogas sold in the market as extra income;
GasErg = Biogas for energy (heating, fuel or electricity) to be used in other activities on the farm;
CC = money from carbon credits as extra income.
A = Actual use, E = expected use

7.1.2 Actual use and expectations of BP at Sadia

I analysed ten interviews with key informants: the initial consultant from Company Sigma, the coordinator, engineer, operational manager and field work technician from the SI, two engineers from Sadia, the regional manager responsible for the area of swine production at Sadia, and two field work technicians (advisors). Moreover, I also made use of documents, such as Annual reports, guidelines and the plans of the 3S Programme. While listening and reading the data, I found two lines of discourses regarding the importance of BP for Sadia. One line, which was emphasised by SI staff, greatly emphasised benefits such as reduction of pollution and GHG emission. In contrast, the Sadia staff working in the industrial department tended to emphasise the benefits and advantages to the swine production business. SI staff emphasised the increase in Sadia's social and environmental sustainability, while Sadia food processing company staff emphasised cost reduction and the adjustment of the farms to the environmental legislation, which guaranteed the supply of raw material. Such difference in response may be attributed to the different objectives of these two groups, and their specialisation in different aspects of the object.

But why was Sadia, a profit-aiming company, interested in helping farmers? The coordinator of the programme explained that by reducing GHG emissions and the impact of the swine effluent, Sadia could guarantee consumers products that took the environment into consideration. The coordinator considered herself responsible for the company's sustainability, since adjusting the farms to the environmental legislation would allow a supply of raw material to the food industry. In addition to this aspect, the coordinator also acknowledged the importance of expanding the market. This second motivation was much more strategic for the company, and represented the opinions of the top administration. This may explain why more space was devoted in Sadia's annual reports to sustainability and the 3S Programme.

According to the operational manager of the SI, who was also the environmental manager of Sadia, BP and the 3S Programme were ways to make swine production more sustainable, and guarantee a long-term supply of meat. As the engineer explained, the current environmental and economic situation of the farmers were leading to a reduction in their number and threatening the long-term supply of raw material to the food industry. The same opinion was shared by the other SI engineer.

According to Sadia's production manager, the main importance of BP was to reduce the environmental impacts of swine production and improve the environmental issues on the farms. Swine manure management and the environmental legislation were two of the main barriers for the further expansion of swine production in the region, and BP was a partial solution to assure an economically viable supply of swine to the food industry. However, there were still limitations regarding the area of land for distributing the end slurry. Thus, other solutions were needed; to reduce the volume of the slurry and allow it to be distributed more widely; or to increase the area for distributing the slurry; or even a completely different technology that eliminated the slurry.

The main expectation was that the BP in the 3S Programme would provide extra income for the farmers, and help them reduce production costs by using the biogas in farming activities, and/or selling it as electricity or other commodity; in addition, money could be obtained from carbon credits. The increase in farmers' income as well as cost reduction would raise the income from swine production (though indirectly), and reduce the constant pressure on price (Table 7.2).

Table 7.2 Actual uses and expectations of BP for the Sadia food company

Artefact	Actual uses	Expectations
Bio-digester	• To improve work conditions of farmers and keep farmers producing swine • To adjust the farms to the legislation and maintain supply to the food industry • To increase storage capacity and allow further expansion of production	
Biogas		• To increase farmers' income by reducing production costs by the use of biogas as a source of energy, and selling it as a commodity
Carbon credits		• To provide extra income for improving environmental conditions of the farms, and increase the income of farmers; this could reduce the pressure on the price of the swine and make swine producers more competitive
Sustainability indexes	• To use the 3S Programme in the Annual reports as an example of sustainability for consumers and investors, and therefore keep and expand markets	

The table shows that the expectation was that the use of the biogas would reduce farmers' costs, and the use of carbon credits would increase their income. The resulting increase in their economic sustainability would reduce the pressure to raise the price of swine.

7.1.3 Senses of being involved in BP for the outsourced farmers and the Sadia food industry

One important sense of being involved in BP for the Sadia outsourced farmers was the improvement in working conditions in swine production, which was related to the reduction of odour and flies. This meant an improvement in relations with neighbours, and made it easier to handle the end slurry. Another important sense was the reduction of production costs and other activities brought about by the improvement in the quality of the slurry as a bio-fertiliser. In addition being much easier to upload and distribute in the fields, its better quality as a bio-fertiliser increased demand for it by the neighbours, which further reduced the costs of disposing of the slurry, especially during the planting season. For farmers with other agricultural activities on the farm, the bio-fertiliser also meant cost reduction in the acquisition of chemical fertiliser. Table 7.3 summarises the senses of farmers and the Sadia food processing company.

The bio-digester had the benefit of storing the swine manure, and therefore adjusting the farms to the environmental legislation. This could reduce investment costs in a new open tank, or allow further expansion of swine production.

The use of biogas as a source of energy was perceived as either reducing production costs of farming activities (e.g., for heating piglets or chicken warehouses in the winter), or being an extra source of income (using biogas for heating chicken warehouses during the winter and saving money used to buy firewood). Among farmers with no energy demands, some were either interested in selling the gas to their neighbours or producing electricity and selling it to the electric company. Others had no interest in using it at all.

Regarding the carbon credits, the majority of the farmers did not expect, at least in the short term, to earn money from them. Not all the farmers were even aware of the possibility of obtaining carbon credits, and it was not an important motivation for most of them. They knew that the burnt gas would be used somehow by Sadia for paying back the investments made in the bio-digesters. Some farmers recalled that something was mentioned about receiving money in the future from the biogas. The general idea of the biogas was that Sadia would use the money for a period of about 10 years to pay back the investment. Only one of the farmers interviewed was expecting to receive "money" from the burnt biogas earlier.

The farmers' sense could be summarised as: reducing investment and operational costs in farming activities, being an extra source of income, adjusting the farms to the environmental legislation in order to maintain swine production, and satisfying Sadia technicians in order to maintain swine production. The diversity of actual uses and expectations may be explained by the diversity of activities, interests, and knowledge about BP.

Within Sadia, the main senses of being involved in BP were that it would maintain and expand swine production so that Sadia could expand its supply of raw material and its production. At the higher levels of administration the 3S Programme was also intended to expand the company's markets, as it would show that the company cared about the sustainability of its production chain.

Table 7.3 The sense of being involved in BP for farmers and the Sadia industry

	Sense for farmers	Sense for Sadia and SI
BP as a manure treatment technology to treat manure and reduce greenhouse gas emissions	• Improves working conditions (by reducing odour and flies) • Adjusts the farm to the environmental legislation • Allows an increase in production capacity • Maintains good relations with Sadia technicians	• Maintains the supply of swine to the food industry • Allows expansion of the production capacity • Expands markets, and raises the value of market shares of the company
Use of biogas on the farm and for the markets (electricity and money from carbon credits)	• Reduces costs in swine production • Provides an extra income	• Reduces pressure on prices of swine and keeps Sadia suppliers economically viable and competitive

The sense for farmers and Sadia are both complementary and interdependent. Such interdependency is understandable as these two activities were tightly linked. Farmers supplied the material used in the food processing company. Thus, the challenges of farmers were challenges for the industry and vice versa. In general, Sadia perceived the need to improve farmers' economic and environmental conditions in order to maintain a long-term supply. BP was used in both farming and the food processing company as an instrument for expanding production. On the farms, BP increased storage capacity, facilitated adjustment to the environmental law, and in some cases increased storage capacity beyond that required by the law, allowing the future expansion of production. Sadia also used BP as an instrument to expand markets. In this sense, it is possible to say that BP was relatively efficient in dealing with the contradiction between expansion and the limitation of storage capacity. However, BP did not solve the problem of limitation of insufficient land area for distributing the slurry. Other solutions still need to be developed.

Regarding the contradiction between farmers' livelihood and lowering of swine prices, BP was helping to reduce costs in swine manure management, but was still not being fully used as initially expected. With only one exception, biogas was not being used as a source of energy nor to generate extra income for farmers. In this regard, there was still much potential for further use of the gas.

7.2 Analysis of disturbance processes

This section analyses some disturbance processes observed during field visits related to the 3S Programme. These disturbance processes are interpreted and located in a model of the network of activity systems to identify the activities involved in the process of disturbance, as well as the activities that would have to be involved in their solution. Such knowledge may indicate who and what should be done to further develop the BPfS network. The questions addressed in this analysis are:

- What kind of typical disturbance processes were taking place in BP?
- How did they emerge?
- What were the activities involved in these disturbances?

The expected outcome is to identify a set of typical disturbance processes, and the contradictions behind them. For this purpose, I used five main analytical concepts: *disturbance, rupture, innovation and asynchrony*. These concepts describe different kinds of deviations from the coordinated flow of actors' complementary actions proposed in scripts and plans of the activity.

The analytical concepts, the method and the data used in the analysis are presented in Section 5.7 in Chapter 5. I begin with disturbances that could be observed during the field visits in May 2008. I proceed by reconstructing the disturbance process with an analysis of the explanations people gave about the observed events. The explanations are interpreted with the analytical concepts and located at the level of network of activity systems.

7.2.1 Observed disturbances, ruptures, asynchronies and innovations

The first step in the analysis was to identify the typical disturbances, ruptures and innovations that took place during my field visits in May 2008. The visits were audio and/or video-recorded and fully transcribed. I first divided the dialogue into episodes according to the topic of the conversation. Once the observed disturbances were identified, I searched for explanations given by people for these disturbances, ruptures and innovations. The disturbances taking place during the visit are called **observed disturbances, ruptures, innovations and asynchronies,** while those that were mentioned by people are called **reported disturbances, ruptures, asynchronies and innovations** (Section 5.7.1 in Chapter 5). The reported disturbances are presented throughout the analysis of disturbance processes only when they are relevant to an explaination of the observed disturbance. The reported disturbances, ruptures and innovations were commented on by the actors either during the field visit, or during other occasions, such as interviews or informal talks.

I observed in total 17 disturbances, 18 ruptures and 2 innovations. Several other innovations which had taken place either in the past or on farms other than those visited were mentioned. Those innovations are not included here, but rather explored when they are considered to have a causal relationship with the observed disturbances. I classified the disturbances, ruptures and innovations according to their effect on the functioning of the technological system. I identified six types of disturbances: I) failure of the combustion system; II) under production and leakage of gas; III), rusting of metal parts of the bio-digester; IV) deterioration of the flare; V) obstruction of tubes; and VI) explosion of the balloon and other burning accidents. Table 7.4 shows the disturbances observed and where they were observed, as well as a code of reference for identification.

Table 7.4 Observed disturbances, ruptures and innovations

Code*	Description	Farm
Leakage of gas and rusting of metal parts of the bio-digester (I)		
D2	Rusting of the metal fence	Mr Paulo
D4	Leakage of water from the security valve	Mr Paulo
D16	Rusting o the metal parts of the digester	Mr Ugo
D10	Rusting of the fence and metal junctions	Mr Lino
D13	The fence was completely rusted	Mr Antonio
D14	Leakage of gas from the balloon and metal junctions	Mr Ugo
I1	New security valve installed	Mr José
I2	Larger canvas in order to avoid erosion of the solids	Mr José
R1	Farmer did not remove a branch beside the bio-digester	Mr Paulo
Under production of gas and low quality of gas (II)		
D8	Tubes conducting the manure from the swine installation to the digester were disconnected	Mr Marcio Mr José
R4	No money was being received for burning the biogas	Mr Marcio
R5	Biogas was still not being used	Mr Marcio
R6	Farmer was not mixing the manure	Mr Lino
R18	Farmer was not mixing the manure often enough	Mr Paulo
R9	Farmer was not mixing frequently enough	Mr Ugo
Failure of the combustion system (III)		
D1	Failure of the Programmable Logical Controller (PLC)	Mr Paulo
D5	Temperature on the flare was not rising up to 200 degrees during a test	Mr Paulo
D11	Combustion system was not working	Mr Lino
D12	Biogas valve was broken and the combustion system was not working	Mr Antonio
D15	Combustion system (the ignitor) was not working	Mr Ugo
R7	Delay in repairing the combustion system	Mr Antonio
R8	People responsible for repairing the combustion system had not come yet.	Mr Ugo
R10	Delay in repairing the combustion system	Mr Paulo
Deterioration of the flare (IV)		
D3	Flare was dented	Mr Paulo
D6	Flare was rusting	Mr Omar
D7	Flare was rusting and damaged	Mr Marcio Mr José
D17	Flare was rusting very quickly	Mr Ugo
Obstruction of tubes (V)		
D9	Obstruction of slurry tubes	Mr Lino
Explosion of the balloon and other burning accidents (VI)		
R3	Smoking around the bio-digester	Mr Omar
R2	Farmer touched the flare	Mr Paulo

* D = disturbance, R = rupture, I= innovation, and the number is the reference of each of them.

7.2.2 Disturbance processes

After identifying the disturbances, ruptures and innovations, I proceed by describing their disturbance processes, the chain of actions, ruptures and innovations that led to these disturbances and followed them. The process was constructed by combining the observed disturbances with data from interviews and informal conversations with farmers and engineers.

1) Disturbance processes leading to the leakage of gas from and rusting of the bio-digester

The leakage of biogas was a problem for several actors of the activity. It was a problem for farmers because in addition to producing an odour, it also led to the rusting of the metal parts of the system, which increased the maintenance costs (such as replacing the door and the fences), and later to the replacement of the metal junction. From the view point of the SI (SI engineers and the financial administration of the programme), since the gas that leaked was not burnt, in the future it might mean reducing the number of carbon credits that could potentially be obtained, and consequently extending the time for paying back the loan obtained by the SI. Furthermore, the leaked gas escaped into the atmosphere, contributing to global climate change, which the 3S Programme aimed to mitigate. Figure 7.1 shows a rusted metal fence that would need to be replaced soon, and the metal junctions which needed maintenance. Despite these consequences, the leakage and rusting were not considered a serious disturbance for engineers and farmers, but this disturbance is interesting because it reveals some major ruptures in the implementation of the system.

During the visits, I could observe rusting of the metal junctions and fences, and the leakage of gas from the security valve. I interpret these disturbances as belonging to the same disturbance process because they are causally related. Rusting was a consequence of the leakage of gas. Rusting or leaking was pointed out as a problem in four of the seven farms visited in May 2008.

One of the objectives of biogas production was to burn the gas created by wine production in order to reduce the odour and the impact of methane on greenhouse effect. The gas was collected in a balloon and conducted through tubes to a flare that burned the gas, transforming the methane into carbon dioxide, a gas without odour and with a lower impact on the environment. The gas collection and burning was expected to occur without losses. However, biogas leakage was occurring from mainly three places: a) from the security valves (exit); b) from damaged points in the balloon (canvas); or c) from the metal junction that anchored the balloon to the digester's beam.

Figure 7.1 Rusted fence

Disturbance process of rusting of metal parts around the security valve

The disturbance process of rusting of metal parts and the security valve is shown in Figure 7.2. According to farmers and engineers, the most common place where rusting occurred, was in the area around the exit of gas from the security valve (**disturbance**), the reason being that the burning system was not installed until 2008, while most of the bio-digesters were installed in 2006 and 2007. Without the burning system, the gas was released directly from the security valve, leading to the rusting of the metal parts nearby. There were two main causes for the delay in the installation of the burning system (**asynchrony**). The first was a change in the UNFCCC methodology (**innovation**), which in turn changed the rules about the accounting of carbon mitigated with an open flare. In the new methodology, projects using an open flare would be able to account for only 50% of the burnt gas. Engineers had to develop a closed flare and a measuring system in order to keep the project viable and be able to request up to 90% of the methane burnt as a carbon credit. One problem was that the technologies available were adapted to large scale production of biogas, and therefore, the closed flare and measuring apparatus were too expensive to be installed on a small farm. Thus, engineers had to develop new technologies for burning and measuring that could be adapted to small farms. The development of these technologies took several months, causing a delay in the implementation of the burning system. The consequence was that during several months, and in some cases even years, the gas was released directly from the security valve into the air, rusting the fences and other metal parts close to it.

But why did UNFCCC change the rules? As explained in an interview with Sadia's consultant company (Company 3), it was not that UNFCCC intentionally wanted to exclude small farmers; it was an outcome of what he called the paradox of the Clean Development Mechanism (CDM) (Excerpt 7.1).

Excerpt 7.1

> ***Researcher:*** *you mentioned that this new methodology ACM 010 emerged. How will it impact the production of carbon credits from biogas? In the case of Sadia, what was this impact?*
> ***Consultant:*** *Not only in the Sadia case, but for any other business there. It has implications for everybody. The amount [costs] that you are assuming is higher. You will need to spend more money on monitoring. What does it imply? At the end of the day, this implies that you must have larger farms, and the small ones would continue to be excluded. This is what I call the CDM paradox. What is the CDM paradox? At the same time that you want to contribute to sustainable development in an unrestricted and broad way, with these ever more rigid methodologies you exclude a lot of people, basically the smaller and the poorest will not participate, unless you subsidise them. Notice that I am not criticising the method, nothing like that, because I know that these teams have a close relation with the Brazilian society. I understand them perfectly. The problem is not the exclusion of smaller and inclusion of the big farms. The problem with these methodologies is the certification of reduction that is not effectively taking place. So in the end I think that I am mitigating the problem, when in practice I am not. In order to improve the system, it would be needed to be like this: the methodologies would have to become even more rigid. Why? Because otherwise there is no credibility.*
> *(Interview with Joao, 18/05/2007).*

The second reason for the delay was related to the change in the management of the programme. In 2006, the contract between Sadia and its consultant company was broken, and the programme suddenly had noone responsible for managing the implementation. The engineer Jorge, assumed the duty in 2007, months after the installation of the bio-digesters was started (Excerpt 7.2).

Excerpt 7.2

> ***Jorge:*** *When Company 3 left, we had to adjust to that. The project suffered a huge delay... This ... In my opinion I think was what delayed the project completely, because Sadia... Sadia had Katia, Jorge, Alberto and Company 3. Who worked on the same project, and took care of all the documentation. It was Company 3, "okay"? When Company 3 left we were uncovered. We did not have anyone who understood PDD ...Understood PDD, CDM understood, this kind of thing there.*
>
> *What happened? It was not that nobody understood, but we did not understand the operational part of the thing, "okay"? What happened? We*

had to pick up and go on to the market and then learn it, develop it there. Which is what led to this delay, this gap. We were already installing digesters and suddenly, we did not know how to burn the biogas. We did not know how to operate it and all that, right? So this was a really big problem (Interview with Engineer Jorge, 28 May 2007).

But, why did Sadia and Company Sigma break the contract? I have two hypotheses, one based on the explanation given by Sadia engineers and its coordinator, and the other based on the explanation given by a consultant from Company 3. The first version was that Company 3 sold the idea of Programme 3S to Sadia's competitor, Company C food industry. The second version was that Sadia felt it was ready to conduct the project on its own. Selling the project to the competitor was an undesirable action because Sadia had invested a great deal of its own resources in this project (Excerpt 7.3).

Excerpt 7.3

Engineer Jorge: *We had a contract with them and they went there and gave the material on a tray ... which Sadia, Sadia has developed, spent energy, spent its own resources, right? ... At that time the institute had not, we spend Sadia's own money in the project, right? They went there and delivered it to one of our biggest competitors; they even gave our slides used in presentations. Company C (competitor) made presentations on the market with our slides just changed the name, removed... Sadia... They took away Programme of Sustainable Swine Production and replace it with Company C Programme of Sustainable, something like this, you know? ... Then Company 3 got out (Interview with Eng. Jorge, 28 May 2007).*

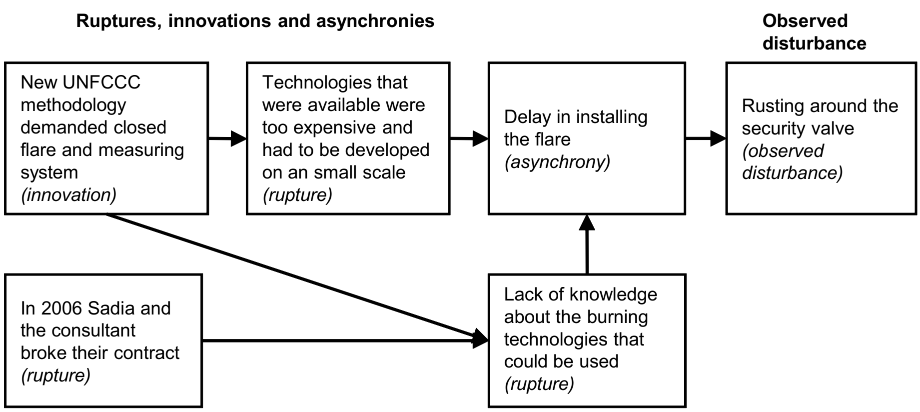

Figure 7.2 The disturbance process leading to the leakage and rusting around the security valve

The disturbance of rusting around the security valve was attributed to the delay in installing the combustion system. The delay was due to the engeers' and planners' lack of knowledge about the burning technology used to burn the gas for obtaining carbon credits, and the lack of ready economically accessible burning and measuring technologies. These limitations were caused by the broke contract with the consultant company and the emergence of new UNFCCC rules, which required closed flares and measuring technologies. The flare and measuring system available at the time were too expensive for small farms.

Location of the disturbance process in the model of the network of activity systems

The network of activity systems involved in the disturbance process of rusting around the security valve is shown in Figure 7.3. The disturbance process started in 2006 with an innovation from UNFCCC (Annex 13), in which new rules were established concerning the number of carbon credits that could be certified from open flare, making it uneconomical for small farms. This rule in itself was the outcome of a contradiction in the object of the UNFCCC, which the consultant called the "CDM paradox". On the one hand, the UNFCCC wanted to contribute to sustainable development in an unrestricted way, including as many small-scale projects as possible. On the other hand, it had to make rules that guarantee the reduction of GHG emissions, which in practice was translated into expensive technologies that excluded small farmers. This is interpreted in the model as an inner contradiction in the UNFCCC's methodology.

The new methodology entered the transitory activity of the 3S Programme as a new rule, contradicting the object of the activity: small scale farms. These new rules were also in tension with the knowledge and technologies accessible to the programme staff. The situation is interpreted as a secondary contradiction in the activity of management of the programme between the new rules and the knowledge that Sadia staff had about CDM and the closed flares, and a tertiary contradiction between the objectives of the management of the programme and the equipment of the measuring systems available in the market. As mentioned, the devices available in the market were uneconomical on the small farm scale. This situation is interpreted as a secondary contradiction between the existing tools (technical devices for burning and measuring) and the object (small scale farms).

The innovation of the rules, and the rupture in the supply of tools (mainly knowledge about CDM and technologies that could be used) led to a rupture in the installation of the flares, which led to the rusting of the metal parts, a disturbance that could be observed on the farms. Thus, the disturbance of rusting of the metal parts around the security valve had its roots in activities other than swine production on farms which had installed BP technological systems.

