LEARNING FROM NATURE: AN ECO-INDUSTRIAL DEVELOPMENT OPPORTUNITY FOR IMPROVED FOOD AND ENERGY SELF-SUFFICIENCY IN THE PROVINCE OF SANTIAGO DE CUBA

by

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Submitted in partial fulfilment of the requirements for the degree of Master of Environmental Studies at

Dalhousie University
Halifax, Nova Scotia
October 2013

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Al pueblo cubano

To the Cuban people
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ABSTRACT

Recently, one of the more significant measures on the part of the Cuban government to enhance resiliency of the existing economy was the announcement of a series of economic and social policy proposals referred to as lineamientos. These emphasize the importance of achieving long-term solutions for sustainable development, including, among other things, a need to improve food and energy self-sufficiency for the country. This research explores the possibility that an eco-industrial development approach could support these goals with a focus in the agricultural and agro-industrial sectors. Two concepts were applied to this intended new paradigm; namely integrated food and energy systems (IFES) and industrial symbiosis (IS). Three municipalities of the eastern province of Santiago de Cuba provided the regional basis for the research and were explored using an asset mapping approach to identify key facilities, material inputs, outputs and flows, infrastructure, and skills sets. Consultations with various stakeholder groups were conducted to gain insight in the current relationships and existing operational conditions that could inform the types of barriers and opportunities related to undertaking exchange and collaborative activities. The findings show that residues and by-products flows from various agricultural and agro-industrial operations can provide the basis for symbiotic networks that enable the generation of energy and added-value products of use to the region. The symbiotic linkages among agricultural and agro-industrial actors can give rise to an integrated food and energy production network (IFEPN) in the region where existing agricultural cooperatives, along with other emerging forms of social enterprise can support the development of this network. Considered a vital approach to solve problems in Cuba, collaboration is their most valuable asset for the successful development of the network.
## LIST OF ABBREVIATIONS AND SYMBOLS USED

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ACPA</td>
<td>Asociación Cubana de Producción Animal (Cuban Association of Animal Production)</td>
</tr>
<tr>
<td>ACTAF</td>
<td>Asociación Cubana de Técnicos Agrícolas y Forestales (Association of Agricultural and Forestry Technicians)</td>
</tr>
<tr>
<td>AD</td>
<td>Anaerobic digestion</td>
</tr>
<tr>
<td>ANAP</td>
<td>Asociación Nacional de Agricultores Pequeños (National Association of Small Farmers)</td>
</tr>
<tr>
<td>BOD</td>
<td>Biochemical Oxygen Demand</td>
</tr>
<tr>
<td>CAI</td>
<td>Complejos agro-industriales (Agro-industrial complex)</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined heat and power</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical Oxygen Demand</td>
</tr>
<tr>
<td>CPA</td>
<td>Cooperativa de Producción y Servicio (Cooperative of Agricultural Production)</td>
</tr>
<tr>
<td>CSS</td>
<td>Cooperativa de Créditos y Servicio (Cooperative of Credit and Services)</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization</td>
</tr>
<tr>
<td>GMOs</td>
<td>Genetically Modified Organisms</td>
</tr>
<tr>
<td>GJ</td>
<td>Gigajoule</td>
</tr>
<tr>
<td>GWh</td>
<td>Gigawatt hour</td>
</tr>
<tr>
<td>IFEPN</td>
<td>Integrated Food and Energy Production Network</td>
</tr>
<tr>
<td>IFES</td>
<td>Integrated Food and Energy Systems</td>
</tr>
<tr>
<td>IMF</td>
<td>International Monetary Fund</td>
</tr>
<tr>
<td>IS</td>
<td>Industrial Symbiosis</td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt hour</td>
</tr>
<tr>
<td>MJ</td>
<td>Megajoule</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-Governmental Organization</td>
</tr>
<tr>
<td>SCCR</td>
<td>Sugarcane crop residues</td>
</tr>
<tr>
<td>SE</td>
<td>South East</td>
</tr>
<tr>
<td>UBPC</td>
<td>Unión Básica de Producción Cooperativa (Basic Union of Cooperative Production)</td>
</tr>
<tr>
<td>Country Code</td>
<td>Full Name</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>USSR</td>
<td>Union of Soviet Socialist Republics</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>WB</td>
<td>World Bank</td>
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ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor Dr. Michelle Adams for her continued support, understanding and guidance during the course of this research. I infinitely appreciate her dedication and interest in supporting me to develop my interests, shown from our first interactions when I was still in Chile and until the process of writing this thesis. My acknowledgements also extend to the members of my committee Dr. Patricia Lane and Dr. Peter Tyedmers, as well as to Martin Willison and Marjorie Willison for their insightful comments and suggestions.