The analysis of this apparently rather simple and insignificant disturbance (rusting of the metal parts around the security valve), nicely shows the roots of the problem in the network, and the need for network level solutions for sustainable

BP. The central factors behind this disturbance were: (a) a change in the UNFCCC methodology, (b) a break in collaboration between the management of the project and the consultancy, and (c) the lack of adequate tools for burning and measuring.

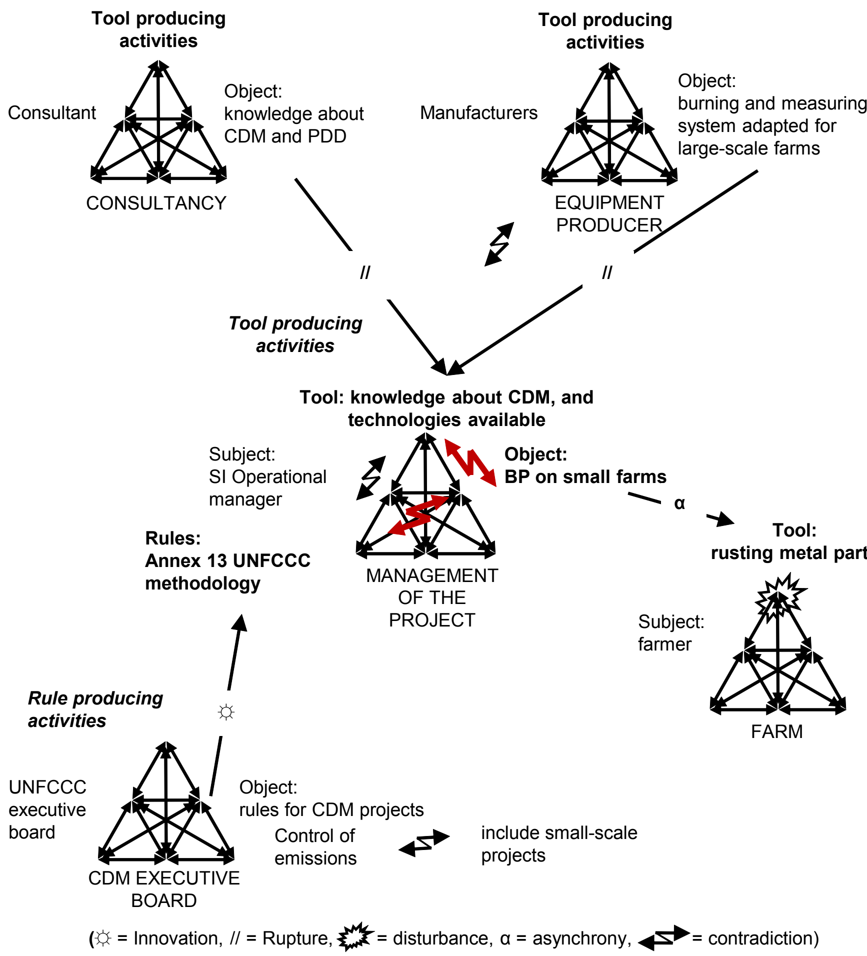

Figure 7.3 Activity systems involved in the leakage and rusting of the security valve

Disturbance process of rusting from the break in the canvas

Another source of rusting and leakage was from the break in the canvas (**disturbance**), which was also considered rather common by the engineer. Although I could not observe it during the field visit, it was reported to have occurred on at least two of the farms visited (**past disturbances**), the farms of Mr Antonio and Mr José. This may indicate that the disturbance was solved, or alleviated in 2008. According to the interview with the environmental engineer in May 2008, the damage to the canvas was explained by the natural expansion and contraction of the bio-digester, or by branches (**hypothetical causes**). In the case of

Mr José's farm, the leakage was explained by the low quality of bio-digester installed. During the visit, I could observe a rupture: the farmer had let branches grow close to the bio-digester (**observed rupture R1**). In this case the branch was too small to cause any damage to the canvas, but according to the engineer, when branches grow close to the bio-digester the wind may cause the branches to break the canvas, as had occurred at Antonio's farm in the past (**past disturbance**). The farmers were instructed by engineers and it was also stated in the guidelines (Document MOB-2006 and MOB – 2008) to keep the surroundings of the bio-digester clean. The farmer explained that he had already cut the branch several times, but the branch grew again. Unfortunately, there is not enough data to speculate why the farmer could not remove the branch. Some hypotheses for why farmers did not conduct necessary operations will be discussed later when I discuss ruptures related to the leakage from metal junctions, and the rupture of not mixing the slurry frequently enough. Another potential cause of breaks in the canvas was rats. This was one of the concerns at Mr José's farm when the engineer discussed the problem of whether to leave the canvas longer or not, because rats could make their nest under it. Unfortunately, I do not have further data about this cause. Thus, it is not theoretically interpreted (Figure 7.4).

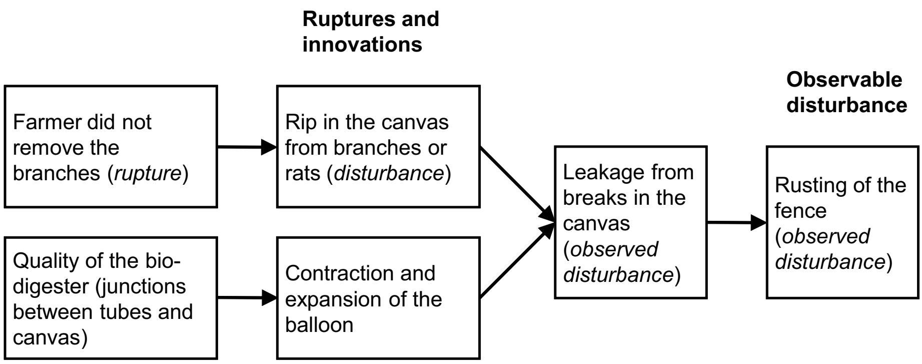

Figure 7.4 Ruptures related to rusting and leakage were attributed to the rip in the canvas

Disturbance process of leakage of biogas from the metal junctions

Another cause of rusting was the leakage of biogas from the metal junctions (D14 and D10). This source of leakages was considered difficult to resolve, as it was related to the inappropriate operation and maintenance of the bio-digesters. During my field visit to Mr Ugo's farm, the SI engineer suggested that this specific problem of leakage was mainly related to overpressure episodes in the balloon. Regulation of the pressure of the security valve was a simple task: the level of water in a bucket simply had to be checked once or twice a week. Thus, the leakage and the rusting from metal junctions were caused indirectly by a) the wrong regulation of the pressure in the security valve, and b) the delay in installing the burning system (**rupture**), as explained by the engineers Jorge and João, in an interview conducted in December 2006. The two engineers were discussing a case of overpressure in the bio-digester (Excerpt 7.4).

Excerpt 7.4

> ***Engineer João:*** *I went there yesterday. It [the bio-digester] was becoming a pumpkin. It was a sign that it had too much pressure.*
> ***Engineer Jorge:*** *He [the farmer] must have a routine to release the pressure of the digester, to release the biogas. This time of the year with the heat... Imagine.*
> ***Engineer João:*** *As we have not yet installed the flares, because what will regulate the pressure of the gas is the flare, right? So we depend on them [the farmers] today. We have a security valve which is installed, a bucket with a certain level of water, but this is not always at an acceptable level. In Irani [name of a town where bio-digesters are installed], there are 4,000 animals. The water level was supposed to be 1 cm, and it was at 10 [cm]. It rained and the water came inside, and the guy [the farmer] did not remove it. When he opened the valve a bad odour came out. But this is an issue for him to adapt to [to the operation].*
> *(Interview with Jorge and João, 28 May 2007)*

The delay in installing the flare was already discussed in regard to the disturbance process of rusting around the security valve. Why did farmers not maintain the security valve? There were three hypotheses for this rupture: a) The farmers did not know that they had to regulate the valve; b) although they knew, they did not know exactly how much water had to be added; c) they knew but did not do it because they did not have the motivation (or time). Hypotheses “a” and “b” are related to the farmers’ lack of knowledge and lack of information, while hypothesis “c” is related to their motivation. The lack of motivation was pointed out by engineers as an important reason why the farmers did not take care of the system, and did not take action to maximise the BP. However, I did not find evidence that this specific disturbance: overpressure episodes, was being caused by lack of motivation on the part of the farmers.

Evidence supporting hypothesis “a” was found in my field notes from the visit to Mr Lino’s farm, where I could observe broken beams beside the bio-digester. According to Lino, the beams broke because of overpressure. As he explained, he was not informed that he was supposed to control the pressure, and how this should be done. The information was not passed onto him when the bio-digester was first installed (**reported rupture**), what led to the breaking of the beams. In Excerpt 7.5 he explained that the bio-digester was implemented, and no information was given that he should have to open the gas valve.

Excerpt 7.5

> ***Farmer Lino:*** *Have you seen these broken beams?*
> ***Researcher:*** *Yes, what is it?*
> ***Farmer Lino:*** *When they did it [the bio-digester]. Just after they did it…*
> ***Researcher:*** *Ah!*
> ***Farmer Lino:*** *They did not give us any information about opening the water here, to open the gas, and they would come back. It had rained a lot. Then felt to inside. It broke the two of them.*
> *(Field interaction to Lino farm, 30/05/08)*

According to the division of labour, the field work technician was responsible not only for monitoring the installation of the equipment conducted by outsourced companies, but also for instructing farmers (Document FRI-2006). According to the field work engineer, he himself had no training in the functioning of the bio-digester. He was a former rural advisor on swine production, and the knowledge he had about the bio-digester was his practical experiences in the programme (Interview with Igor, May 2007).

Another disturbance that may be related to the training of farmers was the explosion of the balloon and burning accidents, which were the most serious disturbances according to all the actors. During the field visits, I observed two ruptures related to this type of disturbance. One disturbance happened on Mr Omar's farm; the farmer was smoking while we were walking around the bio-digester (R3). According to him it was not dangerous because the gas was burning only in the flare. However, according to the guidelines written by the engineers, smoking could lead to an explosion if there was gas leakage. Another observed rupture occurred during the visit to the farm of Mr Paulo. He touched the flare while the gas was burning (R2). This action did not lead to consequences during the visit because the temperature of the flare was still low, but it could have caused severe injuries if the flare had been hot (it can reach up to 900°C). In these two cases the farmer did not know why it was dangerous to touch the flare or to smoke around the bio-digester (**rupture**).

During my field visit to Mr José's farm, he asked the engineer, Iara, about an explosion of a bio-digester used by a Sadia outsourced farmer in the city of Xenxere. According to Mr José, the explosion occurred while the farmer was removing the slurry from the bio-digester, and the explosion was caused by a spark from the tractor. He had heard that the farmer had been severely burnt and he had lost the tractor. According to Iara, the burns were minor, and the explosion probably occurred because the farmer was smoking while doing the operation. According to Iara, it was unlikely that a spark came from the tractor. The tractor was quite far away from the bio-digester. However, one could not be sure about the causes because the farmer was alone during the episode. In this case, a box of cigarettes was found close to the bio-digester. If the farmer had been found guilty, he would have had to pay for the damage using his future carbon credits.

Ruptures of inappropriate operation of the gas and risks of accident have been pointed out since 2006 in the report of the field work engineer, Igor, and my first interviews in December 2006. Engineers were worried about farmers who were experimenting with burning the gas without the required precautions, as the engineer, Silva, explained in Excerpt 7.6.

Excerpt 7.6

> ***Engineer Alberto Silva:*** *We started installing bio-digesters on a larger scale on the farms, and the farmers saw that gas burning day and night, and they started having wonderful ideas, right? And accidents almost happened ... He forgets that this is a thing that is mobile, that the wind swings the balloon and the flame is sucked in.... The guy puts a tube an lights a fire at the end of the tube. Then the swing of the balloon sucks the flame inside the bio-digester. Things like this have happened, strange, isn't it? .... Then the balloon explodes, and he says: "the balloon exploded, I do not know why." You know things like this. This is why we created guidelines, to see if it helps to diminish these problems.*
> *(Interview with Eng. Silva, December 2006)*

To deal with this kind of disturbance engineers had written guidelines and started conducting training lectures to instruct farmers about the functioning of the bio-digester (**reported past innovation**). Moreover, the engineer explicitly requested farmers to stop using the gas to avoid accidents. However, according to engineer Reginaldo (Excerpt 7.7), despite the training and the recommendations, some farmers were still burning the gas without precaution.

Excerpt 7.7

> ***Engineer Reginaldo:*** *You approach them, you instruct them. You say: "Do this, this will help you"... Then turn your back and they do not do anything. We do it at the beginning [the training lecture]. He signs [a term of agreement]. "Do not burn because it is dangerous". You go back and the guy says: "My biogas is not burning". "What have you done?" "Ah! I burned it" "Have you done the training, why did you burn it? " Because I wanted to burn" So, it is like this. The truth is that the farmer is a veterinarian, the farmer is a doctor, the farmer is an architect; they do everything and problems emerge. It gives us problems. It gives us huge problems. In the last two weeks, Igor and me, we have only responded to problems.*
> *(Informal talk with engineer in the car May 2007)*

The disturbance of explosion and the two observed ruptures were related to actions taken by the farmers without the necessary precautions. The more likely hypothesis is that the farmers did not know about the dangers of explosion or underestimated them. It does not mean that farmers were not trained. According to Excerpt 7.7 some farmers tried to burn the gas even after receiving the training. This suggests that the training and the guidelines were not sufficient tools for helping farmers to realise the risks of bio-digesters.

According to the engineer, more frequent visits and more interaction with the farmers were needed to check how the bio-digesters and the combustion system werw operating. The plan was that Sadia technicians would assume the responsibility of monitoring the system and advising farmers, but in 2006 they were not doing this (Document FR – 2006). The reason was that the operation of the bio-digester and the combustion system were not part of their goals (**reported past rupture**). After some negotiations it was agreed that the industrial department would assume the responsibility once the project was registered by the UNFCCC (Interview with Carlos May 2008).

According to a SI engineer the installation of the automatic systems of burning and pressure control and the training helped to reduce considerably the episodes of overpressure, but they were still relying on farmers when the system failed.

During the field visit to José's farm, I observed that a new security valve had been installed (**observed innovation**). This was an innovation made by the manufacturer of the bio-digester. During the visit the SI engineer, the engineer from the outsourced assembling company and the farmer discussed the new valve and considered that it might be difficult to maintain, and could therefore cause episodes of under or over pressure (**expected future disturbance**).

Another important cause for the rusting of the metal junctions was the lack of maintenance. The bio-digester required frequent oiling and the pressing screws. According to the engineer, Iara, such maintenance should have been done by an outsourced company, but the company had not yet been hired (**rupture**) because the financial administration of the programme had not yet approved the budget. Consequently, the company that would be hired for doing the maintenance service was not yet doing it (Excerpt 1.3 from Section 1.4, Chapter 1). From the financial administrators' point of view, the maintenance costs were too high, about five times higher than the initial estimated value. In addition, there was no income coming in from the carbon credits, as yet, which meant that the money would have to be borrowed.

As Jorge explained, the sharp increase in the cost of the equipment and its maintenance was closely related to the complexity of the new combustion system in comparison with the open flare. As already discussed, these new closed flares and the measuring system were an outcome of change in the UNFCCC methodologies. Figure 7.5 summarises the disturbance process of rusting and leakage from the metal junction

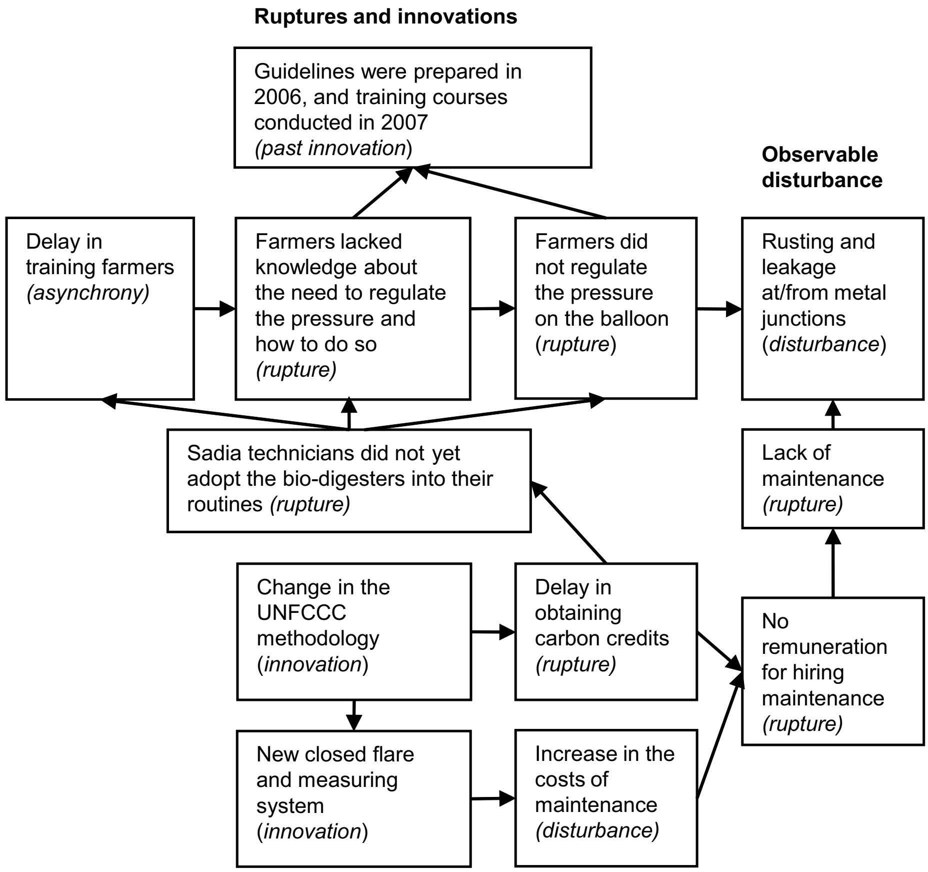

Figure 7.5 A representation of the disturbance process of rusting and leakage from/at the metal junctions

Location of the disturbance process in the model of the network of activity systems

Figure 7.6 represents the network of activity systems involved in the disturbance process of rusting and leakage from/at the metal junctions. Such disturbance was caused by events of overpressure and lack of maintenance (for instance, oiling the junctions). The overpressure was related to the lack of maintenance and farmers' lack of knowledge. Such a situation is interpreted as **a secondary contradiction** between farmers' knowledge about the maintenance of the security valve (at the time of the episodes) and the security valve. Farmers did not receive the training and information about the regulation as soon as the bio-digesters were installed, which is a **rupture** in the activity of advice and training. Such a rupture may be explained by the limited number of staff in the SI for conducting this task, which I interpret as a **secondary contradiction** between the community (staff available) and the object (hundreds of farms). The idea of the project was that Sadia's technicians would assume the task of advising and monitoring farmers about BP, but this was not taking place yet **(a rupture).** I interpret the situation as a

secondary contradiction between the rule that the Sadia industrial department should assume the responsibility of monitoring and training the farms only after the registration of the project by the UNFCCC, and the urgent need for training and monitoring of the already installed bio-digesters and combustion systems.

The **rupture** of lack of maintenance was explained by the fact that no company was yet hired to do the work because the financial management had not approved the budget. I interpret this situation as a **secondary contradiction** between the object maintenance of the technological system and the rule of approval from financial management.

2) Disturbance process of underproduction of biogas and low quality of the gas

The underproduction of biogas was mentioned by Reginaldo, one of the engineers, as one of the main future challenges in BPCC (Table 7.4). Although I could not observe the under production of biogas during the field visits, I could observe ruptures, which in the opinion of the engineer, were causing the problem. Here, I focus on two observed ruptures associated with the underproduction of biogas: the farmers were **not mixing the manure** frequently enough, and biogas was not being used. According to Reginaldo (Interview with Reginaldo, May 2008), these ruptures, among others, were leading to the underproduction of biogas. Reginaldo estimated that the actual production of biogas in 2008 was only one third of the originally calculated amount. According to him, this was because some tasks that were not being carried out at the approapriate intervals.

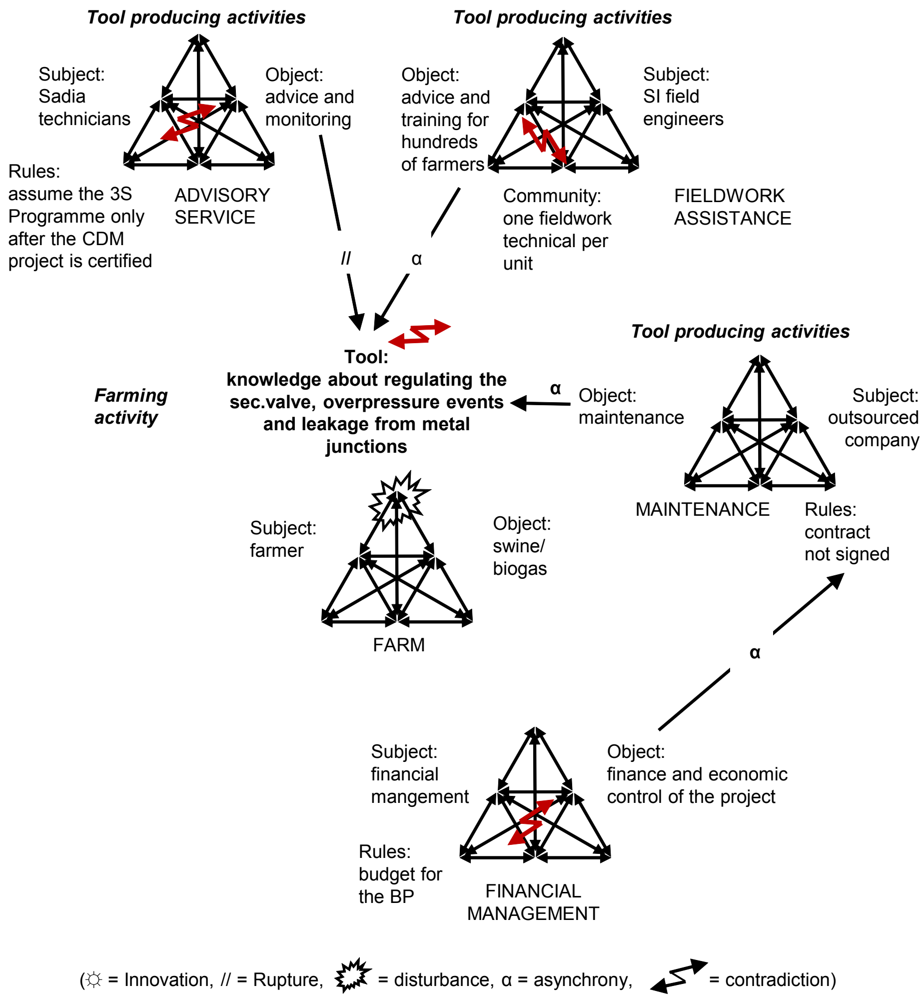

Figure 7.6 Network of activity systems involved in the leakage from the

The low the unfrequent mixing of the slurry could cause an accumulation of solid residues at the bottom of the digester (R6 and R9) (Figure 7.7), which could lead to an obstruction of the bio-digesters if the rupture was not corrected in time. The engineers had predicted that in the third year of the project, they would start having problems with accumulation of solid residues at the bottom of the bio-digester, what could imply opening up the bio-digester to remove the residue with heavy machinery at an undesirable, extra cost to the 3S Programme. Moreover, the low frequency of mixing the residue could lead to lower BP, which could directly imply fewer carbon credits in the future.

One explanation for the farmers not doing the appropriate operations was that they did not know they were supposed to mix the slurry. I could find evidence of this hypothesis in the data from May 2007, but I did not find evidence from the data collected in May 2008. All the farmers that I visited knew that they were supposed to mix the slurry. Unfortunately, I do not have data showing whether the farmers were really doing what they said, or whether they were just answering to comply with the engineers. Even if they did, however, the frequency was still very much lower than the frequency recommended by the engineers. Ugo's reason, for example, was that he did not have the appropriate tools **(rupture)** (Excerpt 7.8).

Excerpt 7.8

> ***Embrapa researcher1:*** *Tell me a little bit about the management of the bio-digester. When we came you said something about the management here, the removal of the residues. Do you do anything?*
> ***Farmer Ugo:*** *Yes, When the tractor comes here, when it comes to remove the fertiliser we always do this exchange [mixing] We remove some from there, then we remove some from the other tube and we put it back here, then we put it into the field. Then we take another from the other exit, and do that ...*
> ***Embrapa researcher 2:*** *And how frequently do you do it?*
> ***Farmer Ugo:*** *Ah, every 60 days. Sometimes the machine comes to remove the slurry, because...*
> ***Embrapa researcher 2:*** *Then every time you remove the slurry, you do...*
> ***Farmer Ugo:*** *I do not have a tractor, so when the tractor comes from the association to take the fertiliser we take advantage of the machine being here and we do it.*
> ***Embrapa researcher 1:*** *It is easier.*
> ***Farmer Ugo:*** *It would be better to do it more, but ...*
> ***Embrapa researcher 1:*** *more times.*
> ***Farmer Ugo:*** *more times.*
> *(Field work interaction at the Ugo farm, May 30 May 2008)*

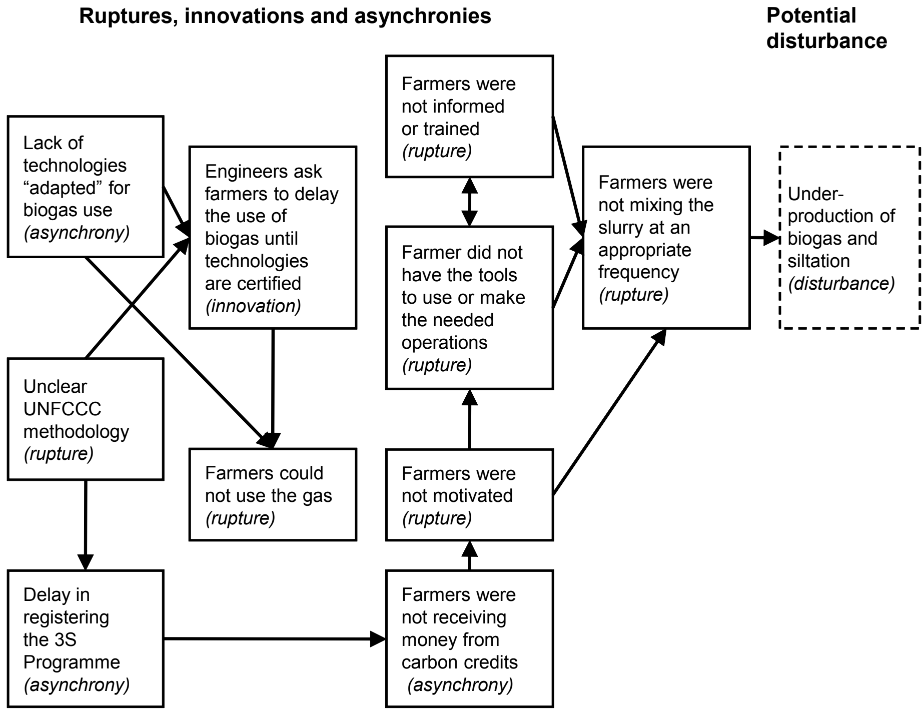

Figure 7.7 The disturbance process of underproduction of BP

According to other field work engineers the general explanation of why the farmers were not taking care of the bio-digester was their lack of motivation, which was related to the delay in using the biogas **(asynchrony)**. This explanation was also shared by the manager of Sadia's technicians (Excerpt 7.9).

Excerpt 7.9

> ***Engineer João:*** *Do you know what the problem is? I see it like this: to keep the farmers motivated and aware that this benefits them. If they lose the motivation, and if they think that it [the bio-digester] is only one more thing on the farm, and that they are only losing time with this, they will leave the bio-digester to become obstructed. They will not clean it; they will not take care of the burning. These are my worries. We are delayed with the generation of electricity from the bio-digesters. Because for them, reducing pollution ... they do not have much sensibility about this. For them, things stay the same. The bio-digester is equipment on the farm. Sometimes it is even an ornament. But if you do not motivate them financially, they will lose motivation and the wish to take care of the equipment. We are also like this, if something does not give me anything back, I do not*

... if people do not pay me a salary, I will leave. So, if we manage to make it viable in a good way, I think we will have fewer problems. But if it does not work ... but I believe that it will work, we will have fewer problems then (Interview with Jorge and João, December 2006).

Mr Fabio case was evidence that the use of biogas affected the farmers' motivation in doing operations to maximise BP. In 2006, he was using the biogas for heating his chickens' warehouse during the winter. He built the heating system himself by adapting equipment for LPG (natural gas) **(innovation)**. The use of heating was viable and was helping him to save money in fuel and time. During the field visit of 2007, in addition to the heating system, Mr Fabio was also installing an electrical generator and pumps to mix the slurry accumulating at the bottom of the bio-digester. To get this equipment, he made a deal with the biogas equipment manufacturers, through which the manufacturers could use his farm to test their equipment and show Sadia's engineers that the equipment worked. If Sadia approved the equipment, Mr Fabio would be able to have the equipment for free. It is possible that if Fabio had had to buy new equipment on the market, it would have not been economically viable.

He mixed the manure daily to maximise the BP. Moreover, he was also interested in closing another open tank in order to capture all the remaining gas from the out slurry. The mixing of the slurry allowed him to have higher production levels of biogas compared with the production of his neighbours.

The lack of motivation of the farmers and the non-use of biogas had been considered a crucial challenge in the 3S Programme since my first data collection in December 2006, and persisted until May 2008. This rupture has been explicitly pointed out as important during interviews with the SI staff and experts in BPCC.

The field work engineer's report from Sep/Oct 2006 shows that some farmers were trying to use the biogas **(innovation)**, but without the appropriate precautions **(rupture)**. In the interview with the engineer, Jorge, I was told that the farmers were being asked to delay the use the biogas until proper technologies could be identified and approved by the institute. According to him, this delay was related to the lack of viable technologies and the UNFCCC rules. Although the UNFCCC methodology did not restrict the use of biogas, the rules were not favourable for using it on a small scale. In practice the UNFCCC methodology had two requirements: a) that the gas burnt outside the flare would have to be measured, which required the installation of an extra measuring apparatus (Interview with Jorge, May 2007), and b) that the information about the performance of the biogas use equipment would have to be provided and warranties on performance would have to be given. The measurer was an expensive device in the combustion system, and was responsible for increasing the fixed cost of using the gas. Moreover, the estimation of the performance required a certification, which also increased the costs per equipment, or restricted the equipment that could be used. These resulted in increasing the costs of using biogas to such a level that it became nonviable on a small farm scale. In practice, until May 2008, no equipment had been certified. Thus, the farmers were not authorised to use the biogas **(rupture).**

During the visit, Pedro (see Figure 7.8) explained to me that they joined the programme with the idea of using the biogas for heat for the chickens. He had in mind one specific technology that he had already seen, and to adapt his current heater from firewood to biogas. According to him, the technology seemed to work and could save money and labour invested in collecting or buying the wood. In addition, it could reduce the pressure on the wood-fire market, which sometimes included illegal wood from protected natural areas. Pedro proposed the idea to the Sadia's engineer, Reginaldo, who denied saying that the technology that the farmer mentioned was still not certified by the manufacturer, and therefore, he could not use it **(asynchrony).** As the engineer explained, Sadia could not allow to the farmers to adopt a technology that was not secure, unviable or of low performance. A certification was needed to reduce the risk of accidents and assure that only safe and efficient equipment was used.

Figure 7.8 Farmer explaining how he would adapt his heating system to use the gas

The security of the equipment was an important argument for engineers to restrict the use of biogas with technologies which were not certified. Legally, the biogas technological system (the bio-digester and the combustion system) was the property of the SI, at least until it was paid through carbon credits. Thus, the SI (and its engineers) would be responsible for damages caused by the misuse of the equipment. The requirement of certification was a way to measure and guarantee a high performance of the equipment, avoid legal and professional risks, and at least partially transfer the responsibility to the institute responsible for the certification.

Safety and high performance were not the only reasons for prohibiting the use of biogas. In an interview with Reginaldo, I was told that in addition to the security issue, there were other even more important reasons for restricting the adoption of biogas use. According to the engineer, good technologies were already available in the market for using biogas but these technologies were usually adapted to large scale use of BP, and were very expensive**.** The SI was searching for technologies for the small scale use of biogas, but so far none had been successful. The production of gas was too small, especially during the winter nights, when some farmers needed most of the gas to heat the chicken warehouses (Excerpt 7.10).

Excerpt 7.10

> ***Reginaldo:*** *You know, it would be very nice. We would really want everybody to have a mini [electrical] generator, or a heating system with biogas. But, for example, if the farmer has chickens, and he has 300 pigs, or 400 pigs, and he wants to use the gas as heat for the chickens, he will not be able to heat anything. He will not be able to generate heat for the animals. With the production that he has, he will not be able to. Why? Because the gas is produced during the day. If there is no system for storing the gas to be burnt during the night, it does not work. It does not work. You will make an investment... Here, André came yesterday. Look, look [pointing to a document]. He was here yesterday. It cost R$ 16 thousand the machine. He is trying; he brought the material to me. There are some reports here for us to analyse and then to certify this equipment to sell to the farmers, but it does not work. (Interview with Reginaldo, May 2008)*

Another point was that allowing the farmers to freely adopt whatever technology they wanted would have increased the administration costs for applying for carbon credits. Even though the technologies would have been certified, highly diverse technologies would have increased the complexity of the project as well as the labour needed to write and validate the project (Interview with Jorge, May 2007).

In order for the engineer to authorise the use of biogas, first, some technologies would have to be certified, and second, an extra measurer would have to be purchased by the farmer. These requirements contradicted the characteristics of outsourced farms, which had a high diversity of needs regarding the use of biogas, difficulties obtaining financing for acquiring the BU equipment, and high diversity of local conditions. Farmers wanted a cheap technology that could fit their local needs. Some farmers, for example, wanted to use the biogas for drying the cows' food; others, for heat for piglets; others, for chickens, or even to sell the gas to a neighbour.

Another potential source of motivation was the carbon credits. According to the financial director of Sadia, the carbon credits would mean a considerable increase in the farmers' income when they received it. Although some farmers knew that they would receive money from carbon credits, they did not know when and how much **(rupture).** Mr Paulo thought that the carbon credits would be used mainly to pay back the investments in the bio-digesters. Ugo doubted that he would ever receive anything, while Marcio and José thought that they were supposed to receive it on a weekly basis. This indicates that farmers were not well informed about when, how and how much money they would receive, and the information did not yet exist as the project was not yet registered by the UNFCCC. Writing and applying for the carbon credits was proving to be more demanding than initially thought, and causing a delay in the registration.

To sum up, the disturbance of underproduction of biogas was related to the lack of a series of operations. On the field visit, I could observe the rupture of farmers not mixing the slurry frequently enough. Three hypotheses were suggested for explaining the inappropriate operation of the bio-digester: a) lack of tools, b) unawareness of the need of mixing, and c) lack of motivation. The majority of the farmers were already informed about the need of mixing the slurry, and they could easily buy a pump or hire a tractor if they wanted. Thus, the most likely hypothesis was the lack of motivation for maximising the BP. The lack of motivation was related to the fact that farmers were neither using the gas nor receiving money from carbon credits.

Location of the disturbance process in the model of the network of activity systems

Figure 7.9 represents the network of activity systems involved in the disturbance process of underproduction of biogas. As argued above, the most likely explanations for the underproduction of biogas were the lack of tools for mixing the manure and the lack of motivation. The lack of motivation is interpreted here as **a primary contradiction**, inherent within the object of BP, between the benefit of producing biogas and its costs (such as time consumed in the operations).

The explanation for the lack of motivation was that farmers were neither receiving money from the carbon credits nor using the biogas. The latter was because there was no certified technology, and therefore, no technology was allowed by the SI engineer. This situation is interpreted as a **secondary contradiction** inherent in the activity system of farming, between the rules imposed by the operational management activity that required biogas-use technologies to be certified and an extra measurer purchased (in case the gas was burnt in both the flare and the biogas-use device), and the technologies currently available, which were too expensive. The rules imposed by the operational manager reflected the need for safe and efficient technologies. The biogas should be burnt in equipment with a known performance and efficiency so that the burnt gas can be counted towards applying for carbon credits. The situation is interpreted as a **secondary contradiction,** intrinsic to the activity system of operational management, between the rules and the object of the management of biogas among small scale farms.

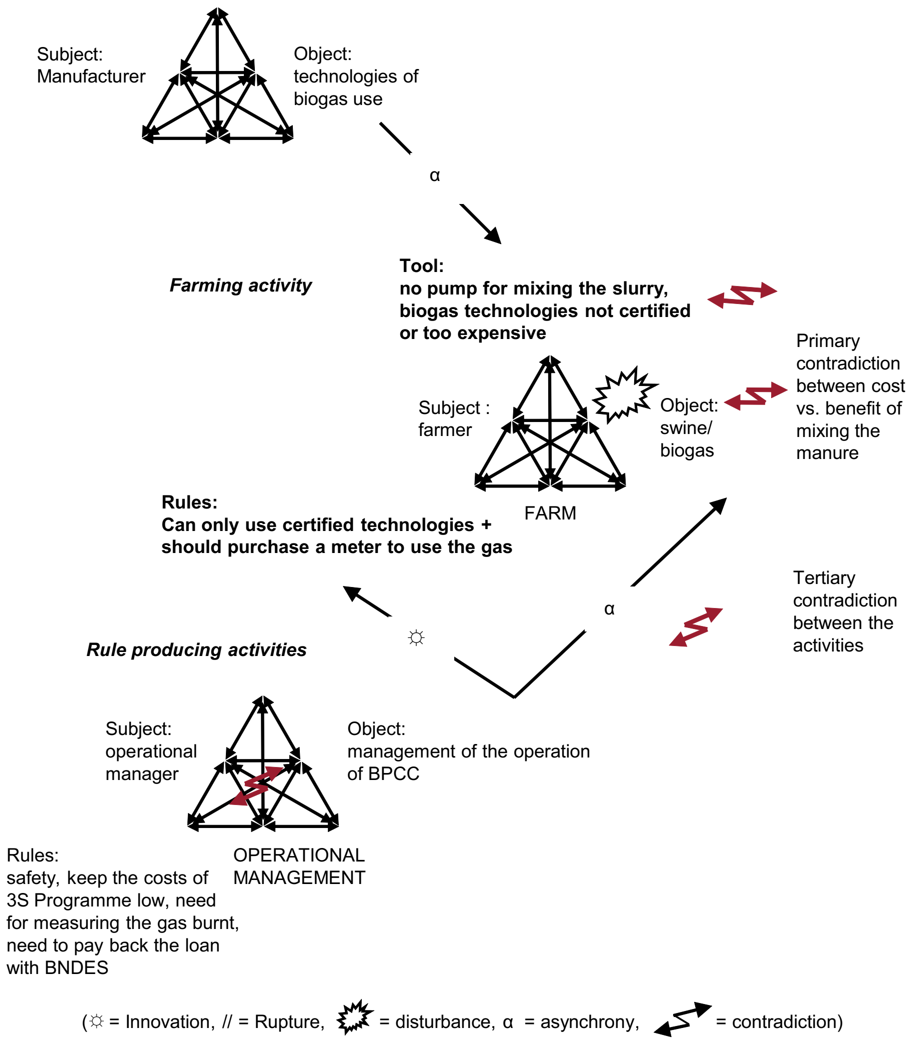

Figure 7.9 Activity systems involved in the disturbance of underproduction of biogas and non-use of biogas

Another reason for not allowing the farmers to immediately use the gas with whatever technology was available was that it would complicate the PDD and the validation process, and increase the costs of writing and validating the project. The engineers wanted the farmers to adopt standardised and certified technologies, which were relatively expensive; while the farmers wanted the least expensive technologies possible not necessarily the most efficient and safe. Thus, the farmers demanded flexible and cheap technologies, while the engineers wanted them to use standardised and safe biogas technologies. I interpret this situation as a contradiction between **centralisation** and standardisation of the technology to reduce costs versus **decentralisation** and flexibility to satisfy the farmers' local needs. This contradiction is represented in Figure 7.9 as a **tertiary contradiction** between the activity of engineers and farmers. To sum up, the main factors contributing to this disturbance were an asynchrony in the development of technologies for biogas use, and the contradiction between centralisation and decentralisation.

3) Disturbance process of the failure on the combustion system and the lack of maintenance

The failure in the combustion system was a relatively common disturbance during the field visits of May 2008, but nonexistent in December 2006 and May 2007, because the combustion system was not yet installed at that time. According to Reginaldo (phone call interview, May 2008), there were problems in the combustion system but he did not consider them a threat to the programme because they could be solved. Nonetheless, I analysed it because in my opinion it could reveal other more important ruptures. Moreover, this kind of disturbance was rather common on the field visits, occurring on four of the six farms visited. The failure in the combustion system was not necessarily a consequence of the malfunctioning of the technological equipment, but could also be a reflection of inappropriate operation of the bio-digester. The following is a discussion of disturbances D1, D5, D11, D12 and D15 (Table 7.4).

On Mr Paulo's farm, the failure in the combustion system was caused by the **malfunctioning** of the Programmable Logical Controller (D1), a device that was installed in each enclosed flare system (Figure 7.10). The PLC was responsible for storing and controlling the data sources (including pressure, temperature and biogas flow). This device operated the system automatically and provided all the needed data about the volume of biogas burnt at each farm. Thus, its failure could lead to the failure of the whole combustion system. On Mr Paulo's farm, the PLC was not responding; consequently the burning system was not working and the gas was escaping from the security valve.

Figure 7.10 Reginaldo testing the PLC at Mr Paulo's farm

According to the engineer, the PLC device was not responding, probably because of an electrical discharge; or possibly because it was already not functioning when it was installed (Figure 7.11). According to the farmer the gas was not burning because the people who installed the flare did not check that the combustion system was working: "*Those who installed it. They left and did not turn it on.*"

Reginaldo removed the PLC and brought another one from Sadia's main office in the afternoon, and tested it. The gas started to burn, confirming a failure in the PLC. This indicated that the PLC installed on Mr Paulo's farm was not functioning, and according to him it had never worked since it was installed. If this was true, it meant that the outsourced company installed the system and left it assuming that it was functioning, and did not come to check it subsequently. As Reginaldo explained, people from the company were busy installing the flares. They had to install hundreds of flares in a short period of time. I interpret this cause as the company's insufficiency of staff and resources to deal with the demand. Figure 7.11 illustrates the rupture, innovation, asynchrony and disturbance involved on the disturbance taking place in Mr Paulo's farm.

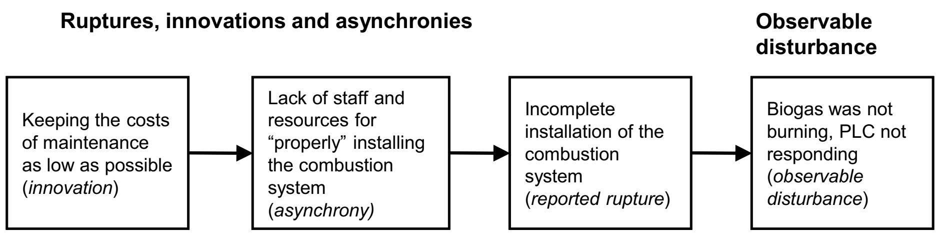

Figure 7.11 The rupture, innovation, asynchrony and innovation involved in the failure of the PLC at Mr Paulo's farm

Another episode of the failure of the combustion system was taking place on Mr Ugo's farm. The gas was not burning because **the ignitor was de-located** (D15) (Figure 7.12). In this case, the causes were not discussed. No further data is available about the preceding ruptures that led to the dislocation of the ignitor.

Figure 7.12 Farmer showing the cause in the loose ignitor of the combustion system

On Mr Antonio' farm the failure in the combustion system was caused by a **breakdown of the biogas valve** (D12). According to Reginaldo, this type of disturbance was related to the quality of the material of the valve (Figure 7.13). The valve that controlled the flow of biogas was made of plastic material which did not resist the force applied during the automatic operation of opening and closing. The broken valves were being replaced by others made of metal. This was a disturbance because it generated the extra costs of replacing the old valves with new ones.

In Mr Lino's farm, the cause of the failure of the combustion system (D11) was not identified. As he informed us, the disturbance had been occurring for a long time. He called the SI to send an outsourced company to repair it, whose conclusion was that the pressure of the balloon was not correctly regulated. This disturbance could have been avoided if Mr Lino had been taught how to regulate the pressure once the combustion system was installed. I discussed the lack of information and instruction earlier when analysing the disturbance process of underproduction of biogas.