I would also like to thank Dr. José Suárez and Ronoldy Faxas, from the Faculty of Mechanical Engineering at the Universidad de Oriente in Santiago de Cuba, for hosting me and supporting me during the two months I was there doing my field research. Without their cooperation this research would have been impossible to complete. I would also like to extend my deepest gratitude to Norbelys Fajardo, Yunier Córdova, Mirtha Serguera and her family, and all the santiagueros that in one way or another supported me and collaborated in the development of this research.

Finally I want to thank my friends in Canada, who always gave me their friendship and company, to my family and friends in Chile for their love and support, and especially to Mauricio, for being my partner and companion at the distance and for waiting for me patiently in Chile during these two years.

AGRADECIMIENTOS

Quisiera agradecer profundamente a mi supervisora Dr. Michelle Adams por su continuo apoyo, comprensión y orientación durante el transcurso de esta investigación. Agradezco infinitamente su dedicación e interés por apoyarme a desarrollar mis intereses, demostrado desde nuestras primeras interacciones cuando yo aún estaba en Chile y hasta el complejo proceso de la escritura de esta tesis. Mis agradecimientos también se
extienden a los miembros de mi comité Dra. Patricia Lane y Dr. Peter Tyedmers, y a Martin Willison y Marjorie Willison por sus valiosos comentarios y sugerencias.

Asimismo quisiera agradecer al Dr. José Suárez y a Ronoldy Faxas, de la Facultad de Ingeniería Mecánica de la Universidad de Oriente, en Santiago de Cuba, por recibarme y apoyarme durante los dos meses que estuve allí realizando mi investigación. Sin su cooperación este trabajo hubiese sido imposible de completar. Mis agradecimientos también se extienden a Norbelys Fajardo, Yunier Córdova, Mirtha Serguera y su familia, y a todos los santiagueros que de una u otra manera me apoyaron y colaboraron en el desarrollo de esta investigación.

Finalmente quiero agradecer a mis amigos en Canadá, quienes me brindaron siempre su amistad y compañía; a mi familia y amigos en Chile por su apoyo y cariño; y sobre todo a mi amado compañero Mauricio, quien me acompañó a la distancia y me esperó pacientemente en Chile durante estos dos años.
CHAPTER 1 INTRODUCTION

1.1 PROBLEM STATEMENT

In recent years Cuba has initiated a series of socio-economic transformations aimed at revitalizing the country’s economy. Such changes seek to solve the serious structural problems faced by the nation for the past 20 years, such as the lack of hard currency, monetary duality, low productivity within most industrial and agricultural operations/sectors, inefficiencies of the public sector, among others (Pérez Villanueva, 2011; Sánchez Egozcue, 2012). The actions to counteract these problems are contained in a series of social and economic policy guidelines - known as the ‘lineamientos’ – that were approved by the 6th Congress of the Communist Party of Cuba in April of 2011. The ‘lineamientos’ address a broad range of socio-economic and political issues, including new models of enterprise development and economic management to policies that address environmental issues and resource availability. Some of the measures included in the ‘lineamientos’ have an immediate urgency, while others are intended to be developed over the long term. Most solutions have a specific sustainable development focus, especially addressing issues related to food and energy self-sufficiency (Peters, 2012a; Sexto Congreso del Partido Comunista de Cuba, 2011).

Faced with this scenario, the challenge for Cuba is to find new economic structures that do not erode the social achievements that the country has reached related to education, health care and other societally-focused initiatives. A particular emphasis is on improved food and energy self-sufficiency and productivity that does not come at the cost of increased social inequity that is often found in market-based economies of developing and developed nations. This research emerged in light of this challenge and proposes the adoption of a new paradigm of industrial development based on a holistic and systemic view, inspired by the understanding of natural ecosystems, known as industrial ecology. Two concepts that emerge which show promise in terms of contributing to this new paradigm are integrated food and energy systems (IFES) and industrial symbiosis (IS). The main characteristics of these systems are the reliance on renewable sources of
energy, efficient and efficacious resources use through improved utilization and cycling, and the creation of value-added products (Liwarska-Bizukojc et al., 2009; Nielsen, 2007).