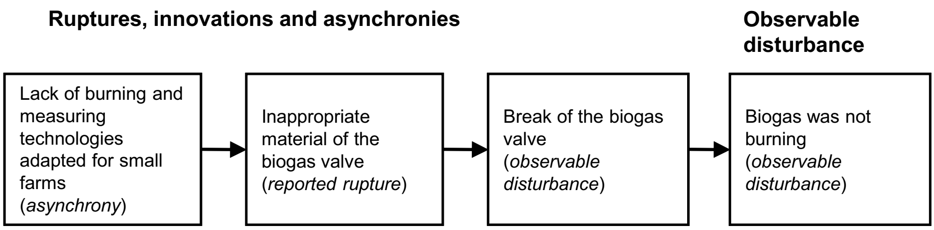

Figure 7.13 The ruptures involved in the break of the biogas valve on Mr Antonio' farm

During our visit to Mr Lino's farm, although the outsourced company had visited the farm and re-regulated the pressure on the security valve, the combustion system was still not working. First it was thought that the bio-digester was not achieving the necessary pressure. However, the pressure increased above 14 mm, which excluded this hypothesis. Another explanation pointed out by the engineer was the quality of the biogas (high concentration of carbon dioxide in the gas), which was a relatively common cause. This was due to the "incorrect" management of the manure before it enters the bio-digester and the incorrect management of the slurry accumulated in the bio-digester. It could be caused, for example, if too much water was mixed with the manure, decreasing the concentration of organic matter. However, this latter hypothesis was also not probable because the ignitor was not starting, which suggested another kind of failure in the technological system not identified during the visit.

There were two hypotheses for the failures in the combustion system: a) the outsourced company was not properly installing the combustion system due to lack of personnel, or other resource limitation; b) the system, which was highly sophisticated with many electronic devices and was developed in a short period of time, still demanded adaptation to the local conditions of the farms, such as the quality of the valve, the fixation of the ignitor.

In the original plans of the 3S Programme and the first guidelines of the bio-digester printed in 2006, the combustion system was simple and cheap, mainly an open flare. This technology was replaced by a complex automatic and electronic system. The complexity of the combustion system was related to the change in the UNFCCC methodology for applying for carbon credits. Both the closed flare and the continuous monitoring sharply increased the costs of the burning system, and complicated it. In other words, the cost of technology increased while the production of gas decreased. The technological complexity of the system was needed to assure that the project was really reducing the greenhouse gases.

Another reason for automatising the system was to avoid the farmers opening and burning the gas; in other words, the engineers were afraid that they would not burn the gas appropriately (Excerpt 7.11).

Excerpt 7.11

> ***Engineer:*** *Do you understand the type of problem that we face in the field? We have to put in an automatic system because of this. We have to take away the responsibility of farmers to open a register, to open a valve to burn the digester. This guy [farmers in general] goes to a party, turns off the digester, then goes away and the gas is not burnt. Do you understand what we face every day?*
> ***Researcher:*** *And why is there this problem? Is it that the producer is not motivated?*
> ***Engineer 1:*** *No, it is not that they are not motivated. The farmer knows everything. The farmer is a veterinarian, the farmer is an engineer, the farmer is a doctor …*
> ***Engineer 2:*** *but he does not!*
> *(Informal talk in the car, May 2007)*

To sum up, the failure of the combustion system was related to the malfunctioning of several of the devices, which was probably related to the complication of the system. The sophistication of the system was explained by the change in the UNFCCC methodology, and the need to automatise the system. Moreover, there were complaints that the outsourced company did not install the system properly. This could be explained by the limitations in the staff and resources for installing the flares and answering calls for repairs. According to the plans, an outsourced company would be hired once the project was registered in the UNFCCC, but it had not been hired yet **(asynchrony)** (Figure 7.14).

Delay of outsourced companies in repairing the combustion system

A rupture that could be observed on most of the farms was the outsourced company's delays in repairing combustion system (R7, R8 and R10). This rupture was leading to persistent leakage of gas from the security valve. As already argued, this caused odour, rusting and contributed to climate change. At Mr Antonio' farm (R7), there was already a delay of 60 days (Excerpt 1.1, Chapter 1).

At the time of my visit, the repairing of the combustion system was being conducted by the outsourced company, Company 2, the same company hired for installing the combustion system. The repairs related to the malfunctioning of the devices were part of the guarantee and no extra costs were required of the SI; on the other hand, the SI was charged for problems caused by inappropriate operation or accidents.

While the bio-digester repair services were relatively fast, the same was not true for repairs of the combustion system. The company hired to install the system was taking a long time to visit farms that had requested the repairing service.

At Paulo's farm, I could observe a delay in painting the flare (D3, D6, D7 and D17). According to the engineers, it was the responsibility of the hired outsourced company to paint the flare, but they were not doing it. The reason was that **the company was too busy**: "*They are too busy, but they will come back and do it. They will first finish installing all the flares, but they will come back.* " My interpretation is that the outsourced company did not have the personnel and resources for doing all the required services on time, and thus, they decided to finish the installation before painting. Such a situation may be temporary, while the combustion system was being installed, and probably the staff currently available would be sufficient for doing the repairing and maintenance after the installation. But the fact was that it was not sufficient at the time of the data collection, because of the need to install the combustion system as fast as possible to obtain the carbon credits on time to pay back the loan.

As Jorge explained, there was a great pressure to keep the costs of the 3S Programme as low as possible so that the loan could be paid back, and still have some money left to return to farmers. The pressure mounted when the methodology changed. In the new methodology (Document Annex 13), the number of carbon credits generated by the project was reduced by 40% of the original calculation, while the costs of the technology and the maintenance of the new equipment increased significantly. Thus, the worries of the financial administration were understandable. It was trying to avoid creating further costs before obtaining carbon credits. There was uncertainty about when and how many carbon credits could be generated.

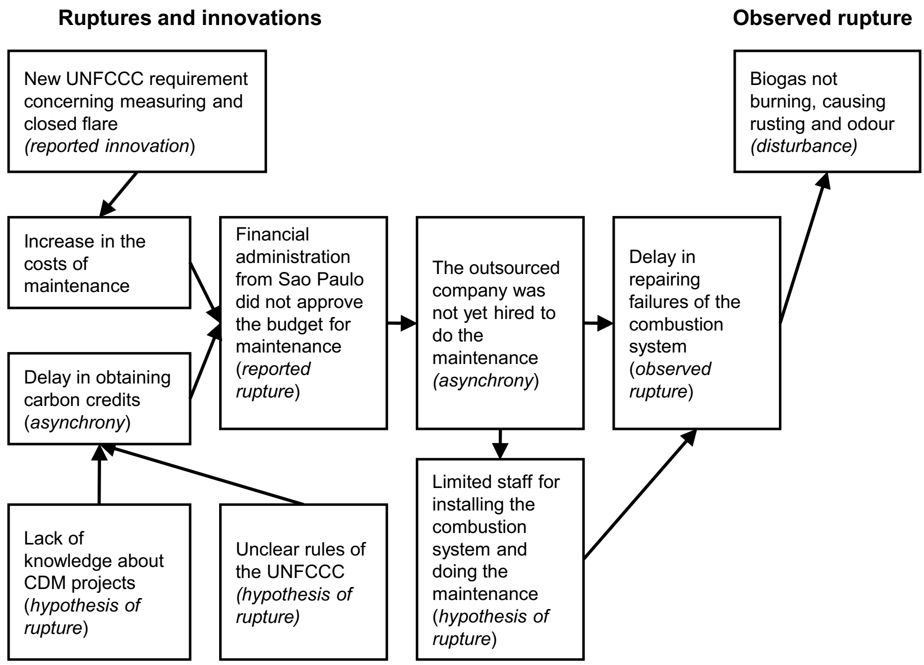

Figure 7.14 Disturbance process of rusting and malfunctioning of the combustion system

Location of the disturbance process in the model of the network of activity systems

Figure 7.15 depicts the network of activity systems involved in the disturbance processes of failure in the combustion system, and their persistence in the three observed cases: the farms of Mr Paulo, Mr Antonio and Mr Ugo. In these cases, the disturbances were either related to the rupture of incomplete installation of the tool (Mr Paulo's farm), or the "quality" (or needed adjustments) of the tools installed (Mr Antonio' farm). On Mr Antonio's farm the break was related to the material used in the valve (plastic), which was not robust enough, while on Mr Ugo's farm the disturbance was related to how the ignitor was attached to the flare. In farming activity, the observed disturbances of failure in the combustion system are interpreted as the expression of a contradiction between the tool and the object. As the engineer explained, such disturbances were common and excepted because the flare and the measuring system were new and still required adjustments. At the farming level, the disturbances seem to be related simply to technical adjustments. However, a deeper look shows that these disturbances are much more interesting because they show the existence of other contradictions in other activity systems. The disturbance at Mr Antonio's farm (break in the biogas valve) was caused by the quality of the material. The plastic biogas valve was selected to reduce costs. This situation could be seen as a primary contradiction inhent in the object of technology production.

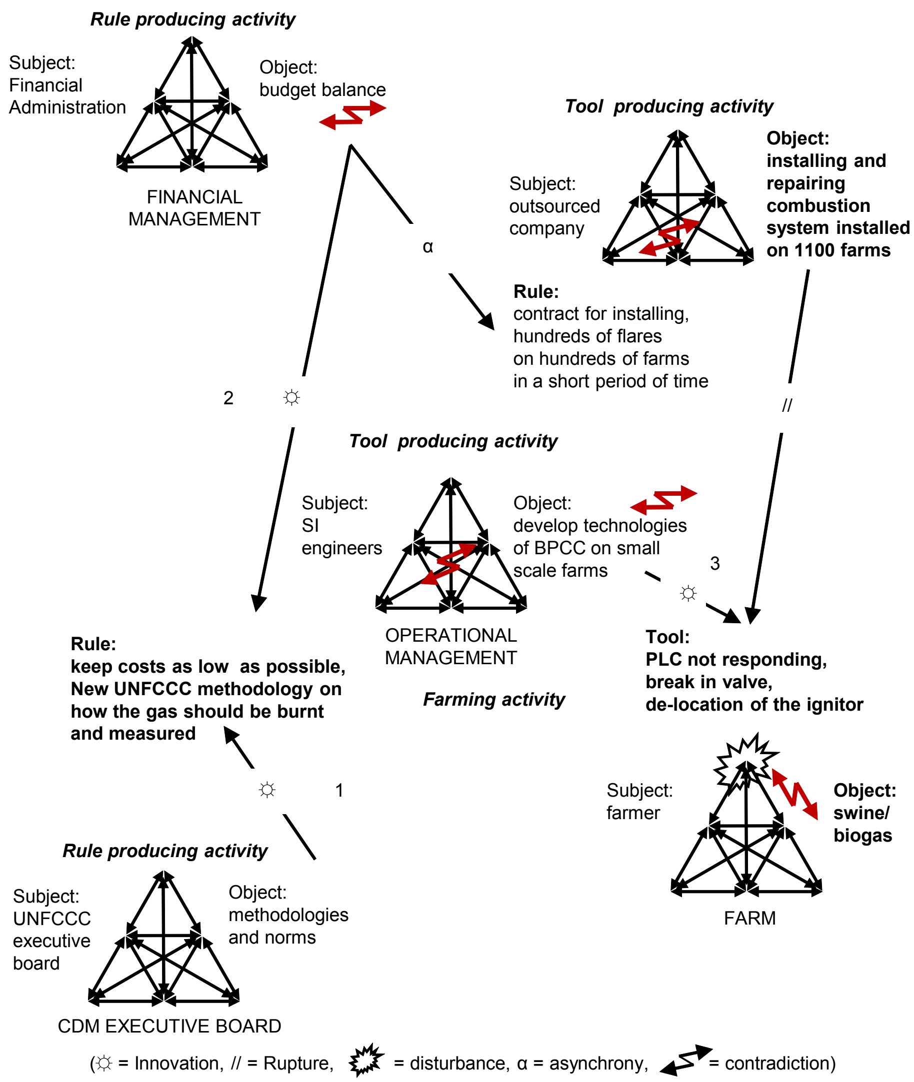

Figure 7.15 The disturbance process of the failure of the combustion system

Engineers' object (combustion system) had a contradictory characteristic: high performance and durability, and as cheap as possible. This contradiction reflects the contradictory rules of this activity. On the one hand, engineers received rules from the financial administration of the programme to keep costs low; on the other hand, they had to follow the UNFCCC rules, which defined the minimal requirements for assuring the credibility of the burnt gas. The combustion system was an innovation that was indirectly "demanded" by the new UNFCCC rules to pay back the earlier investments. The new UNFCCC methodology was an innovation from the point of view of securing the carbon credits. As already mentioned, this innovation was required to make sure that the credited emission reductions were indeed being made. This situation was interpreted as a contradiction within the object of UNFCCC (see the theoretical interpretation of the disturbance of underproduction).

The incomplete installation of the flare can be attributed to the lack of staff and resources in relation to the large number of combustion systems to be installed in a limited period of time. The situation can be interpreted as a **secondary contradiction** between the object (installing hundreds of flares on geographically distributed farms) and the community. The contradiction also reflects a **primary contradiction** within the rules of this activity: standardised services with limited financial resources. The delay in reparing the failures in the combustion system could also be attributed to this contradiction. The company was expected to provide services of maintenance, but it had yet not been hired to do so. This is also interpreted as a contradiction between the rules and the object, caused by the rupture by the financial management activity, which did not approve the budget for hiring the company; this was an **asynchrony** in the implementation plan. The decision reflected the disequilibrium between costs (high maintenance costs) and income (non-income as yet from carbon credits) in the project.

7.2.3 Summary of findings

To summarise the findings concerning the disturbance processes, I use the model of the network of activity systems presented in Chapter 4. Here I present only those activities which were directly involved in the disturbance processes analysed. It may be that other activities could also have been involved, but they were not identified in the analysis. In the network, the outcome of one activity becomes an element in another activity, and a change in one element may, thus, lead to disturbances in another.

The depiction of the disturbance processes in the network of activity systems shows that the conection between the activities did not function as planned, due to a rupture or an asynchrony. Three root sources of disturbances were identified in the analysis: a) the broken contract with the consultancy, b) the change in the CDM methodology from the UNFCCC, and c) the lack of technologies for biogas-use adapted to small-scale farms. These three sources are interrelated but not mutually dependent. The main source of disturbances seems to be the new CDM methodology. It emerged in 2006 when the CDM executive board of UNFCCC launched a new methodology that was much more demanding in terms of bureaucracy and measuring apparatus than the previous one. This event, together with the broken contract with the consultant company, led to a rupture in management of the project, and to a delay in the installation of the burning system. The broken contract with the consultant contributed to the asynchronies as the project was suddenly left without managerial structure. It took about six months for the SI staff to re-organise a new division of labour, and get the project running again in 2007. Consequently, the project could not be validated and registered in the UNFCCC, resulting in a delay in obtaining carbon credits. Without revenues, the financial department of Sadia did not approve the budget and did not hire the maintenance company; thus, the installed system received no maintenance. This led to rusting and delays in repairing the combustion system (rupture). Moreover, as the project was not registered, the Sadia industrial department did not assume the task of monitoring the bio-digester and combustion system, and farmers were not advised about the operation of the bio-digester. Thus, the change in UNFCCC criteria caused delays and asynchronies in the implementation of the project (which started on the basis of the previous criteria) and further to disturbances in the BP.

Another source of disturbances was the lack of biogas technologies adapted for small farms. Although this asynchrony was not caused by the change in the UNFCCC, the methodology had an important negative impact on biogas use, aggravating the problem. The costs for applying for carbon credits (such as writing and validating the project), as well as the need to use certified and reliable technologies, and an extra measuring device; increased the costs for local use of the biogas on small farms. The small farms needed inexpensive technologies, and obtain it in some cases by adapting already available local technologies. The gas burnt in these locally adapted technologies could not be used as a basis for applying for carbon credits, as the equipment was not certified and tested. The non use of the gas was an important reason for the lack of motivation among farmers. Moreover, the delay in registering the project led to a delay in transferring money from carbon credits to farms, and further contributed to the lack of motivation.

7.3 Contradictions between and within the activity systems in the network

The basic methodological idea of the actual-empirical analysis done in this chapter is to elaborate, correct and interpret the hypotheses formulated in the historical analysis in Chapter 6. In Chapter 6, I proposed that BP was part of Sadia's attempt to expand the object of swine production towards environmental sustainability. Sadia was in the phase of application of its new concept of swine production through the 3S Programme. In the new model the object of Sadia's activity was expanded to include the environmental and social impact of swine production. In this new model, BPfS was a technical and financial instrument for expanding the object. Thus, in order for BP to contribute to the expansion of the object of Sadia and the farmers, it needed to be integrated into swine production. The analysis of the sense of being involved in BP confirms the hypothesis that BP is part of Sadia's attempt to expand the object of BP. For the farmers, involvement in BP had a double sense of supporting directly their farming activities and of providing extra income. As an alternative source of income, BP would be a separate and independent activity, while as part of farming, it would be integrated and dependent. Moreover, the analysis also shows that BP was not a fully satisfactory solution for either farmers or Sadia, but would have to be combined with other solutions. BP was not yet being used and no carbon credits were being obtained.

In Chapter 6, I have hypothesised that BP, as part of the solution to expand swine production towards environmental sustainability, was in the phase of application of the new concept. I hypothesised that the contradictions experienced in the current phase were an expression of contradictions between elements of the new and the old activity of swine production. This contradiction was expressed in biogas production as several secondary contradictions. An example is the mismatch between the "old" knowledge of farmers about how to manage the manure and the demands of the new biogas production. Another example is the mismatch between the "old" technologies avaliable on the farms (such as heating systems based on wood fire) and the "new" biogas avaliable.

The UNFCCC methodology and the operational management of the Programme led the transitory activity system of the 3S Programme back to a double-bind phase that called for the re-construction of the BP system. This produced asynchronies in the implementation of the system and to several of the disturbances and ruptures, such as rusting and lack of maintenance. I interpret this situation as a contradiction between the object of transitory activity of the 3S Programme, which was small farms and biogas burning, and measuring technologies available in the market, which were adapted to large farms.

The plan of the 3S Programme was that BPfS would be used as a financial and technical instrument to improve the environmental, economic and social conditions of outsourced farmers, and therefore to make swine production more sustainable. The model predicted that BP would produce carbon credits and be locally used to invest in improving environmental management and the quality of life of farmers. However, in practice, this model seems to be problematic. The production of carbon credits required such sophisticated equipment that undermined the capacity of farmers to use the gas locally. Moreover, the increase in the cost of the project excluded the smallest and poorest farmers. This contradiction became aggravated with the new UNFCCC methodology, which required even more sophisticated and expensive burning and measuring systems. Thus, the production of carbon credits and the local use of the gas seemed to be contradictory. This contradiction explained some of disturbances related to the motivation of farmers to perform operations to maximise BP.

The result of these contradictions was that BPCC was having difficulties in supporting farmers and Sadia to expand the object of their activities. In order to make the expansion possible the contradictions would have to be re-solved, but how? What has to be further developed? These questions are discussed in the next chapter.

8 THE ZONE OF PROXIMAL DEVELOPMENT OF BP FOR SUSTAINABILITY IN THE SADIA FOOD PRODUCTION CHAIN

In this study, I followed the DWR (developmental work research) methodology to investigate the learning challenges of BPfS in the Sadia food production chain. In **Chapter 2**, the object of the study was introduced. Aided by an ethnographic account, I depicted the many activities involved as well as the plans and daily operations of the 3S Programme. In **Chapter 6** I analysed the development of the concept of BP for sustainability and the development of BPfS in the Sadia food production chain. In **Chapter 7** an actual-empirical analysis was conducted aimed at correcting and further elaborating the hypothesis of the inner contradictions elaborated in the historical analysis made in **Chapter 6**. The aims of this chapter are to summarise the findings and to identify the future possibilities of BP in the Sadia food production chain. I also interpret the findings with the matrix proposed in Chapter 6. In doing so, I will construct the zone of proximal development of the BPfS in the 3S Programme and the learning challenges that this would imply for the network of activities involved. I will end the chapter by proposing some expansive actions that could allow BP for sustainability in the Sadia food production chain to overcome the current inner contradictions and to develop further.

8.1 Discussion of the findings of the empirical chapters

8.1.1 The development of concepts of BP for sustainability in the Sadia food production chain

On the basis of the analysis of the development of concepts of BP for sustainability, I constructed a general hypothesis of the zone of proximal development of systems of BP for sustainability (see Section 6.2 in Chapter 6) that I use as a framework for interpreting the empirical findings. Here it is important to point out the difference between the general ZPD of BPfS, which is the framework model in Chapter 6, and the specific ZPD of BPfS in the Sadia food production chain (the 3S Programme) that will be presented later in this chapter. The general ZPD model is used to depict the specific model.

Research question 1 – What are the main dimensions in the historical development of concepts of BP for sustainability?

The main dimensions in the historical development of concepts of BP for sustainability identified in the study were societal integration into the market exchange *and the integration of production. When these two dimensions were combined, four ideal types of BP for sustainability were identified: BP for carbon credits, BP for waste management, BP for local use and BP for multiple markets.*

First, the analysis of the development of BP for sustainability in the 3S Programme (see Section 6.4.3 in Chapter 6) showed that it was an attempt to resolve the aggravating contradiction between the increasing environmental impact of swine production due to its concentration and specialisation, and the degradation of natural resources. BP was a technical and financial instrument to make it possible to diminish the negative environmental impact of swine production and thus to make possible its further expansion. In this way, an important motive for BP was its capacity to diminish the pollutants from swine production. The creation of the Sadia Institute (SI) as well as the implementation of BP expressed Sadia's intention to expand the object of swine production to take into consideration the environmental problems related to it.

Second, the analysis showed that within the cycle of expansive learning of swine production, there were smaller expansive **cycles** related to the specific elements needed for BP for sustainability. According to Engeström (1999b), cycles of expansive learning of activities typically involve macro, meso and micro cycles of expansive learning. Meso cycles are related to major changes in the elements of the activity. These meso cycles can be comprised of several micro cycles of expansive learning actions that may take place within a few days or even hours of intensive collaborative analysis and problem solving. In the case study, the marco cycle of the expansion of swine production lasted several years, while the meso cycles, such as BP for sustainability, lasted from months to years. During the implementation of the concept, several cycles took place during the formation of the structure needed to apply the more expanded object. Some examples of meso cycles within the macro cycle of the expansive learning of swine production were the development of the bio-digester, the development of the combustion system and the foundation of the Sadia Institute.

Third, the analysis showed that BP for sustainability was part of the **phase of application of Sadia's new concept** of sustainable swine production. Based on this hypothesis concerning the current developmental phase of Sadia's swine production, I have interpreted the disturbances observed in the biogas production as the expression of contradictions between the old form of swine production and the new model of swine production, which included the reduction of GHG emissions and the pollution caused by swine manure.

The emergence of the 3S Programme may be understood as due to the increasing interdependence and tightening connections between Sadia and farming activity, a process that may be explained with Marx's concept of the **socialisation of objective forces of production** (see Section 4.3.1 in Chapter 4). Socialisation refers to the increase in the differentiation, specialisation and interdependence between branches of activity, and is promoted by competition and profit making.

In order to increase or preserve the rates of profits, costs have to be reduced and production expanded, which may also expand the unintended and undesirable effects of human activities. The resolution of such "side effects" requires the construction of new instruments, which in themselves require the development of a new network of activities. Socialisation has many advantages, such as increases in productivity and production capacity with lower costs. However, in the case of swine production in Santa Catarina, Brazil, such historical and societal changes in the way of producing swine also led to several negative outcomes, such as the concentration of manure in the area and, consequently, a significant increase in the environmental impact of manure management. There was an increase in the pollution of local rivers and the emission of green house gases. In order to deal with these problems, several instruments were created: BPfS in the 3S Programme was one of these instruments.

Although the farmers own the land and the infrastructure used to produce the pigs, they are dependent on the food processing company, which supplies them with piglets, veterinary services, medicine, technical assistance and feed for the animals. In this new form of division of labour, although it consists of as exchange of commodities, the parties are far from independenc from each other. The progress of the socialisation of swine production in Brazil in the last 20 years has led to an increase in the interdependence of the activities in the food production network. BP can be seen as one aspect of this development. The activities of swine and food production became so interdependent that some of their problems became common. Challenges affecting the farming activity threatened the supply of raw material and consequently also affected the food processing company. This historical increase in interdependence may explain why Sadia had to expand the object of food production to incorporate the impact caused by their outsourced farmers.

I interpret the development of the 3S Programme using the developed framework of the general zone of proximal development of BPfS. The aim is to identify the developmental directions followed by BPfS in the 3S Programme and its possible future alternatives. The development of the concepts of BP for sustainability is depicted in an idealised form in Figure 8.1. The idealised model in Figure 8.1 is a conceptual tool for analysing the operating logics of systems of BP for sustainability. Individual systems such as Sadia's BP system can comprise these purified forms in different combinations in different phases of their development.

In 2003, the Carbon Project (conducted before the 3S Programme) was aimed at obtaining extra income from environmental management activities (2003 – 2004). This project can be located in field 3 because its basic idea was the production of carbon credits as extra income.

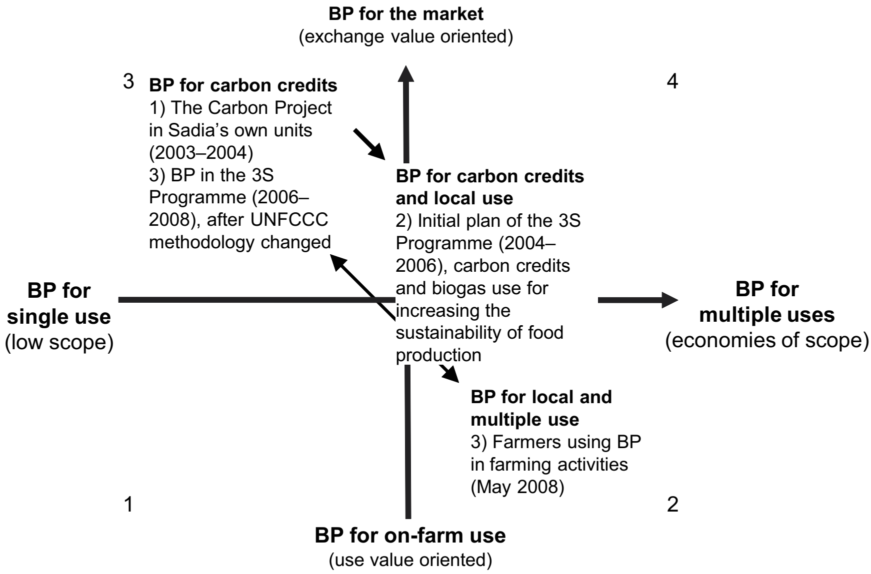

Figure 8.1 The developmental path of BPfS in the 3S Programme

In 2004, Sadia developed the 3S Programme, a new transitory activity for designing and implementing BPfS. The idea of the 3S Programme emerged to combine the production of carbon credits with the local use of biogas for making swine production farms more sustainable. BP in this phase followed a BOOT model, in which a specialised organisation (the SI in this case) was responsible for managing the design, implementation and production of carbon credits. BP in this phase can be located between fields 2 and 3, as it combines local use, carbon credits and a market orientation. In December 2006, the new UNFCCC methodology increased the costs of BP, and it became economically unviable to produce biogas for carbon credits on small farms. Moreover, it became more difficult to use the biogas locally within the farms because of the expensive equipment necessary for measuring and burning the gas. In the light of the developmental dimensions, the new methodology set the 3S Programme back to field 3.

In Chapter 4, I presented three types of community: market exchange, hierarchical control and collaborative communities. These concepts are useful to identify of what kind of community BPfS was and what kind community it should be (see Section 4.3.2 in Chapter 4 for details).

In the Carbon Project BP (field 3 in Figure 8.1), the relationship between Sadia, a consultant and suppliers of equipment was predominately characterised as a market exchange community, in which Sadia bought the supplies, technologies and knowledge from the market. This kind of community was very similar to the "old" swine production, in which the relationship between Sadia, the suppliers, the outsourced farmers and the consumers was mediated by contracts, guidelines, methodologies and so on, being rather fixed and rigid. This type of network seemed to be the most appropriate for producing cheap and highly standardised swine and carbon credits, but was it suitable for the "new" object, a sustainable swine production and biogas for local use?

Having been designed and implemented by Sadia staff, the BPfS in the 3S Programme (phase 2, field 4, Figure 8.1) was characterised as market exchange and hierarchical control types of community. In the 3S Programme, the relationship between Sadia, the SI, the equipment manufacturers and the farmers was also mediated by contracts. The BP system was owned by the SI until the farmers paid for it through the production of carbon credits. Thus, farmers were leasing the equipment from the SI. The market and hierarchical types of network seemed to be necessary to produce and trade the carbon credits, to certify the mitigation of GHG and to increase the scale of production so that the costs could be reduced. However, in practice these types of community seemed to be not enough.

The "new" broader object, a "sustainable swine", which also took into consideration the environment and the social conditions of farmers, seemed to call also for a collaborative type of community. This deficiency became clear, for instance, in the maintenance of the BP system and the development of new technologies. In the 3S Programme, the costs of the maintenance of the BP system by hiring a company increased significantly because of the geographical location of the farms and the complexity of the system. This made it economically unviable to hire a maintenance company to carry out the entire maintenance process: from mixing the slurry to fixing the components. One solution proposed by the SI administration was that part of the money from the sale of carbon credits should be given in advance to the farmers. This solution would be based on a market exchange, where farmers would be hired to do part of the maintenance in return for money. This solution would be effective with the successful trade in carbon credits, which was not yet the case at the time of my study. Because of the uncertainties regarding the UNFCCC's methodologies, it was at the same time still not clear whether carbon credits could be obtained, and even if they were obtained, it was not clear if there would be a surplus that could be transferred to the farmers. Thus, the solution based on a market exchange was not good either. An alternative solution found by the SI engineers was to try to force farmers to carry out the basic maintenance through signing new terms of agreement, but in practice this did not work. It was not even possible to gather all the farmers together in training courses, and even less possible to force them to do the required operations. The contracts were not sufficient to force farmers to carry out the operational tasks. These attempts show that hierarchical control was also not effective.

The object of the 3S Programme was not simply to produce biogas, but to improve the life and environmental conditions of the farmers. The high diversity of local conditions was in contradiction with the standardised managerial and technical tools in use. BPfS seemed to be calling for a **collaborative community** (Adler & Heckscher, 2006). The SI staff perceived that collaboration between the farmers and the Sadia industrial department was crucial for the sustainability of BP. This, does not, however, necessarily imply that it would be the most predominant or the only form of organisation. Rather, it would be a new layer in the relationship already existing between the activities. As pointed out by Adler and Heckscher (2006), in practice all the forms of organisation are necessary, and therefore all should be present in reality.

The need for a collaborative type of community was evidence in the attempt made by SI engineers to try to involve the farmers and the Sadia industrial department in BPfS by making BP more useful. To engage farmers to help maintain the BP system, SI staff (a coordinator and engineers) was searching for new ways to use biogas. Further evidence was see in how the technology for BP use was developed. The avaliable technology for BP use was not economically viable for small farms. An alternative was to develop new technologies in collaboration between manufacturers and farmers. In the empirical chapters, several cases of such collaboration were cited (see Section 6.3.1 in Chapter 6 and Section 7.2.2 in Chapter 7). One of these cases was Mr Fabio, who developed a locally adapted technology in collaboration with Embrapa for using the biogas. Mr Fabio's case seems to be a germ cell of an emerging new type of collaboration in which farmers themselves become active actors in the network and agents responsible for developing and identifying technologies, carrying out the maintenance and maximising BP. Another case was the collaboration between Sadia, farmers and the Embrapa research institute to develop new technologies to complement BP in swine manure management. All these cases are evidence to suggest that a more collaborative form of organisation would be crucial to the development of BPfS.

Additional evidence of the need for further collaboration can be seen in the established platform called Check Meeting, composed of Sadia staff for discussing problems in the 3S Programme, and the coordinator of the SI's idea of creating a platform for discussion between Sadia staff and outsourced farmers for discussing the problems and possibilities of BP.

Research question 2 – How has the object/purpose of BP for sustainability emerged and developed in the 3S Programme?

BP for sustainability in the 3S Programme was an expansion of the object of swine production towards environmental sustainability. BP for sustainability emerged as a solution to the growing environmental and social problem created by the concentration, intensification and specialisation in swine production. This contradiction created a threat to the supply of swine to the food processing company. In the food production activity, the contradiction was expressed as a contradiction between the desire of the food processing company to become "a sustainable company" and the situation in the outsourced farms. For the swine producers the contradiction was expressed in contradictory rules, in which there was market pressure for the further increases in scale, specialisation and concentration to keep the production economically viable, while the environmental rules imposed a limit on expansion.

The idea of BP started when Sadia discovered that they could use BP to obtain carbon credits as an extra source of income. During the implementation of BP within Sadia, the staff discovered that they could also use BP for carbon credits as an instrument to solve the environmental problems of their outsourced farmers. To implement the idea, the 3S Programme was created to design and implement BPfS systems on the outsourced farms. During the implementation, the UNFCCC methodology for applying for carbon credits changed, becoming more rigorous concerning the measurement of the biogas burned. This considerably increased the costs of the equipment, making production on small farms unviable. To reduce costs and to include as many farms as possible, the Sadia Institite's engineers redesigned the technologies of biogas burning and measuring, and continued the implementation process.

8.1.2 Changes in the senses of being involved in BP for swine producers and representatives of the Sadia food processing company

The analysis of the senses of being involved in BP for farmers (Section 7.1 in Chapter 7) showed that all the interviewed farmers acknowledged the improvement in the conditions of work in swine production brought by BP. This improvement reduced complaints from neighbours about the odour and made it easier to handle the end slurry. It also reduced the costs of the disposal of the slurry because it became easier to upload it and distribute it into the fields. Moreover, it increased the demand for the slurry as a bio-fertiliser. For some farmers, the bio-fertiliser also meant a reduction in the need for expensive chemical fertilisers. In addition, the bio-digester had the sense of storing the swine manure and adjusting the farms to the environmental legislation, allowing further expansion of swine production without the need to invest in an expensive, new open tank. Although the farmers expected to use biogas as a source of energy, it was not used for that purpose. The expectations varied among farmers. Some farmers, for example, intended to use the biogas as a source of energy to reduce production costs in farming activities (e.g., heating piglet or chicken warehouses in the winter) or to provide an extra source of income. Most of the farmers were not expecting to receive money from the carbon credits in the next five to ten years.

The sense of being involved in BP for the farmers could be summarised as improving manure management, reducing investment and operational costs in farming activities, providing an extra source of income, adjusting the farm to the environmental legislation to allow the expansion of swine production, and satisfying Sadia technicians in order to continue swine production. In regard to the function that BP played in swine production, the senses of being involved in BP could be summarised as supporting swine production and providing an extra source of income.

Regarding the senses of being involved in BP for Sadia, I found two slightly different senses, one from the SI and the other from Sadia's industrial department.

The SI staff tended to emphasise the improvements in the quality of life of the farmers, the reduction of GHG emissions and the treatment of the swine manure, while Sadia industrial department staff emphasised the benefits for maintaining and expanding the supply of swine. These different senses may be attributed to the different aspects of the object that the staffs from the two groups were dealing with.

It was revealed in the analysis that the senses of being involved in BP for the farmers and for Sadia were rather complementary and interdependent. The farmers supplied the raw material used within the company, and the food processing company consumed the commodities produced by the farmers. Thus, a challenge for farmers was a challenge for the industry, and vice versa. In general, Sadia perceived the need to improve the farmers' economic and environmental conditions to secure the supply of raw material in the long term. The overlapping of senses regarding BP for sustainability can be explained by referring to the historical development of swine production, in which there is an increasing interdependence between Sadia and farming. The tightening of this relation in swine production gives them common senses. BP was an aspect of the increasing interdependence and tightening relationships between the outsourced farmers' activity and Sadia's food production.

BP was, at least temporarily, a relatively efficient way of dealing with the contradiction between the expansion of swine production and the limited capacity for storing the manure. However, BP was still not a sufficient solution because it did not solve the problem of the lack of land for applying the slurry as fertiliser. Further solutions had to be developed. BP helped the farmers to manage the contradiction between income and lower prices in their activity by reducing the costs of swine manure management, but this contribution was rather limited as the biogas was still not used. In general, the biogas was being used neither as a source of energy nor as a source of extra income for the farmers. In this regard, there was still potential for further development of the use of the gas.

Comparing the farmers' actual use of BP with their expectations concerning its use, I conclude that BP was only partially integrated into swine production. There was still some potential to be explored, either for the production of carbon credits and electricity as extra income, or for reducing the production costs in other agricultural activities. The lack of integration hindered the full use of BP for increasing the environmental sustainability of the farms.

I will now locate the different identified senses of being involved in BP for the farmers and Sadia in the matrix developed in Chapter 6 (Section 6.2) to see which of the BP concepts they represent. Figure 8.2 shows the location of the farmers' senses in the matrix of the four BP concepts. Using the BP system as a storage tank for the manure and satisfying Sadia technicians (BStor and BTec) were the most basic senses of being involved in BP at the present time for the farmers. I located this kind of use in field 1 of the matrix because the senses are based on the use of the BP within the farm, and BStor and BTec represent the minimum needs that could be satisfied by BP. All the uses from field 2, 3 and 4 are additional to field 1.

BP was, however, not economically viable merely as a manure treatment technology, and there were other cheaper technologies which were as efficient as BP for this purpose.

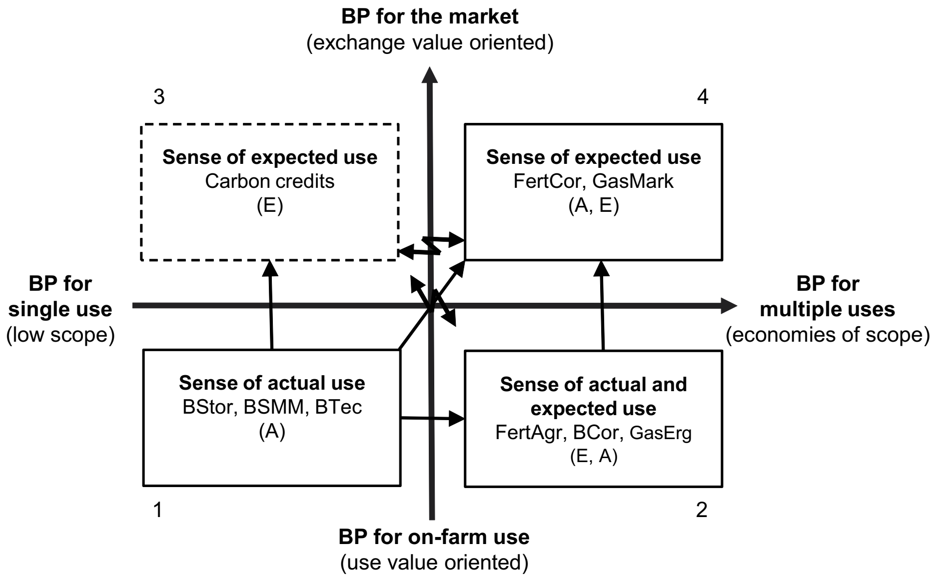

Figure 8.2 The sense of being involved in BP for farmers in relation to different concepts of BP, in which A = actual use, E = expectation of future use. BStor = Bio-digester for storing manure and adjusting the farm to the environmental legislation; BTec = Bio-digester for satisfying Sadia's technicians; BCor = Bio-digester for reducing investment costs in open tanks; BSMM = Bio-digester for improving the swine manure management (e.g., odour and flies); FertCoR = Fertiliser for cost reduction in uploading and distributing the slurry; FertAgr = Fertiliser for reducing costs in other agricultural activities within the farm; GasMark = Biogas sold on the market, as extra income; GasErg = Biogas for energy (e.g., heating, fuel or electricity) to be used in other activities within the farm.

FertAgr refers to the use of the biofertiliser within the farm in other farming activities. This use did not involve an exchange of commodities with other activities outside the farm. In this case, the bio-fertiliser was consumed locally. For FertCor the slury was also consumed as a fertiliser, but on another farm. This practice helped the farmers to reduce the costs of disposing of the slurry. GasErg refers to the use of biogas within the farm as a source of energy, bio-fuel or electricity, while GasMarket refers to the sale of gas on the market either directly as gas or indirectly as electricity. Thus, the main difference between the senses in these two fields is related to who would consume the biogas, whether it was consumed within the farm or outside the farm. Farmers expected in the future to be able to sell the bio-fertiliser to neighbours. The senses in fields 2 and 4 were not mutually exclusive but could be combined. Farmers could use the gas within the farm when they had a demand for it (e.g., in the winter for heating a chicken warehouse) and sell it on to the market when they did not need the gas (e.g., as electricity).

Both carbon credits and GasMar and FertCor were exchanged either for money (e.g., as carbon credits or electricity) or products or services (FertCor). In theory (according to the UNFCCC methodologies and the 3S Programme plans), carbon credits could be combined with other uses of BP. However, in practice such a combination was difficult, especially on small-scale farms. The extra costs for buying the equipment certified for biogas use and an extra measuring apparatus made the production of carbon credits and other uses mutually exclusive options. I interpret this mutual exclusion as a contradiction between field 3 and fields 2 and 4 (represented with a lightning arrow in Figure 8.2). The dotted lines in field 3 denote that the sense of carbon credits was rather weak, as only one farmer mentioned it.

The arrows represent the farmers' opinions on how BP for sustainability should develop in the future. Field 1 was the most basic ways of using biogas. BP is integrated in farming activity in fields 2 and 4, but in different ways. In field 2, BP is integrated with other activities within the farms. In field 4, BP is integrated with other activities outside the farm, but with several products that complement each other. In this field, the sense of being involved in BP is based on economies of scope as the utility comes from combining different functions. As I will argue later, these different senses require different logics of production.

There was consensus among Sadia and the SI staff that BP should contribute to improving the social and environmental conditions of the outsourced farms. However, there was a tension regarding how this should be accomplished. The SI operational manager thought that the first priority should be obtaining the carbon credits so that the operational costs could be paid back, while the industrial department staff and the coordinator of the SI thought that biogas use should be prioritised. I interpret this tension as as expression of the contradiction between the concepts of BP for carbon credits and BP for local use, which will be discussed in the next section.

Holland and Reeves (1997) relate differences in perspectives to ongoing tensions and contradictions within and outside an organisation. They explain the differences in perspective as an outcome of historical contradictions. In BP in the Sadia food production chain, the differences seemed to be an expression of the contradiction between the social and environmental aspect of swine production and the economic aspects. Despite the differences, the main sense of being involved in BP for both groups was to guarantee the supply of raw material and expansion of the production. At the higher level of the administration of the company, the 3S Programme was also intended to expand the market for Sadia by showing that the company cares about the environmental sustainability of its production chain.

My study suggests that people do not need to have the same vision and expectations towards what is being collectively constructed, but what is needed is that the collective object that is being jointly constructed incorporates the needs of the actors. This finding is similar to Grin and van de Graaf's (1996, p. 90) proposition that people can "act jointly provided that an artefact that incorporates these various meanings can be envisaged". This suggests that the "success" of a sustainable technology does not require that everyone has the same motivation. The diversity of perspectives is the outcome of the division of labour within activities and between activities (the societal division of labour), and therefore, this is not only natural but necessary in order for activities to take place. Rather than seeing different perspectives as fixed to individuals or actors, the study proposes that they should be attributed or linked to the tasks and activities in which people take part. Different actors are part of different activities, and therefore have different senses towards sustainable technologies.

The analysis of the senses of being involved in BP shows that important motivations for BP for sustainability were based on the senses in fields 2, 3 and 4, which were not yet being satisfied. The analysis shows what people thought to be the developmental direction of BP, which does not necessarily equate with the future developmental direction of BP. Each of the types of senses required different logics of production. In order to grasp this direction we have to understand further the contradictions in each of these concepts.

Research question 3 – What are the senses of taking part in BP for the swine producers and the representatives of the Sadia food processing company?

The sense of being involved in BP for the farmers can be summarised as improving manure management, reducing investment and operational costs in farming activities, providing an extra source of income, adjusting the farm to the environmental legislation to allow it to continue swine production, and satisfying Sadia technicians to be able to continue swine production. In regard to the function BP played in swine production, the senses of being involved in BP were to support the activity of swine production and to be an extra source of income. Regarding the senses of being involved in BP for Sadia, I found two slightly different senses, one for the SI and the other for Sadia's industrial department. The SI staff tended to emphasise the improvements in the quality of life of the farmers, the reduction of GHG emissions and the treatment of the swine manure, while Sadia's industrial department staff emphasised the benefits for maintaining and expanding the supply of swine. This difference in senses may be attributed to the different aspects of the object that the staffs from the two groups were dealing with. The senses of being involved in BPfS for farmers and Sadia representatives were partially overlapping, which could be explained by the increasing interdependence between their activities.

8.1.3 Contradictions within and between activities in the BPfS in the 3S Programme

In the analysis of disturbances processes, I found disturbances and interpreted them as expressions of three basic types of contradictions (Section 7.3 in Chapter 7):

a) contradictions between the new, more expanded activity of sustainable swine production and the old activity;
b) a contradiction between the concepts of BP for carbon credits and for local use;
c) contradictions between elements of the 3S Programme as the transitory activity of building the BP system.

The contradiction between new and old (a) refers to the cycle of expansion of swine and food production (the macro cycle of expansion). The contradiction between the concept of BP for carbon credits and BP for local use (b) was related to principle of the BPfS, which was aimed at transforming both of the activities of swine and food production towards environmental sustainability. The activities of swine and food production were in the phase of application of the new concept of sustainable swine production, while the BPfS (see Section 6.4.3 in Chapter 6) was in the phase of a double bind. The contradictory elements of the transitory activity of the 3S Programme are related to changes in the elements in the activity, which led to misfits between them (see Section 7.3 in Chapter 7).