The main goal of this research is to understand the potential and to identify specific opportunities to apply the IFES and IS approaches in one of the provinces of eastern Cuba. Existing industrial operations, infrastructure, regional resource flows (with particular attention paid to shortages, scarcities and import dependencies) and key stakeholder relationships were identified. Secondly, the major barriers to integration of such models and strategies were investigated as well as the opportunities offered by the socio-political and economic context. The primary intent of this research has been to develop a contextually relevant approach to Cuban industrial re-development (thereby linking to economic development) that respects the limits (or ‘carrying capacity’) imposed by natural processes, while respecting the socialist character of the Cuban economy, where success is created through synergistic relationships and mutually beneficial exchanges.

This research has embraced the Cuban view for sustainable development and their determination to improve food and energy self-sufficiency and aims to introduce a range of applications and ideas to work on this objective. The overall criteria to prioritize these alternatives are towards food and energy generation, the final criteria is expected to be set by Cubans based on their specific needs and capabilities.

1.2 STUDY PURPOSE

This research examines how the IFES and IS approaches can offer a sustainable pathway to improved productivity and resource allocation and provide solutions to the main problems of the Cuban economic structure: the dependence on imports and the low efficiency of the real economy - industry and agriculture. This is a regional approach, in response to one of the tenets approved by the Congress: the development of local projects and more autonomy to local governments.
Since one of the priority areas for development in Cuba is the eastern region, the basis of this research was an analysis of the opportunities offered by IFES and IS to support integrated food and energy production networks (IFEPN) in the province of Santiago de Cuba. Most industrial activity is concentrated in the municipality of Santiago de Cuba; the balance of the municipalities within the broader province are focused on agricultural and agro-industrial activities (ONE, 2011a). Due to the importance that these other municipalities place on these sectors, the primary objective of this research is to identify the potential integrated networks that can be established among agricultural and agro-industrial sector actors that facilitate the types of increases in resource efficiency and productivity needed in Cuba. The networks that can support the creation of new products and/or the substitution of imported materials are emphasized.

A secondary purpose is to investigate the main constraints and opportunities for the adoption and facilitation of IFES and IS in the Cuban context, and to recommend an iterative approach that can support its appropriate implementation and facilitate its further development where applicable.

1.3 RESEARCH QUESTIONS

In 2010, various government and academic officials expressed an interest in novel industrial development strategies that could be implemented to address the re-development needs of Cuba in a manner in line with the tenets of sustainability. Emerging from relationships between various academic institutions in the Oriente region of Cuba and Dalhousie University was an interest to investigate strategies to this end. As such, based on the: a) urgent need of Cuba to improve its economic performance; b) special need to achieve food and energy self-sufficiency; and c) tenet to protect their social achievements, it was suggested that industrial ecology could be one avenue to support the new paradigm of industrial re-development needed. This option is achieved through the application of the more holistic and systemic view inspired by the understanding of natural ecosystems; conceptualized in this particular instance through integrated food and energy systems (IFES) and industrial symbiosis (IS). These concepts applied appropriately, integrating the specifics of the Cuban socio-political context, can
provide an opportunity for improved food and energy self-sufficiency in the province of Santiago de Cuba.

In order to explore this hypothesis the following questions arise:

1. Who are the main actors (enterprises, cooperatives, institutions) currently participating in the agricultural and agro-industrial sectors regionally?
2. What are the current material (raw materials, products, by-products and residues) and energy flows within and between existing agricultural and agro-industrial operations?
3. What are the potential synergistic opportunities offered by the exchange of residues and by-products between existing and potential actors?
4. How can the potential synergistic linkages be organized in order to support the development of integrated food and energy production networks?
5. What primary enabling factors and barriers exist regarding the development of these integrated food and energy production networks in the province of Santiago de Cuba?