The BP for sustainability in the Sadia food production chain was running as planned until two events took place: the UNFCCC methodology changed, and Sadia ended their contract with the consultant. The change in the rules and the division of labour changed the structure in Sadia, and the new structure was inadequate to implement the programme. This made BPfS to return to a double bind phase, while the attempt to expand swine and food production towards environmental sustainability continued. The backwards movement of part of the system can explain the co-existence of contradictions that characterise the implementation phase and contradictions that characterise the phase of the double bind. This movement can also explain the emergence of asynchronies that led to the emergence of several of the observed disturbances and ruptures, such as the presence of rust and the lack of maintenance.

Another source of disturbances was related to a contradiction central to the concept of BP for sustainability applied in the case study: the process for obtaining carbon credits was undermining the process of using the biogas locally. The change in the UNFCCC methodology aggravated this contradiction even more. The new methodology required the acquisition of rather expensive equipment for measuring the gas burned and required certified biogas use technologies that were more expensive than the locally adapted ones, undermining the possibility of using the gas. This contradiction could explain some of the disturbances and ruptures observed, especially those related to the farmers' lack of motivation.

The concepts of BP for carbon credits (BPCC) and BP for local use differed in relation to how BP would contribute to the expansion of swine production. In BPCC, the biogas was transformed into carbon credits, which were traded for money. In this concept, the contribution to the environmental sustainability of swine production is mediated through money, which may not necessarily be invested in swine production. In the second concept, BP is directly used in swine production or another farming activity. In this concept, the usefulness of BP for the environmental sustainability of swine production is based on its use value, i.e. , on its physical properties and consumption. Thus, the BPCC concept is directed to **exchange value**, while BP for local use was directed towards the **use value** of the system (Marx, 1867/1976, p. 126). The analysis of the sense of being involved in BP shows that the senses of the farmers are neither purely monetary nor purely the usefulness of the BP system, but a combination of both.

The analysis shows that most of the disturbances that were observed in the on-farm BP system were formed in other neighbouring activities, pointing to contradictions not only within and between elements of the on-farm BP system but also between other activities. This can be seen as an indication of **tight coupling** (Perrow, 1984) between the activities in the BP network. The delay in obtaining carbon credits led to a delay in hiring maintenance, to the lack of motivation of the farmers and to the rusting of the equipment. Because of the tight coupling between the elements of the BP system, a change in one activity led to a chain of failures in other activities. This strongly suggests that in order to fully understand and solve the disturbances present in the on-farm BP, we must examine a network of activities.

The two actual-empirical analyses suggest that there is a contradictory tendency towards the separation and integration of BP and swine and food production. The analysis done in Chapter 7 gave some general hints on what the elements causing the separation were, e.g., the new UNFCCC rule for burning and measuring the gas, the lack of knowledge about the CDM mechanisms, the expensive biogas use technologies, and the disequilibrium between the volumes of bio-fertiliser produced and used within the farms. The elements that were facilitating the integration of BPCC to swine production seem to be the possibilities of using the bio-fertiliser and the bio-digester for better manure management and to increasing the volume of swine production as well as filling the need for energy source (the gas) for other farming activities .

Research question 4 – How were the observed disturbances, ruptures and innovations related to the structure of the network of activity systems involved in the BP for sustainability in the 3S Programme?

Malfunctiosn in the biogas system, such as rust and leakage, were relatively common disturbances identified during the field visits. Although such disturbances seemed to be merely technical and localised within the farms, the analysis showed that these disturbances as well as ruptures, innovations and asynchronies were formed in and between the activity systems involved in the network of BPfS during its implementation. The disturbances observed can be explained by four contradictions: a) contradictions between the new, more expanded activity of sustainable swine production and the old activity, b) a contradiction between *the concepts of BP for carbon credits and BP for local use in the BPfS that was implemented, and c) contradictions between the new UNFCCC methodology for applying for carbon credits and the small size of the farms, and d) a contradiction between the technologies of biogas use and burning available on the market and the small size of the farms.*

8.2 The zone of proximal development of BP for sustainability in the Sadia food production chain

In Section 4.5 in Chapter 4 I presented the concept of the zone of proximal development (ZPD) as a concept with which to grasp the concrete future possibilities of solving the current contradictions within and between activity systems. The main idea of the ZPD is that an inner contradiction within a system that cannot be overcome at the systemic level can be overcome through changes at the next higher systemic level. In human activity, such systemic levels are individuals' actions, the system of joint activity and the network of activity systems. The expansion implies a movement of the problem-solving process up and down these systemic levels, from actions to activities and networks of activities to systems of joint activity and individuals' actions (Engeström, 2000). By saying that a solution is needed on the next systemic level, I do not mean that the lower levels are not needed. Actually, activities do not exist without actions, just as networks do not exist without activities. What I mean is that certain types of contradictions can only be overcome through structural changes on a higher systemic level that are implemented through changes on lower levels. In the study, the contradiction faced by the farmers could not be solved without actions (e.g., desisting from throwing manure in the river) to change their activity, but neither would they change their farming activities without changes in the collaboration within the network of food production.

The hypothesis concerning the ZPD of BP in the Sadia food production chain summarises and interprets the findings of this study, and is graphically represented in Figure 8.3. The model was first developed in Section 6.2 (Chapter 6) as a general model of the concepts of BP, and is further developed here to reflect the specific case of BP in Sadia. This model is a conceptual construction, a depiction of an idealised and elaborated zone of development of BP in theSadia food production chain. This model should be seen as a hypothesis to be further tested through interventions.

The model in Figure 8.3 depicts two developmental dimensions. The vertical arrow represents the dimension of the integration of BP into the societal network of production through markets. On one extreme, the products of biogas are used locally within the farms, while on the other extreme, biogas products are exchanged on the market. The direction of the arrows from "BP for on-farm use" to "BP for the market" represents a historical trend of the societal integration of BP through market exchange, making the interdependence between activities to increase. The horizontal arrow represents the dimension of specialisation (scale) versus functional integration (scope). In the 3S Programme, this dimension was expressed as the question of whether BP would focus on producing a single product (low scope) or on many products (high scope). The direction of the arrow from single to multiple products represents the movement towards the functional integration of complementary products, and therefore, towards economies of scope.

By combining the two dimensions, I obtained four possible concepts of BP for sustainability. Each of these concepts from Figure 8.3 differs in relation to the object/purpose, and each of the concepts requires a specific logic of production in terms of forms of organisation and tools. The concept of biogas production for waste management (BPWM from field 1) represents the actual developmental phase of BP for sustainability in the case that I studied. In this concept, BP was used basically for managing the swine manure produced on the swine farms. The concept of biogas production for local use (BPU from field 2) represents the production of biogas to be consumed within the farms (e.g., the use of the bio-fertiliser in agricultural production, the use of biogas for heating chicken warehouses) for reducing the operational costs of other activities within the farms. The concept of biogas production for carbon credits (BPCC from field 3) represents the production of biogas for obtaining income either to repay the investments in BPWM or to complement income from other farming activities. This concept involves the certification of production so that the carbon credits could be obtained and traded. The concept of biogas production for multiple markets (BPMM from field 4) represents the commercialisation of several products from BP, such as biogas, bio-fertiliser, heat, electricity and even carbon credits. This option involves trade of the products in nearby markets, such as trade with neighbours, municipalities or local farmers.

The concept of BPWM in itself was not sustainable, as it did not produce enough earnings to repay the investments made in the bio-digesters. Here, it is important to recall that in this study, sustainability refers to both swine production and biogas production. When referring to BP, sustainability means stability across time, while in swine production it means environmental sustainability, which implies the reduction of environmental impacts on natural resources and improvement in the quality of life of farmers and workers (Section 1.3, Chapter 1). To use biogas to increase the environmental sustainability of swine production, biogas production has to be temporarily sustainable (stable). Historically, we have seen that that many biogas programmes emerged and ended because of the lack of economic viability (Section 3.1 in Chapter 3). I argue in this study that the concept of BPMM in field number 4 is the way to keep BP more sustainable so that it can help swine production to become sustainable. BP can become economically viable when its products are marketed in different markets. In order for BPfS to become sustainable, it would have to move from BPWM to BPCC and BPU. BP for waste management was the most basic use of BP and was not the most attractive one, as there were other cheaper ways of treating the swine manure. Most of the concepts could be combined. The concepts of BPCC and BPU involved BPWM, and the concept of BPMM could also involve BPU and BPCC.

Adler and Heckscher's (2006) forms of social organisation help us to understand these four concepts. In the concept of BPMM, there is a combination of collaborative community and market exchange (Adler & Heckscher, 2006) forms of social organisation, while in the concept of BPCC, hierarchical control and market exchange are more predominant. The concepts of BPWM and BPU seem to be characterised by collaboration but not directed towards markets. As Adler and Heckscher (2006) argue, these social organisations are not mutually exclusive but complementary.

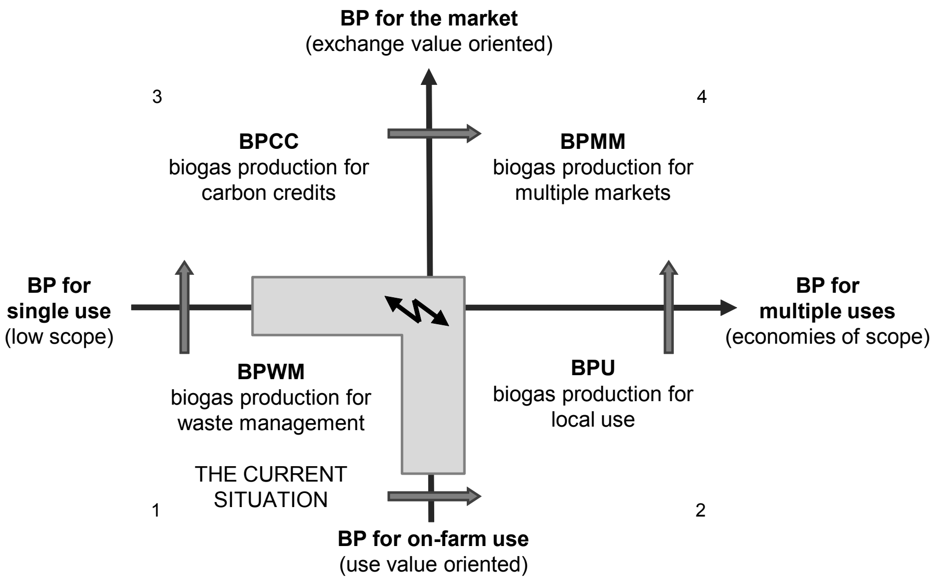

Figure 8.3 The hypothetical ZPD of BP for sustainability in the Sadia food production chain

Learning Challenges in the ZPD

As mentioned in Section 4.5 in Chapter 4, the concept of a learning challenge is a conceptual tool for moving from the analysis of systemic contradictions towards more concrete actions. A learning challenge points to a proximal step in the way of solving the current contradictions within the system. The ZPD presented below is not the ZPD of on-farm BP but the ZPD of the BP system, which means that it concerns the whole set of activities involved, or the activities that would be needed to develop BPfS. In the model presented in Figure 8.3, the learning challenges are represented by the arrows between the fields.

In the study, I pointed out several innovations that the actors were already implementing to facilitate the move from field 1 to fields 2, 3 and 4 (see Section 6.3.1 in Chapter 6 and Section 7.2.2 in Chapter 7). Some examples in field 3 were the development of a cheaper combustion system and measuring apparatus, and the elaboration of as "umbrella" methodology which would reduce the costs of certification and allow the inclusion of more farms in the carbon projects. Some examples of innovations from field 2 would be the attempts of farmers to use the biogas for heating and electricity in chicken production. Examples from field 4 were rather rare, such as farmers' attempts to sell electricity to the local electricity company and the distribution of bio-fertiliser to neighbours.

The identification of the learning challenges presented below is based on a) the actions that were observed (empirical Chapters 6 and 7), b) deductions from the developmental logic of BPfS and c) previous empirical studies on BP, such as the Finnish case (Pereira-Querol et al., 2010). Here, it is important to clarify the importance of combining these strategies in order to determine learning challenges and the ZPD. The ZPD cannot only be based on actions that have already been taken by actors. The ZPD and learning challenges also refer to actions that can be deduced to be possible under new forms of organisation and production. In this sense, the ZPD should not be based only on empirical generalisation, but rather on a theoretical generalisation based on the general historical modes of production. Past experiences, either within the 3S Programme or other BP projects around the world, can help us to make guesses of what the future may look like, but not predict it. In this sense deduction and logic are also important.

Moving from the concept of BPWM towards the concepts of BPCC and BPU involves two main learning challenges. The **first learning challenge** is related to the move from BPWM to BPCC, represented with an arrow between fields 1 and 3 in the model. This learning challenge involves the development of cheaper and more practical technologies of burning and measuring the gas, as well as the reduction of the costs of the process of certification so that small farms could also be included. The **second learning challenge** is related to the movement from BPWM to BPU, represented by the arrow between field 1 and 2. This learning challenge involves the development of new ways of using the biogas within the farms.

The sustainability of BPfS in the case involves both BPU and BPCC, the capacity to repay which would provide investments and to satisfy the needs of the actors involved. BPCC would be able to repay back the investments, while BPU would be able to satisfy the local needs of the farmers so that they would collaborate in the BPCC. The movement to BPCC and BPU has, however, to be synchronised. The delay in using the biogas led to the dissatisfaction and resistance of the farmers and Sadia's industrial department staff from taking actions requested by the SI staff. This was evidenced in the formation of a committee of farmers to oppose the rule that the gas would have to be burned only in the flare. Further evidence is the delay of Sadia's industrial department in assuming the task of monitoring and controlling biogas production. This resistance of the farmers and Sadia's industrial department shows that the actual situation was not sustainable, as it did not take into consideration the farmers' need to use the biogas.

However, these two concepts are contradictory in the sense that the production of biogas for carbon credits requires such a level of sophistication and standardisation of tools that it undermined the local use of the gas on small farms. The production of carbon credits required rigid rules, large-scale production, standardised technologies and centralised administration, while the local use of biogas required the decentralisation of administration and locally adapted technologies. One possibility for solving this contradiction is to develop a concept that is more collaborative and supports the multi-purpose products of BPfS. BPMM could be such a concept. In saying that the concept of BPMM is more sustainable, I do not mean that it is the best choice and that it is the recommended direction for the future of BP. Each of the concepts has their strengths and weakness. What I mean is that this concept would resolve the contradiction between local use and the production of standardised carbon credits. In the case, this was the main contradiction affecting BPfS. The contradiction is represented in Figure 8.3 with the lightened arrow between fields 2 and 3. To solve this contradiction, BPfS had to move towards BPMM from field 4.

In the concepts in fields 1, 2 and 3, BP is part of the farming activity as a tool, an extra source of income or a way to reduce production costs. The concept of BPMM seems to be leading BP to a more independent activity specialised in organising and commercialising the sub-products of BP. The independence of BP in this concept is not related to production, which would probably remain on the farm, but to the specialisation of the actions of organising, marketing and commercialising of biogas products. This process of further specialisation can be understood as a process of socialisation explained above (Adler, 2007). Actually, the transformation of BP from an action within the farming activity towards an independent activity took place in the Finnish case previously analysed by my colleagues and me (Pereira-Querol et al., 2010). In the Finnish case, BP developed from a way to dispose of the manure towards the profitable specialised activity of waste management.

To move to the concept of BPMM, it is necessary first to learn both BPU and BPCC. This leads us to the **third learning challenge**, which was related to the creation of new local markets and networks for selling the BP products. This would imply going in the direction of more varied ways of using BP products than only the production of carbon credits. Learning new ways of using BP on the farms locally would also contribute to finding ways to commodify BP products.

The model of the ZPD proposed here should not be understood as a straight line between the concepts but rather as a zone or area with many options and alternatives. This idea of a zone is depicted in the model as a gray area between fields 2, 3 and 4. In practice, the idea of a zone means that there is not only "one" possibility or best practice but that many kinds of actions can contribute to the development.

In the ZPD, **expansive actions** are needed to move the BPfS in the 3S Programme to another concept. Here I present my interpretation of what concrete expansive actions should be taken to further develop the system. Expansive actions here are not the individual actions of individual actors, but rather the actions of a combination of individuals who are creating new solutions (e.g., cheaper biogas use technology, complementary BP technologies for reducing the volume of the slurry). I base my proposal of actions on my discussions with the actors and the innovations observed in practice.

Regarding learning challenges 1 and 2, the actual strategy of the Sadia engineers for finding BP use technologies was to ask manufacturers to test their products and send reports. However, this strategy had not produced any results during the two years that I followed the programme. An alternative solution was the development of technologies in collaboration between Sadia engineers, farmers, R&D workers and manufacturers. At the time of my research, some on-farm experiments were already being carried out in collaboration between Sadia, researchers and manufacturers. However, farmers were not taking an active role in designing the system in any of these experiments. Only one farmer was developing a technology in collaboration with manufacturers, but in this case Sadia engineers were not involved. It is not enough that the technology is developed on the farm. It is also necessary to involve farmers in the design in order to make sure that the technology is adapted to the farms' local conditions. The constellation of actors that would have to collaborate in the construction of the BP use concept is farmers, Sadia and SI engineers, manufacturers of BP use equipment, and if possible an expert or representative of the activity of producing carbon credits. Such a combination of actors would be able to gather the basic resources and knowledge needed to design a concept that was more likely to be economically viable, to be adapted to the local conditions of the farms and to be combined with the carbon credit "production".

The need for the involvement of farmers in the design of the technologies has been acknowledged by Sadia engineers and was one of the reasons for allowing some farmers to test new technologies on their farms. However, an important challenge in the collaboration between farmers and Sadia would be to make sure that the farmers assume the position of an actor contributing to the development of the system, rather than just its technical infrastructure.

Regarding learning challenge 3, a series of actions would be necessary in order to sell the biogas products to local markets. A new network of activities would need to be created for commercialising such products. Today, the relationship between farmers and consumers of biogas sub-products is rather informal and spontaneous and does not involve the exchange of money (e.g., the distribution of bio-fertiliser to neighbours). However, if we desire that all the sub-products of BP are commercialised, it is necessary that the network is formalised. Moreover, the commoditisation of biogas products for sales in the market would require actions of marketing, such as planning, product standardisation, the creation of a consumer base and so on. The organisation of this new network of consumers of biogas outside the farm and the marketing actions would be a great challenge. These tasks would not be individually possible by each farmer but would rather require collaboration between farmers and some kind of specialised organisation.

Currently there is no such organisation. Market research tools to gather knowledge about the needs of consumers and tools for organising the networks of consumption of biogas products around the farms would be needed.

An organisation purely composed of farmers may not be viable as farmers have limited capital with which to invest and limmited technical knowledge of biogas use technologies and marketing. An alternative would be that the Sadia Institute would be responsible for the organisational and marketing tasks. However, tasks such as these involve a more decentralised form of support to the farms, which is different than the actual support given in swine production. The needed support for developing markets would require a local analysis of the opportunities for each farm. Moreover, such a task would go beyond the tasks of a swine production advisor. These limitations lead us to the need for a specialised organisation that would be responsible for organising the network and planning reasonable and profitable ways of commercialising the biogas products in each area or type of farming activity. Based on the above mentioned, a hybrid form of organisation, such as an association composed of representatives of the farmers, Sadia, the SI, manufacturers of biogas use equipment, potential consumers and public rural developmental institutions would be the most suitable for doing the tasks needed to organise the network of biogas product consumption.

The actions proposed here should not be seen as the only possibilities, but just as hypothetical actions that could help the move towards BPMM. These actions must be further tested though interventions, and other actions would have to be developed in collaboration between the different actors.

Here, I have presented some expansive actions which I considered the most urgent for allowing the further development of BP in the Sadia chain of food production. However, the proposed actions are neither exhaustive nor exclusive. Many other alternatives could be developed, and the ones proposed here could be combined with others as well. As already mentioned, the proposed expansive actions should be seen as hypotheses to be tested in future interventions.

Research question 5 – What are the main learning challenges for developing a sustainable system of BP in the 3S Programme?

Three central learning challenges for developing a sustainable system of BP in the 3S Programme were identified: 1) the development of cheaper and more practical technologies for burning and measuring the gas, as well as the reduction of costs of the process of certification, 2) the development of new ways of using the biogas within farms, and 3) the creation of new local markets and networks for selling the BP products. A general learning challenge involved is to find more varied and synergic ways of using the BP products than only in the production of carbon credits.

9 SUPPORTING LEARNING FOR SUSTAINABLE PRODUCTION IN AGRICULTURE

In this chapter, I will discuss the contribution of this study to the understanding of learning and development for environmentally sustainable agricultural production and the generalisability of the results. First, I will discuss the methodological contributions and then the contribution of the study to solve the contradiction between the efficiency of production and environmental protection. I will continue by discussing its theoretical contributions to the study of learning and development of sustainable agricultural production. Finally, I will evaluate the research process and discuss the lines of future research that this study has opened and how the concept of a *learning challenge* can be used to support collaboration between researchers and practitioners.

9.1 Methodological contributions

9.1.1 Two forms of generalisation and societal problem solving

Traditional research focuses on finding the general laws of how nature, humans or even society works by empirically testing the validity of proposed theories through the statistical analysis of correlations between properties or cause-effect relationships between objects or processes. Generalisation in this type of research is characterised by what Davydov (1990) calls *abstract-empirical generalisation*. Such generalisations of cause-effect relationships can be used as tools to produce expected effects by creating the causes. This type of research is particularly useful when the relationship between the variables and factors are stable and relatively unchanged. However, this approach is limited when the empirical conditions vary and/or the object of the research in itself is under construction or does not yet exist.

In my research, I was interested not only in the properties that already existed, but also in those that could be constructed in the future. In order to accomplish this task, I followed a different research approach, which is based on what Davydov (1990) calls *theoretical-genetic generalisation*. The knowledge produced from theoretical-genetic generalisation focuses on revealing the genetic roots of a phenomenon and the system of functional relationships determining its occurrence and development. The knowledge produced can be used to help practitioners to identify and realise developmental possibilities.

The differences between these two types of research are related to their ontology (the understanding of how the world is and develops). Empirical abstraction is based on what Tolman (1981) calls the "metaphysic of properties" and "metaphysic of relations" ontologies, while the theoretical-genetic generalisation is based on a "dialectical" ontology. Research based on the *metaphysic of properties* is interested in the stable characteristics of objects and their qualities. The main limitation of this ontology is that it ignores the qualities of objects that emerge from relationships (Tolman, 1981:35). Modern science has been based on acknowledging the importance of relationships as crucial for understanding phenomena, and a new ontology emerged which Tolman (1981) characterises as the *metaphysic of relations (e.g., gravitation can only be understood as a relation between two bodies).* In this new ontology, qualities emerge from the relationships between objects. Change and development in this ontology are outcomes of a recombination of objects. These two ontologies share the assumptions that objects exist prior to their relationships and that in this sense relationships are external to the objects. Therefore, it is difficult to explain from the standpoint of these ontologies how new objects and qualities emerge.

In the dialectical ontology, the first assumption is that things do not exist "pre" or without their relations *but* evolve in systems of relationships. In other words, the essence of things is inseparable from and constituted by their relations (Hegel, 1892, cited by Tolman, 1981), and can only be understood in the contexts of developing systems of relationships, movement and evolution. Things are constantly changing and evolving, and do not exist without movement. Such movement and evolution can be explained through contradictions within the internal relationships that constitute things. Development (a higher form of the motion of matter) is a movement that originated in contradictions inner to the developing thing. In other words, development is the outcome of the 'negative' which a thing posses in itself (Hegel, 1969, cited by Tolman, 1981).

9.1.2 The method of ascending from the abstract to the concrete

The philosopher Ewald Il'enkov (1977) has described the method needed to study the emergence of new forms of production.[12] Il'enkov (1982) argued that a new phenomenon arises as an anomaly and an exception:

> *In reality it always happens that a phenomenon which later becomes universal originally emerges as an individual, particular phenomenon, as an exception from the rule. It cannot actually emerge in any another way. Otherwise history would have a rather mysterious form. (Il'enkov, 1982, p. 83)*

Il'enkov (1977) proposes that the task of the study of the whole consists of discovering the initial, genetically earliest, abstract occurrence of a new principle on which the system is based, the "germ cell" of the totality under investigation, that is, a principle realised through a specific configuration of relationships, and de-

[12] Il'enkov's (1977) method is based on the work of Karl Marx (1976) in the book *The Capital.*

veloping it into its full concrete diversity. By "abstract", Il'enkov does not mean something general and common to many objects, but something unique and isolated. The components of a system are related not because they possess the same, identical attributes, but because they contribute to the realisation of the same principle. A new structure and principle that exists first as an isolated, unique case can, however, become general.

To comprehend a phenomenon means to establish its place and role in the concrete system of interacting phenomena in which it is necessarily realised, and to find out precisely those traits which make it possible for the phenomenon to play this role in the whole. To comprehend a phenomenon means to discover the mode of its origin, the rule according to which the phenomenon emerges with necessity rooted in the concrete totality of conditions, it means to analyze the very conditions of the origin of phenomena. That is the general formula for the formation of a concept. (Il'enkov, 1982, p. 177)

The method presented by Il'enkov (1977), the method of ascending from the abstract to the concrete, consists of two processes: first, the reduction of the concrete (the sensual totality that is directly observable) to an initial abstraction (a germ cell, a general principle); second, the derivation of the abstract to a concrete form of manifestation. This method has similarities with other approaches, such as actor network theory, which proposes that innovations are formed through the stepwise construction of networks, which become ever more complex and stable (Knorr-Centina, 1997; Latour, 1999).

This method has been further developed by Davydov (1990: 281–282), who proposes three steps for creating theoretical-genetic generalisations. The first task is to identify the contradictions to be resolved. The second task is to identify a "germ cell" of the phenomenon. Third, the germ cell should be tested by trying to develop it in practice.

To illustrate the method of ascending from the abstract to the concrete, I will introduce the work of Reiner Seidel (1976). Seidel (1976) developed a theory of societal problem solving. He argues that societal changes lead to changes in human activities, which lead to the emergence of contradictions. These are, however, not solved as general problems, but in a local activity, in which the contradiction is aggravated and people experience a need and have the resources to solve it. When the solution is created, it spreads to other activities in which the same contradiction exists.

In a reference to Seidel (1976), in this study the societal problem in which BP for sustainability was embedded was the environmental degradation caused by the expansion of agricultural production. The changes in agricultural production, usually called the "modernisation of agriculture", increased the negative environmental impact of agriculture. There is a contradiction between the increase in the volume and productivity of agriculture, on the one hand, and environmental protection, on the other. This contradiction was aggravated in the activity of swine production in the south-west region of Santa Catarina, Brazil, leading to a crisis that required a new solution. In this specific case, the solution was biogas production for sustainability. This solution may (or may not) diffuse through different forms of agricultural production in which the same contradiction between production versus environmental protection is present.

The generalisation in the theoretical-genetic type of study is not simply the multiplication of a solution or the generalisation of an empirical observation to similar cases, but a process of applying and further developing a new principle in different contexts in which the same general contradiction is present. Thus, the assessment of the generalisability of the results obtained in this study can be divided to in two questions: Did the study produce a germ cell for overcoming the contradiction between intensive agricultural production and protection of the environment? If yes, under which circumstances or conditions can this germ cell be applied and enriched?

9.1.3 Developmental work research as a methodological contribution of this study

Here, I discuss the contributions of the methodology used in this study to the studies described in Section 3.2 in Chapter 3. The methodological contribution of this study is in bringing the developmental work research methodology (Miettinen, 2000; see Section 5.2 in Chapter 5), which is an application of the method of ascending from the abstract to the concrete, to the study of the development of agricultural activities towards sustainability. The purpose of this study has been a) to reveal and describe the development of a system of swine production and its inner contradictions, b) to identify and/or produce a germ cell of a new structure and principle of swine production that can be applied and further developed to create an environmentally sustainable new system of swine production, and c) to produce conceptual tools for researchers and practitioners to develop their local activities.

The theoretical-genetic approach requires a theoretical unit of analysis that takes the system under study into consideration. The introduction of an activity system (Leont'ev, 1978, Engeström, 1987) as a theoretical unit of analysis for studying learning and development towards sustainable production can be seen as a central methodological contribution of this study. The model of the activity system helps us to overcome several limitations of previous studies by giving a systemic picture of the local activity and its historical development. The unit also helps to understand and model both the developmental challenges and the new form of activity to be created. In this sense, it can also be used as a tool for analysing and planning local activities. In other words, such a unit is a framework that allows researchers as well as practitioners to identify inner contradictions in their local activity systems and to create expansive solutions to overcome them.

Regarding the conceptualisation of the relationship between sustainable technologies and the activities in which these technologies are used, in this study sustainable technologies are seen as mediators of human activity that can play different functions in different activities, and their use can have different senses for different people (Section 7.1 in Chapter 7). The unit of analysis proposed in this study, the activity system viewed as a knot in a network of activity systems, is useful for modelling the relationship between technology as the tool and object (including the end product) of an activity, as well as the relationship between activities. A sustainable technology may be an object of the activity of engineers or a manufacturer, but to affect the sustainability of production it has to become a tool in a productive activity.

In the previous studies described in Chapter 3, the preconditions of collective learning were treated in a one-sided way as they supposed that people have to agree on a vision, expectation or a value in order to collaborate. In their focus on the cognitive aspect of the object of joint activity, they fail to recognise its material side and the concrete material conditions that create the need and possibilities for an expansive solution. They fail to see the possibility of collaboration between people with different, even contradictory perspectives. The contribution of this study is to show, with the concept of activity as well as the concepts of the object of activity and sense, how motives emerge from contradictions within activities and how they are shaped by the division of labour within and between activities. The concept of activity helps to analyse how a societal purpose or meaning, such as the sustainability of production, is mediated through individuals' senses of involving themselves in new forms of collaboration.

Although the study did not comprise a formal developmental intervention, one methodological contribution of the study is the tools for researchers and practitioners that it provides for modelling a future system of more environmentally sustainable production by investigating the newly emerging aspects of the production activity and the related network of activities that might become general in the future. The analysis of the historical contradictions and the actual practices may enable actors to model concrete future developmental possibilities for the network of activities and use this model to identify expansive actions and solutions for the resolution of the actual contradictions. The conceptual tools, such as the ZPD and the learning challenges presented in Section 8.2 (Chapter 8), may help practitioners and researchers to solve problems in their local activities. The tools proposed here may also be used in future interventions as tools for analysing and modelling solutions. Together with a historical analysis and an analysis of disturbances, the model may be used to help actors to find their own expansive actions and solutions to develop their activities. The idea of the proposed tools is not to impose a pattern of development for all future BP projects, but rather to help actors to analyse their own situations so that they can move forward.

Although studies on sustainable technologies usually include a historical analysis, these analyses do not lead to a theoretical analysis of the developmental dynamics of a system. The way that the historical analysis was used in this study to reconstruct the development of a system and its inner contradictions can be seen as a methodological contribution to the study of sustainable production. The historical-genetic analysis of the development of an activity system and a network of activities is a powerful method not only for explaining the present, but also for finding avenues for expansive solutions to build the future. The analysis of the development of concepts (Section 6.2 in Chapter 6) can show developmental dimensions and spaces for new concepts. Such a model can be a valuable framework for analysing current practices and elements of a system from the point of view of the basic operating logic of these elements and practices. The analysis of the development of the object, the BPfS in the 3S Programme, was needed to create the hypothesis about the current developmental phase and the current contradictions.

Previous studies have acknowledged the importance of identifying problems and failures and focusing on them to support learning; these studies have, however, not provided tools for analysing the systemic causes the the problems experienced (an exception is the work of van Mierlo et al. 2010). This study goes a step further by applying the concepts of an inner contradiction in the activity system and the different kinds of inner contradictions in the different phases of expansive development. Instead of just describing disturbances and problems, their root causes were analysed by studying the historical development and changes of the system. By going beyond the emerging problems to the inner contradictions that produce them, researchers and practitioners can focus their efforts on the expansive remediation of the activity instead of solving individual problems. The model of an activity system is useful for modelling contradictions within and between activity systems. The combination and interplay between the analysis of the general concepts of BPfS, the local system of BPfS and the actual disturbances identified in the empirical study were helpful in enriching the historically derived hypothesis concerning inner contradictions in the system and for identifying innovations or innovative practices that can indicate germ cells, or potential solutions which could be further developed as solutions for the current contradictions.

9.2 The contribution of this study to understanding the possibilities of increasing the environmental sustainability of agricultural production

9.2.1 The need for a new model of agricultural production

The ongoing intensification of the use of natural resources, increasing specialisation (leading to monocultures) and the concentration of production have led, on the one hand, to an increase in productivity while, on the other, they have lead to the degradation of natural resources. Historically, this contradiction between increasing the efficiency of agricultural production and preserving the environment has been a major problem and challenge of current agriculture. In this study, the possibilities of solving this problem have been studied in swine production in which the main environmental problem is related to the management of the swine manure.

It is tempting to search for a solution from the past and think that sustainable agriculture is synonymous with a self-sufficient and independent farm. Several researchers have proposed that sustainable swine production requires a movement back to family farming (referring to a more self-sufficient mode of production), which could be achieved, for example, through governmental subsides (e.g., Guivant & Miranda, 2004). This proposal is based on studies showing that family farming (understood as a self-sufficient mode of production) has fewer negative environmental impacts than modern industrialised agriculture (referring to the actual specialised and concentrated mode of production). In this study, however, although among the cases there were family farms, a clear and steady process of specialisation and increase in the scale of production was evident. The data proposes that farming activity was becoming more complex and increasingly dependent on other activities outside the farm. In order to consume other products, farmers had to produce products that they could sell on the market. Therefore, rather than trying to return to older modes of production, the solution seems to be in the further development of the current mode of production towards environmental sustainability.

The current concept of swine production, which is based on the logic of mass production, brings us not only negative environmental and social effects but also important positive ones, such as increased productivity and the more efficient use of resources. A return to the craft mode of farming production could imply a decrease in productivity, which could compromise the food supply for the current urban population.

9.2.2 A potential germ cell for an agricultural system that resolves the contradiction between the expansion of production and environmental protection

The contribution of this study to the search for a solution to the contradiction between environmental protection and the increasing scale of production is to propose how BP can contribute to solving this contradiction and how BP can become more sustainable through economies of scope by integrating it into productive activities through commodifying the products of BP and selling them in the respective markets.

The ZPD in Section 8.2 (Chapter 8) suggests how the use of biogas production in swine manure management can contribute to the environmental sustainability of swine production. However, the way in which BP was produced was not sustainable in itself, as it did not take into consideration the local uses of biogas. The concept of BPMM proposed in this study (presented in Figure 8.3 in Chapter 8) might become a **germ cell** for more environmentally sustainable swine production and other agricultural production (for discussion on generalisation, see Section 9.4.2 in this chapter). The basic principle of this concept is a waste management or recycling system based on collaboration, market exchange and the production of multiple and complementary products to achieve economies of scope in agricultural systems. The concept presents a new principle for organising production so that the waste can be recycled in agricultural activities. In it, a functional integration of productive activities and economies of scope is gained by sharing and complementing resources through markets and collaboration. In the 3S Programme the concept of BPMM (see Figure 8.3 in Chapter 8) would mean that a specialised organisation would collaborate with small farms to support them in marketing and commercialising their biogas products. The small scale of production would be compensated by the support from the network. This concept involves the use of BP for multiple purposes and is likely to solve the problem of the allocation of bio-fertilizer to places that it is really needed, as well as to generate extra income to farmers. Therefore, it is also more likely to produce environmental and social benefits.

Guivant and Miranda (2004) note that a more integrated form of agriculture in which the waste is recycled and used is more likely to be sustainable. This study suggests, however, that such an integration would not necessarily have to take place within one farm. It can also be achieved by exchange and collaboration between farms and other activities. Individual farmers' possibilities for creating this type of integration are, however, limited. Therefore, a new kind of activity and organisation might be needed to help them to create it. As discussed in Chapter 8, such an organisation would play a crucial role in representing farmers so that their voice could be more effectively heard by other actors in a network of BPfS as well as in helping them to experiment and learn to bring new biogas products into the market. This suggests that sustainable production requires not only new technologies and rules, but also new forms of organisation and agency.

9.3 Contributions to theories on learning and development towards sustainable production

I found that most of the previous studies on learning and development of sustainable production presented in Section 3.2 in Chapter 3 lack a clear theory to explain why and how the identified factors affected the development of BP. My analysis disclosed two unresolved problems in the units of analysis adopted in those studies: a) the relationship between individual and collective learning, and b) how and why new solutions emerge. Usually, the starting point in the studies was the existence of a societal problem, which was assumed to be a motivation for individuals to act. Although the concepts of learning and development are broadly used in the studies, almost nothing is said about their relationship.

The typical way of treating learning in these studies is based on the general idea of value-rational planning, according to which rational action is based on selecting the best means for realising a value. In collaborative activities people must therefore first agree on certain values, expectations or a vision in order to be able to collaborate. Learning in these theories refers to changes in cognition (knowledge, theories and values), which then direct action. In order to change practices, one must first change peoples' theories.

The contribution of this study to the understanding of learning and development of sustainable production is in bringing a materialist understanding of learning that highlights the central role of the remediation of subject-object interaction, not only with new conceptual tools but with new material tools as well, and the importance of the objectification of ideas in material tools. I have applied in this study a theory of expansive learning in which a new form of subject-object interaction emerges as an exceptional, unique event, a 'germ cell', which is enriched and transformed step by step into a concrete system of multiple, constantly developing manifestations (Engeström, 1987). Such a germ cell can be an action carried out with a new tool or a new form of collaborative activity made possible with it.

Expansive learning means a specific kind of remediation in which a new germ cell is created as a solution to an inner contradiction in the current system of activity, which involves the construction and reconstruction of activity systems in order to resolve contradictions within and between them (Pereira-Querol & Seppänen, 2009; Pereira-Querol et al., 2010). Here it is important to point out that seeing BPfS as a mediator is not the same as seeing it as a technology. Mediation takes into consideration the interaction between subject and object, as well as between other elements of the activity, while a technology does not. As a technology, BP is an independent element, variable or factor. As a mediator BP is neither a cause nor an effect, but an inseparable element in the relationship between subject and object.

This study contributes to overcoming the dichotomy between the individual and the social by proposing activity as a unit of analysis that takes into consideration the relationship between the individual and the social. The concept of activity offers a different basis on which the individual is brought into a relationship with the regime and the landscape, in which activity and learning are mediated through tools and community (Eskola, 1999). Thus, in my activity-theoretical interpretation of learning for sustainability, learning is neither purely individual nor purely societal; it is done by individuals within collective activities, using artefacts that are social and historical in nature. In other words, this interpretation integrates the perspective of the individual with the social order and context through the concepts of tools and the social mediation of individual actions and collaborative activity.

This study applies the concept of contradiction to understand the emergence and development of sustainable technologies (Engeström, 1987, see Section 4.4 in Chapter 4). Failures, breakdowns and conflicts are seen as expressions of contradictions. By analysing failures, breakdowns and disturbances, the subject may create hypotheses on the incompatibilities within their activities and work to remediate them. Such remediation involves not only tools (such as technologies), but also new ways of organising the activity by redistribution of tasks, creating new rules and building a new community.

In this study, the relationship between learning and development of more sustainable forms of agricultural production could be understood as follows. Organised learning sets in motion a series of developmental processes that would be impossible without learning (Vygotsky, 1978). The learning of a new concept and a new tool opens up new perspectives and possibilities of action which lead to the development of thinking, action and collaborative activity. Each step in the development of a productive activity creates new challenges and possibilities for learning. The relationship of learning for sustainability and the development of a more sustainable form of agricultural production is thus dialectical. The central element in realising this dialectic is local, collaborative experimentation which brings new solutions such as the development of equipment for and the use of BP.

The contribution of this study to the activity theoretical approach is related to the specific characteristics of learning and development towards sustainability. In the study, I have struggled to understand or interpret the 3S Programme using the available activity theoretical concepts. One explanation for this difficulty could be that the 3S Programme was under construction and was not yet stabilised, which means that the 3S Programme was still an action within the activity of food production and swine production. However, the 3S Programme was neither an independent activity nor just an action. The difficulty faced in the study seems to reflect a new type of integration of activity systems, which is neither based on a functional network nor a co-production network (see Section 4.3.2 in Chapter 4). The 3S Programme seems to have a different structure than these two forms of networks. The 3S Programme, or a variation of it, would remain once the BP system has been installed to help with the maintenance of the BP system. This difficulty suggests the emergence of a new level of integration between activity systems, a kind of "satellite" activity, a meta-level activity that supports integration and collaboration to facilitate the transformation of the object of the activities towards sustainability. This new type of "satellite" activity seems to play a crucial role in supporting the sustainability of environmental solutions aimed to increase the sustainability of agro-industrial activities.

9.4 The validity and generalisability of the findings

As pointed out above, this research was based on the idea of theoretical-genetic generalisation. The assessment of this research should therefore be based on the question of whether there was something in the analysis of the contradictions and the local solution created in the Sadia food production chain as conceptualised in this study that could spread to different forms of production in which the contradiction between the expansion of production and environmental protection is present.

9.4.1 The validity of the findings concerning the contradictions and Sadia's solution

The analysis of disturbance processes done in Chapter 7 does not and cannot represent all the disturbances that were taking place in the BPfS in the 3S Programme. The most important limitation in this analysis is related to the limitation of time. Most of the observed disturbances, ruptures and innovations took place during the years 2007 and 2008, and do not cover the initial phase of design and the beginning of the implementation of BPfS in the case study. To cover this period of time, I had to rely on people's explanations and stories about what happened and how. Moreover, there were disturbances which were rare and therefore difficult to observe. For example, the explosion of a balloon was a very rare event, but a serious disturbance. There were probably some disturbances, ruptures and innovations that took place during the design of the 3S Programme and the implementation of the bio-digester which I was not able to observe and that people did not mention.

Another limitation is related to the actors involved. Unfortunately, I was not able to incorporate all the perspectives that existed in the case. This task would be extremely difficult. Due to practical limitations, I had to make choices regarding which actors to include and exclude. I selected some key actors within Sadia and the SI, consultants, experts and some farmers. The observed disturbances, ruptures and innovations are limited to the interactions between Sadia, the SI and the farmers, and the observations do not cover actors from other activities, such as the manufacturing of biogas production and use equipment, the certification of carbon credits and so on.

The selection was not just based on my own criteria, but rather on following the object of collaboration. In order to follow this object, I tried to recruit as many people as possible to help me to choose the informants and cases. I followed the work of field work engineers from Sadia and the SI and farmers. In Chapter 5, I attempted to make as explicit as possible the process of data selection and the method of data analysis used in each empirical analysis. Moreover, in each empirical chapter, I discussed the theoretical interpretation as much as possible, arguing the different possibilities and the reasons why I had selected certain interpretations. In this task, I tried to follow the rule of reasoning based on evidence, although I recognise that this was not always possible. Another strategy used to increase validity was to describe as much as possible the context of the activity: the persons involved, places and so on. I also added several excerpts so that the reader could see what the raw data looked like.

In spite of the precautions in the sampling, I recognise that the study does not cover the whole spectrum of Sadia's outsourced farmers in the entire country. My study was focused in the south-west region, in Santa Catarina state, Brazil. Although this region was one of the most important producers and suppliers of swine to the Sadia processing company and in Brazil, the farms in this region do not represent the reality of farms from other states, such as Minas Gerais and

Mato Grosso. In Santa Catarina, the farms were relatively smaller, predominantly family farmed and diversified, while in Mato Grosso and Minas Gerais, the farms were much larger, specialised and predominately used hired labour. Despite this limitation, in my experience as an agronomist, the farms observed do represent the reality of the farms in the region of Santa Catarina, Brazil.

Another important limitation is the fact that there were only minor interventions. Although I was in constant contact with the practitioners and presented my results and hypotheses to them, I still did not have a formal intervention in which to test the hypotheses in practice: to design, implement and evaluate the germ cell.

The validity of this research does not rely on a statistical representation, but on the different logics of the system. In other words, the ZPD relies on historical validity rather than statistical validity. The validity of the ZPD relies rather on how much the observed farms represent the actual situation of swine production farms that are facing the contradiction between the expanded production and environmental protection. Therefore, an increase in the number of observations would not increase the validity. To increase the validity, I would have to increase the length of the time of the observations and to test the hypothesis through an intervention. Unfortunately, because of limited resources, I had to restrict the observations to a period of three years and leave the task of intervention to future research.

During the research process there was dialogue between the practitioners and me. I presented the results from the historical analysis both through personal contact and in a presentation. During the interaction, I received feedback about the findings and the hypotheses, and was given some suggestions. In addition to adding to the data and improving my findings, the dialogue also had the aim of provoking reflection and being a kind of intervention that would lead to change. The researcher, by conducting interviews, led the subjects (farmers, managers, engineers and technicians) to reflect on topics such as challenges and possible solutions. As the coordinator of the 3S Programme told me, she learned by having to explain the history and the challenges to a point that she asked me to send her a summary of what she had told me.

Moreover, during the field work data collection, I also discussed problems and the potential solutions with the farmers. I shared my knowledge about the BP process and the potential uses and benefits of BP. For example, after collecting information about Paulo's plans, I asked him questions that made him reflect on whether it would be a good idea to install another bio-digester in the new warehouse that he was constructing. He found the idea to be interesting and started to discuss it with his son, who both agreed that it would be a good idea and that they should contact the SI to request another bio-digester. Therefore, my role was not neutral, but rather an active actor for change. Throughout the study, I have exchanged emails and made phone calls to key participants such as the coordinator, engineers and one farmer to see what was happening.