1.4 OUTLINE OF THE THESIS

This thesis is organized into six chapters. Following this first introductory chapter, Chapter Two provides a review of the applicable body of knowledge pertaining to this work. The progression of the information provided in this chapter allows the understanding of the Cuban context, followed by the introduction of the concept of ‘learning from nature’ and the contributions made by different disciplines. The last subsection provides a brief overview of the potential of the eco-industrial development paradigm to inform and drive local and regional development. This is followed by an overview of the research design and methods in Chapter Three. The next two chapters are written as stand-alone manuscripts presenting different aspects of the findings emerging from this research. Both are structured in a format that aims to enable their submission to peer-reviewed journals. Chapter Four focuses on the exploration of the province in terms of the identification of the main economic activities, the actors involved (farmers, cooperatives, state enterprises), the flows of materials and energy that can give rise to
exchange linkages, and the potential networks – at the agricultural and agro-industrial level - that can be established on the basis of these exchanges. A brief section is provided to better understand the potential use of several organic residues and by-products emerging from the various agro activities as energy sources or as raw materials for the production of added-value products. A conceptual model for the design and operation of a ‘representative’ local/regional integrated network is provided – emerging from the study of the potential synergies at various levels (both in geographic scale and technical complexity). Chapter Five expands the discussion towards the barriers and opportunities for the development of such an industrial development model within the specific context of eastern Cuba. The focus is not only the technical and economic considerations, but organizational structure and social factors as well.

The concluding Chapter Six links the findings discussed in the two previous chapters, and provides the main conclusions. It also offers recommendations for both further research and potential implementation strategies dealing with integrated food and energy production networks in the province of Santiago de Cuba.

1.5 REFERENCES

Note to reader: Cuban scholars or other latin scholars cited in this thesis use two last names, e.g. Pérez Villanueva.


CHAPETER 2  BACKGROUND

2.1  CUBAN ECONOMIC CONTEXT

In order to understand the economy in Cuba today it is necessary to briefly review a series of historical events, starting with the revolution of 1959. A transition away from capitalism was initiated between 1959 and 1960, followed by the declaration of a socialist revolution in 1961. This led to the imposition of the US economic blockade in the same year and its extension by the Organization of American States (OAS) in 1964. This meant Cuba was largely isolated from much of the Western Hemisphere and Breton-Woods institutions such as the International Monetary Fund (IMF) or World Bank (WB) (Mesa-Lago, 2004).

The different economic organization policies (more or less oriented to market) that Cuba implemented from 1959 to 1990 were always supported with economic aid and trade from the Union of Soviet Socialist Republics (USSR). This aid began to diminish in 1985, and it fell dramatically at the start of the 1990s with the collapse of the USSR and the socialist block in Eastern Europe. The Soviet Union ceased to import Cuban products and to export consumer, intermediate, and capital goods; loans and credits decreased from the equivalent of six billion US dollars annually to just a few million. In addition, most of the projects executed by soviet technicians were abandoned, and oil imports decreased in a 53% from 1989 to 1992 (Stricker, 2007). The sum of these factors had a substantial effect on the GDP per capita of the country, which decreased in a 40% between 1989 and 1993 (Figure 2.1).

By 1991 Cuba was in the midst of a severe economic crisis that was intensified by a tightening of the US economic blockade. An emergency structural adjustments program to save the economy was launched, labeled the “Special Period in Time of Peace”, but known simply as the ‘Special Period’ (Mesa-Lago, 2004). The trend of these adjustments was towards the market and included measures such as the opening to foreign investment and tourism, a constitutional amendment that allowed private and mixed ownership as means of production, the subdivision of some agricultural state enterprises into
Figure 2.1 GDP per capita, 1989-2009 (Source: Ritter, 2010).

 cooperatives, the reauthorization of self-employment within a limited number of sectors, among others (Mesa-Lago, 2004; Nova González, 2011). These arrangements allowed a modest recovery between 1994 and 1996, but some indicators such as unemployment remained high and even though there were not official reports, information available indicated a rise in inequality (Mesa-Lago, 1998). In 1997, the trend of the reforms towards a more market-based economy was halted, in part, because of the above mentioned social cost (Mesa-Lago, 2004; Pérez Villanueva, 2008).

In July of 2006 Fidel Castro transferred his duties as head of state to his brother Raúl Castro, which meant for Cuba the start of a process of political change. Since then, discussions have continued about the challenges of Cuba’s political and economic transition, reflected in the works of Cuban scholars from University of La Habana, Carlos Alzugaray Treto (2009), Omar Pérez Villanueva (2008, 2011) and Jorge Sánchez Egozcue (2012). Some of the most important policy changes introduced by Raúl Castro in 2010 were the leasing of unused government land to small farmers, shrinking of the state sector, and the expansion of small and medium enterprises (Ritter, 2010). These and others measures have the main objective of overcoming the series of structural problems resulting from the Special Period, such as shortage of foreign currency, dual currencies, segmented markets, problems of inefficiency in public entities, and low resource
efficiency, especially in the agro-industries and agriculture (Pérez Villanueva, 2011). These issues have caused Cuba to be highly dependent on imports (Pérez Villanueva, 2011).

In this context, there was a concern among Cuban authorities about making decisive structural transformations in the country, especially to attain higher productivity (Pérez Villanueva, 2011). The need for this economic system update made necessary the call for the Sixth Congress of the Communist Party. The results of this Congress yielded a series of economic and social policy proposals (“lineamientos”) - encompassing everything from models of economic management to policies for industry, energy and the environment. The timeframes to achieve the various initiatives range from short to long-term, where the long term solutions are placed under a sustainable development approach, with the objective “to lead to a high food and energy self-sufficiency, an efficient use of human capital, a high competitiveness in traditional production” (Sexto Congreso del Partido Comunista de Cuba, 2011, p. 10). These measures also comprise the innovative development of new goods and services of higher value-added. Some specific proposals include incentives for private employment, the creation of non-agricultural cooperatives, development of local projects and increasing autonomy to local governments, and the search for self-sufficiency in food production (Peters, 2012a; Sexto Congreso del Partido Comunista de Cuba, 2011).

2.2 Priority Areas of Development in Cuba

Within the territory there are provinces where there is greater urgency to implement the set of proposals aimed at reinforcing the economy. Among these are the so called eastern (Oriente) provinces: Las Tunas, Granma, Santiago de Cuba and Guantánamo, which are disproportionately affected by inefficient agricultural systems and food insecurity (Grogg, 2009; PMA-IPF, 2001). The factors influencing this situation are not only economic and social, but also related to the environmental characteristics of relief, soil condition and effects caused by natural phenomena (EPNU-MINCEX, 2004). Among these are the salinization of soil, high frequency of droughts, particularly in the southern coastal strip of the province of Guantánamo, and a relatively high seismic activity in the
province of Santiago de Cuba (EPNU-MINCEX, 2004; Fernández Marquez & Pérez de los Reyes, 2009).

2.3 NEW CONSIDERATIONS FOR CUBAN INDUSTRIAL DEVELOPMENT

2.3.1 Learning from Nature

Among all the living species inhabiting planet Earth, *Homo sapiens* is the only one with the ability to manipulate its own environment by taking a large amount of resources, living and non-living, from the biosphere. These extractive and processing activities are shaped by a context determined by culture and social structures, another outstanding human feature.

The impact that these human activities have on the biosphere has been largely recognized by humanity for a long time, more so since the 1960s. It was not until 1986 that a large consensus on the responsibility of human activities over environmental deterioration was reached. Mainly concerned about humanity’s long-term wellbeing, the task was to develop these human activities in ways that do not compromise the ability of future generations to meet their own needs (WCED, 1987). With the publication of “Our common Future” and the Earth Summit agreements of 1992, the North and the South reached an unprecedented agreement on the need for sustainable development (WCED, 1987).

During these last few decades a plethora of concepts, frameworks, models, indicators, policies, etc., have emerged to assist and inform sustainable development. Among them, there are a few concepts that call on learning from nature to guide human development towards sustainability (Ehrenfeld, 2007; Nielsen, 2007). Natural systems have evolved for over 3.5 billion years, showing among other things, their ability to sustain a large diversity of living organisms (Figure 2.2) and to recover after being disturbed, a capability known as resilience (Nielsen, 2007). Consequently, it is plausible to postulate that ecosystems are a positive role model to learn from if humanity is to survive intact in the coming centuries.
Traditionally, extractive and processing activities have been classified into agricultural and industrial activities. Through agriculture, all primary sources of food are obtained from cultivating the land and raising animals. Industrial activities are often associated with the processing of raw materials and manufacture of goods. For the purposes of this research the Latin word *industria*, meaning "diligent activity directed to some purpose" has been adopted to broadly encompass sources of knowledge and theories that associated with either agricultural or industrial studies, as both could be referred to as *industrial* activities. Up to now however, such activities were separate; therefore the “learning from nature” concepts have also emerged separately within these two sectors. Examples of such concepts are agroecology and industrial ecology.