I consider the interviews, discussions and presentations as minor interventions that affected the activity, worked as tools for reflection and affected the learning process of managers and farmers. Thus, the study and the researcher affected the BPfS. However, I was just one actor among many others who were intervening and influencing the development of the object.

The validity of the empirical analysis made in this study does not rely on a statistical representation of all the disturbances, events and senses that could be observed in the object of the study. The aim of the analysis was to elaborate the hypothesis of the contradictions and the respective local solutions created in the Sadia food production chain. In this sense, I conclude that the analysis was successful in identifying a possible germ cell that could potentially spread to different forms of production in which the contradiction between the expansion of production and environmental protection is present.

9.4.2 The generalisability of the produced concept

The basic principle of the proposed concept for sustainable agriculture is a waste management or recycling system based on collaboration, market exchange and the production of multiple and complementary products to achieve economies of scope in agricultural systems. The concept proposed here can be understood as a new principle for organising production so that the waste can be recycled in agricultural activities.

The generalisation of a germ cell is a stepwise process. Initially, the concept presented here may be limited to biogas production from swine production in which the contradiction between the expansion of production and environmental protection is present. In other words, there should be already some level of concentration of production, specialisation, intensification and integration in a company or activity. It may be that in the future, the concept could be generalised to other agricultural activities in which biogas can be produced, such as milk production or other agro-industrial activities that produce a large volume of organic residues that can be used to produce biogas. The principles of integration to markets, collaboration and functional integration may contribute to making recycling and waste management more sustainable, and therefore contribute to the environmental sustainability of agricultural production.

9.5 The concept of a learning challenge as a tool for collaboration between researchers and practitioners

Another important contribution of this study refers to the concept of a learning challenge. The concept of a learning challenge can be used as a tool for focusing the work of developers and can be used in interventions aimed to develop sustainable technologies. The concept is located between the tradition of training needs analysis, and the study of collective learning. In training needs analysis the focus is on individuals and the provision of already existing skills and knowledge through training. At the other extreme, there are studies focusing on disclosing spontaneous learning, without any interventions or processes of learning in organisations and projects. A learning challenge defines a new object of collective and individual learning that is based on a scientifically grounded hypothesis concerning a developmental possibility. Such a definition of a learning challenge can direct practitioners' learning attempts and be used as a basis for a developmental intervention. In this sense, the concept of a learning challenge could be seen as the formulation of an object for collaborative learning between researchers and practitioners. Therefore, it supports the collaboration between practitioners and researchers by giving ideas for future research.

Referring now to the three layers of human causality presented in Table 4.1, Chapter 4, the concept of a learning challenge can be understood as a cultural artefact that could be used by actors to move from the contradictory layer, in which they try to find solutions in an unpredictable way; towards an agentive layer in which they take intentional actions to transform their actual activities. In this way, the role of this concept is not simply to explain what happened in the BPfS, but to provide the hypothesis on what must be learnt in order to further develop the BPfS. I expect that the results and conclusions may be used as a tool for supporting not only the specific network of the BPfS in the 3S Programme, but also other actors interested in developing sustainable agriculture.

In traditional research, recommendations about future research usually discuss what must be studied so that further knowledge can be produced about the object of the study. Such recommendations are usually addressed to the research community. However, the type of problem dealt with in this study calls for a different type of research. Instead of simply producing knowledge and waiting for someone to apply it; we need a different approach in which researchers collaborate with practitioners. Thus, it is more realistic to discuss what researchers should do in the collaboration with practitioners. In this type of research, the boundary between 'researching' and 'doing' is mixed; researchers do not have the monopoly to say what is "right" and "wrong", but should be seen as one more actor in a network of actors. The change of the object of the research becomes a shared object between researchers and practitioners. As discussed in the previous section, the learning challenges can point to actions of collaboration between researchers and practitioners.

This study opens up a new field of research on explanatory studies using activity theory to analyse learning and development for sustainable agricultural production. The ZPD model proposed here has to be further tested through interventionist research in which the practitioners, with the help of researchers, try to model and implement the concept of BPMM in practice. In future research, the proposed concept of BPfS should be further tested and elaborated. In this type of research, the researcher has to play an active role in helping the actors of the network to identify new markets for biogas products, to plan and so on. The next research study could be an intervention involving ten to twelve actors from BP-related activities, such as farms, Sadia, the SI and manufacturers of BP use equipment for developing the use of biogas, bio-fertiliser and other products.

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APPENDIXES

Appendix 2.1 Roles of the representative from the SI in 2006

- Gather farmers with the aim of explaining the 3S Programme (to sign the contract and present the budget)
- Make a list of farmers to be approved by the institute to participate in the construction of the bio-digesters
- Visit the farmers with the engineer of the Company “Alfa” to mark the place for the construction of the bio-digester
- Forward the list of farmers for preparing the contracts to the legal department
- Obtain the signature on the contracts with the producers and forward them to the institute in Sao Paulo
- Define the schedule for the construction of the bio-digesters
- Request work orders to start the construction
- Oversee the construction of the bio-digesters and the fences following the defined patterns
- Guide the farmers in
  - Connecting the tubes to be installed in the entrance box
  - Connecting the tubes of the bio-digesters to the decanting lagoon
  - Acquiring gravel for the construction of the fences
  - Pumping the slurry from the open tanks to the bio-digesters
- Guide the farmers in defining the type of material of the connections
- Train the farmer in operating the bio-digester
- Define the guidelines of the installation of the flare and the measuring apparatus for the gas
- Update the checklist of the new candidates with the institute

Appendix 2.2 Roles of farmers established in the guidelines

1. Inspect and clean the sedimentation box frequently
2. Mix the manure daily or at least once a week if the farmers have a tank for distributing the slurry
3. Keep the slurry for at least 80 days before spreading it on the fields
4. Regulate the amount of water inside the security valve in 2 cm
5. Keep the fences around the digester in good condition and the door closed
6. Notify Sadia if the fences are rusting
7. Keep the grass around the bio-digester and the flare at a maximum height of 15 cm
8. Keep the space around the digester clean
9. Paint the pillars of the fence frequently
10. Control the rat pollution
11. Release manure at least once a day into the digester
12. Remove solid residues from the digester when there is an excess of them
13. Spread the pebbles around the digester
14. Communicate to Sadia personnel any failure in the combustion system
15. Inspect the functioning of the digestion and combustion system daily
16. Keep the flare isolated with a fence
17. Paint the tubes that conduct the biogas to the combustion area

On the other hand, the farmers were forbidden from certain actions

1. Do not burn the gas straight from the exit pipe
2. Avoid damaging the cover of the digester with sharp objects
3. Never climb on the digester
4. Avoid leakage of slurry or manure during the uploading of the digester or the loading of the distribution tanks
5. Do not insert dead animals or pieces of animals in the bio-digester
6. Treat only swine manure in the bio-digester
7. Do not have more animals than the ones authorised by the technician
8. Use as little water as possible
9. Do not smoke around the bio-digester
10. Do not use any kind of equipment that could produce sparks
11. Do not allow the entrance of disinfectants or antibiotics
12. Do not touch the flare while the gas is burning
13. Do not try to fix any failure on your own
14. Do not touch the equipment in case of a failure in the system

Appendix 3.1 List of studies included in the review

Reference	Country	Findings/Conclusions	Recommendations
UNESCA P (2007)	Asia (mainly China, Vietnam, and Nepal)	The Steady increase and solidification of BP in China is related to the support of the Chinese government in several aspects, e.g., financial, technical and research. Socio-cultural, political and administrative aspects strongly affect BP development.	Recommendations given by country.
Bhat et al. (2001)	India	The high rate of success is explained by the presence of multiple agencies in the dissemination network and the participation of entrepreneurs, as well as by commissioning, procuring subsidies, guaranteering performance and free servicing.	Entrepreneurs should be trained to provide infrastructure support, to enable sustainable livelihoods and to launch an awareness programme.
Guatam et al. (2009)	Nepal	Only 9% of the potential of BP has been achieved. The main challenges are: remote locations, cold temperatures, financial limitations and the increase in the incidence of mosquitos.	More technical and financial support is needed.
Jian (2009)	China	The vital barriers to biogas development are socio-economic, not technological.	Developmental agencies must be more instrumental and committed.
Jingura & Matengaifa (2009)	Zimbabwe	BP is not optimally used in Zimbabwe.	The promotion of cooperative BP, the co-digestion, the capture of the biogas produced and the channelling into the energy system and the set up of BP plants for digesting municipal solid waste are needed.
Hillman et al. (2008)	The Netherlands and Sweden	The difference in the development of BP between Sweden and the Netherlands may be attributed to differences in system functions and the emergence of cumulative causation.	The government should target multiple system functions rather than aiming at singular ones.
Lantz et al. (2007)	Sweden	Dissemination is at a low level due to energy, waste treatment and agricultural policies.	More incentives from several policy domains are needed to make BP profitable.
Limmeechokchai & Chawana (2007)	Thailand	The main barriers to the development of small-scale BP in Thailand are (i) the high investment cost, (ii) the lack of financial sources, and (iii) the lack of experts and skilled manpower.	The problem of the overproduction of gas is produced, and a biogas pool project to solve the problem is proposed.
Mirza et al. (2009)	Pakistan	Pakistan has been favourable for BP, but there are still some barriers: institutional, market related, informational and social.	Innovative financing programmes should be put in place, and there should be an "indigenisation" of technologies.
Monteiro et al. (2011)	Portugal	The use of the cattle manure for BP is still far from its potential. The main reason is the small size of Portuguese farms, which makes BP unfeasible.	Various options to increase or improve BP such as co-digestion, centralised plants and modular plants are suggested.

Mwirigi et al. (2009)	Kenya	The research concluded that there is a need to promote biogas among farmers, though a multidisciplinary approach that involves all the stakeholders is needed.	Recommendations are given regarding policies, administrative issues, and the role of NGOs, farmers, and research and training institutions.
Negro & Hekkert (2008),	Germany	The study shows that all system functions that are claimed to be important within the innovation systems approach are present in Germany, positively interacting and leading to virtuous cycles and a rapid growth of the system.	Support should involve all the important functions.
Negro et al. (2007)	The Netherlands	Problematic functional patterns in BP in the Netherlands were found. The analysed system functions did not show a continuous build-up over the years.	Government policy should have focused on strengthening three system functions: guidance of the search, market formation and resources mobilisation.
Poeschl et al. (2010)	Germany	The current energy policies allowed the expansion of BP. The authors propose a series of policies that could increase the competitiveness of BP and help it to further expand.	Incentives have to be raised.
Prasertsan & Sajjakul-nukit (2006)	Thailand	BP is disseminated at a low level due to unsatisfactory policy and technical, financial and informational barriers.	Policies for disseminating information, encouraging discussion among stakeholders and giving clear and strong signs to support private investments should be developed.
Rao et al. (2010)	India	The potential production of energy in India from BP was assessed.	
Raven & Geels (2009)	Denmark and the Netherlands	The study shows that differences in patterns can be explained by the micro processes, such as the articulation of expectations, the building of networks, and social learning.	Several suggestions for future research are made.
Raven & Gregersen (2007)	Denmark	The Danish government and circumstances played an important role in stimulating long-term and continuous interaction and learning between various social groups. The main hindering factors are the shift in energy and environmental policies, and the availability of organic waste.	
Szogs & Wilson (2008)	Tanzania	A system of innovation can be identified, and major challenges exist with respect to financing and supportive policies.	To fully develop an innovation system that works well and supports innovative activities, greater emphasis is needed in the area of policies.
Tricase & Lombardi (2009)	Italy	The use of simple technologies and a law supporting renewable energy contributed to the spread of BP in Italy. The limits are the lack of efficiency of the technology of anaerobic digestion and the complexity of the administration.	A legislative reform is needed to make incentives for energy production more efficient.
Uddin & Taplin (2009)	Bangladesh	Several barriers for the use of CDM for promoting renewable energies are identified and discussed.	More appropriate energy needs to be formulated and implemented, and more suitable institutional settings need to be provided to promote energy sustainability for Bangladesh.

Appendix 5.1 An example of news from Sadia's webpage

News 19/1/2004 from Sadia website (www.sadia.com.br)
Sadia from Toledo wins an award in the 11th Premium for Ecologic Expression The production unit of Toledo, PR won in November 2003 the 11th Award of Ecologic Expression. Companies from the south part of the country participated in this event. The company was a champion in the categories: "Agriculture and Conservation of Inputs – Energy" with the cases of "Integrated biosystems in swine production" and the consumption of energy in the food factory.

Appendix 5.2 Field notes and photos

Code of ref.	Document title	Character	Length	Date produ-ced
Notes 2006	Field notes	field notes		
Notes 2007	Field notes	field notes		May 2007
Notes 2008	Field notes	field notes		
Photographs 2006	Photographs taken during the field visit	photographs	70 photographs	December 2006
Photographs 2007	Photographs taken during the field visit	photographs	83 photographs	May 2007
Photographs 2008	Photographs taken during the field visit	photographs	95 photographs	May 2008

Appendix 5.3 List of interviews conducted during 2006, 2007 and 2008

Time duration	Actors present	Space
1:16'15''	Interview with engineer Alberto Silva (2006)	indoor/semi-structured
1:52'11''	Interview with engineer Jorge and technician João (2006)	indoor/semi-structured
2:21'00''	Interview with SI coordinator Katia 16/05/2007	indoor
1:01'53''	Interview with the ex-consultant 18/05/2007	indoor
1:30'19''	Interview with technician Igor 21/05/2007	indoor
42'38''	Interview with engineer Henrique from a local environmental NGO (Fatma) 21/05/2007	indoor
7'10''	Interview with engineer Reginaldo 22/05/2007	indoor
9'00''	Interview with Igor 22/05/2007	
1:21'18''	Interview with engineer Reginaldo 23/05/2007	indoor
36'16''	Interview with farmer Paulo Menegati 23/05/2007	on farm
13'52''	Interview with farmer Mrs Neli 23/05/2007	on farm
1'36''	Interview with a farmer during a visit with technician Julio 24/05/2007	indoor
1:15'34''	Interview with the operation manager of the programme, Alexandre Jorge 28/05/2007	indoor
17'11''	Interviews with farmer Paulo Meneguati 29/05/2007	on farm
10'46''	Interviews with technician Francisco 30/05/2007	indoor
1:17'32''	Interview with the auditor of the carbon project Mr José Rodrigues 04/06/2007	indoor
1:34'00''	Interview with the expert in carbon credits Mr Franscico Santos 11/06/2007	indoor
1:26'01''	Interview with Reginaldo and Ana (SI staff) + interaction by phone with assembling outsourcing company (May 2008)	indoor
6'41''	Engineer Cidinei from Sadia's industrial department (May 2008)	indoor
	Farmer Paulo and his son (May 2008)	indoor
26'33''	Farmer Paulo and his son (May 2008)	indoor
16'33''	Farmer Paulo and his son (May 2008)	indoor
3'34''	Farmer Paulo, his son Alexandre and the researcher (May 2008)	indoor
31'06''	Farmer Omar + his wife (May 2008)	indoor
10'34''	Farmer Omar + his wife (May 2008)	indoor
6'16''	Carlos the manager in the unit of Sadia Concordia (May 2008)	indoor

Appendix 5.4 Fieldwork interactions during 2006, 2007 and 2008

Time duration	Actors present	Type
1:34’20’’	Informal conversation with farmer Frei (2006)	field visit
29’25’’	Informal conversation with farmer Fabio (2006)	field visit
32’46’’	Informal conversation with farmer Laerte (2006)	field visit
1’20’’	Informal conversation with farmer Mr. Fabio 22/05/2007	on farm
31’13’’	Interview with farmer Mr. Zezinho 22/05/2007	on farm
30’45’’	Interaction between technicians and a farmer with a problem in the digester 22/05/2007	on farm
4’26’’	Interaction between a laboratory worker and technicians 22/05/2007	indoor
18’59’’	engineer Julio+ farmer1 24/05/2007	field visit
23’42’’	engineer Julio+ farmer2 24/05/2007	field visit
35’43’’	engineer Julio+ farmer3 24/05/2007	field visit
1’13’’	engineer Julio+ farmer4 24/05/2007	field visit
14’12’’ +10’47’’	engineer Elmo + farmer 1 25/05/2007	field visit
55’19’	engineer Elmo + farmer 2 25/05/2007	field visit
11’39’’ + 6’21’’	engineer Elmo + farmer 3 25/05/2007	field visit
15’34’’ + 1’21’’ + 31’49’’ + 13’41’’	engineer Elmo + farmer 4 ( ) 25/05/2007	field visit
15’17’’	engineer Igor, Reginaldo + farmer José and pump manufacturer 28/05/2007	on farm
21’48’’	engineer Sela + farmer 1 30/05/2007	
15’56’’	engineer Sela + farmer 2 30/05/2007	field visit
1’30’’	engineer Sela + farmer 3 30/05/2007	field visit
14’59’’	engineer Sela + farmer 4 30/05/2007	
2:21’36’’	training course engineer Igor, Reginaldo and farmers 31/05/2007	field visit
18’40’’	engineer + farmer Paulo (May 2008)	on farm
01:02’46’’	engineer + farmer Paulo (May 2008)	on farm
27’20’’	engineer + farmer Paulo (May 2008)	on farm
43’28’’	Farmer Omar + his wife (May 2008)	on farm
16’ 26’’	Farmer Omar + his wife (May 2008)	on farm
5’53’’	Farmer Pedro + farmer Marcio (May 2008)	on farm
45’’	Farmer Pedro + farmer Marcio (May 2008)	on farm
39’09’’	Engineer + farmer Pedro and Marcio, their wives (May 2008)	on farm
04’30’’	Engineer + farmer Pedro and Marcio, their wives (May 2008)	on farm
37’54’’	Engineer Iara + Engineer Fabio + farmer José (May 2008)	on farm
38’49’’	Farmer Manuel and Lino + engineer Iara + researchers from Embrapa 30/05/08	on farm
51’07’’	Farmer Manuel and Lino + engineer Iara + researchers from Embrapa 30/05/08	on farm
29’31’’	Antonio Lorenzeti and his father + engineer Iara + researchers from Embrapa 20/05/08	on farm
5’15’’	Farmer Ugo, SI engineer Iara, a researcher from Embrapa 30/05/08	on farm
36’52’’	Farmer Ugos, SI engineer Iara, a researcher from Embrapa 30/05/08	on farm

Appendix 5.5 Types of data used, their source and knowledge obtained in the analysis of disturbance

Type of Data	Definition	Knowledge obtained	Source of data	Set of data
Observed data	Observed by the researcher	Observed disturbances, ruptures and innovations	Field notes, video-recorded visits and photos	Video- and audio-recorded interactions during field visits in May 2008
Reported data	Event reported by somebody	Reported disturbances, ruptures and innovations	Interviews and informal conversations, reporting documents, video-recorded interactions between actors (conversations)	Interviews, documents and field work notes from December 2006 until May 2008
Hypothetical data	Explanation of the event	Hypothetical disturbances, ruptures and innovations (explanations of the event)	Interviews, informal conversations, explanatory documents, video recorded interactions between the actors	Interviews, documents and field work notes from December 2006 until May 2008)

Appendix 6.1 Elements of the activity system that were changed by the main historical events

Historical event	Element in the activity system that changed
Increases in the concentration of production and specialisation of the farms (1980s)	Object: Reports about the negative environmental and health effects of the release of swine manure in rivers
Regional meetings to discuss the problem of pollution caused by swine production (1993)	Object: Pollution caused by swine production
The TAC agreement signed (June 2004)	Rules: Agreement obligating Sadia to help outsourced farms to adjust to environmental legislation
SST's idea of using BPCC for adjusting outsourced farms (first half of 2004)	Object: Sustainable swine production through BPCC
Idea of BPCC for sustainable swine production presented to the Sadia directors and approved	Object: Sustainable swine production through BPCC
Consultant hired to help in the design of the programme (2004)	Division of labour: Consultant Community: Consultant
Foundation of the Sadia Institute of Sustainability (December 2004)	Division of labour: The Sadia Institute becomes responsible for the design and implementation the 3S Programme.
The Vietnamese model of bio-digesters designed (2004–2005)	Tools: Design of the bio-digesters
Meeting to present the 3S Programme to farmers (2006)	Community: Farmers
Farmers sign the contract (first half of 2006)	Rules: Contract with farmers
First bio-digester installed	Tools: Bio-digester + flare
Manufacturing company proposes a new model of a bio-digester for small-scale farmers (2006)	Tools: Actual design of the bio-digesters
Outsourced company hired (2006)	Division of labour: Outsourced company responsible for the installation of bio-digesters Community: Outsourced company
Installation of the bio-digesters (March 2006)	Tools: Actual bio-digesters
Field work technician hired (first half of 2006)	Subject: Field work technician Division of labour: Field work technician becomes responsible for monitoring the installation of the digesters.
UNFCCC methodologies temporarily invalid (March 2006)	Rules: UNFCCC methodology
Contract between Sadia and the consultant company ended (June 2006)	
New coordinator hired by the Sadia institute (SI)	Division of labour: The coordinator becomes responsible for the implementation of the BPCC and writing the PDD.
New UNFCCC methodology launched (Sept – Dec 2006)	Rules: New UNFCCC methodology, new combustion system requested
Meeting to redesign the organisational structure of the Sadia Institute (beginning of 2007)	Division of labour: The environmental manager becomes responsible for the operation management of the 3S Programme.
Environmental engineer hired to design a new combustion system (2007)	Subject: Engineer
New combustion system tested and defined (May 2007)	Tool: New combustion system
Manufacturer and outsourced company hired (first half of 2007)	Division of labour: The manufacturer becomes responsible for assembling and installing the combustion system.
Installation of the flares (2007–2008)	Tools: New combustion system

Appendix 6.2 Elements of the activity system that were changed by the main historical events in Mr Paulo's farm

Historical event	Element in the activity system that changed
Pig production with 25 sows (1980s)	Object of swine production: Pigs
Open tank built for storing manure as bio-fertiliser (1996)	Tool: Open tanks
Specialisation in piglets and a production increase from 100 to 250 sows (2001)	Object: Piglets
Production of swine food ended (2005)	Object: No further use for swine manure as fertiliser, changing it to exclusively an operational cost
Meeting about the 3S Programme (2006)	Tool: Finding a new tool
Bio-digester installed	Tool: Bio-digester
Combustion systems for testing installed (first half of 2007)	
Son returns home (2007)	Division of labour: Son helps in the operational tasks
Production from 250 to 500 sows and to changed to comodato system	Community: Son
New environmental licence obtained	Object of swine production became more specialised
Construction of new tanks and new warehouses	
New combustion system installed (April 2008)	Object: The installation of the warehouses