Since a broader concept of industry has been adopted in this research, it has been considered that the industrial ecology concept also applies to agriculture. In the same manner, approaches and tools derived from the discipline of agroecology have been adopted to enrich the industrial ecology concept. In this search of other complementary and integrative concepts, the integrated food and energy systems (IFES) concept was adopted as well.
2.3.2 Agroecology

The detrimental effects on the environment and rural communities caused by industrialized agriculture have resulted in the emergence of sustainable restorative agricultural systems (Kristiansen et al., 2006). Recognized under a wide variety of names, such as organic agriculture, biological agriculture, biodynamic agriculture and ecological agriculture, the main objective of these disciplines is to create agricultural ecosystems that maintain their level of production in the long term with limited or non-use of external non-renewable inputs (Kristiansen et al., 2006). In order to do this, ecological concepts and principles are applied to the design and management of the agricultural system (Gliessman, 2007). The agroecology discipline embraces this definition but it is expanded towards the economic and social dimensions. In this manner, it is defined as the “integrative study of the ecology of the entire food system, encompassing ecological, economic, and social dimensions” (Francis et al., 2003, p. 100). Consequently, the discipline comprises the understanding of internal factors affecting the agricultural system, such as energy flows, species interaction and material cycling, as well as external factors, such as changes in agricultural production practices and external drivers that stress agricultural systems (Tomich et al., 2011). In connection with the internal factors, many management practices have been recovered and promoted, including agroforestry, multi-cropping, cover cropping and mulching, integrated pest management, and integrated livestock-farming to name a few (Altieri, 1995). These methods are characterized for promoting, among other things, biodiversity and resource cycling (e.g., nutrients, energy, and water) (Tomich et al., 2011).

2.3.3 Industrial Ecology

Traditional industrial systems and industrial development date back to the beginning of industrialization. As McDonough and Braungart (2002) have pointed out, these systems were unintentionally designed to “put billions of pounds of toxic materials into the air, water and soil every year; produce some materials so dangerous that they will require constant vigilance by future generations; result in gigantic amounts of waste; put valuable materials in holes all over the planet, where they can never be retrieved; … erode the
diversity of species and cultural practices” (p. 18). Such a system is unlikely to be sustainable in the long term.

As part of the conventions that were agreed upon within the sustainable development agenda, the concept of sustainable industrial development emerged at the United Nations Conference on Environment and Development (UNCED, 1992). One of the major conclusions of this conference, and embodied in the sustainable industrial development concept, is the necessity to integrate environmental and resource considerations into the industrial planning and decision-making processes.

Parallel to these events, different actors in academia and industry were already concerned about the deficiencies of the industrial system. In their seminal article “Strategies for Manufacturing”, Frosch and Gallopoulos (1989) realized that a new paradigm for industrial systems was needed, one based on the integration of material and energy inputs and outputs. In other words, a system that reassembles or function as an analogue of biological systems.

According to Graedel (2010), industrial ecology can be conceptualized as “the study of technological organisms, their use of resources, their potential environmental impacts, and the ways in which their interactions with the natural world could be restructured to enable global sustainability” (p. 63). By integrating conceptual and systemic studies with operational tools, industrial ecology is providing knowledge to define and set goals for sustainable industrial development (Harper & Graedel, 2004).

Conceptual studies make analogies from ecology to design and modify industrial operations. Such analogies not only include concepts, but also methodologies, such as material flow analysis and the characterization of industrial food webs (Harper & Graedel, 2004). Through the use of tools based on industrial ecology principles, such as design for the environment or life-cycle assessment, industrial operations can be improved to generate sustainable products and processes. The systemic approach of industrial ecology studies the behavior of the “technological organisms” in the context of
a larger system (e.g. cluster of companies, industrial parks, regions) (Erkman & Ramaswamy, 2006). This is the approach taken by industrial symbiosis.

2.3.4 Industrial Symbiosis

Industrial symbiosis is effectively a sub-topic of the broader concept of industrial ecology, one that focuses on the integration of, ideally but not necessarily, geographically-related industries and organizations in a network to improve their resource efficiency and sustainability through the exchange of materials, by-products, energy and skills (Chertow, 2000; Laybourn, 2007; Lombardi & Laybourn, 2012). Networking among different facilities can maximize resource use and achieve high productivity outputs while diminishing negative environmental effects (Sokka et al., 2011). At the same time it can trigger innovation in a regional system resulting in new industrial outputs that can be used to either replace regional imports or provide the basis for the production of new value-added products (Green & Randles, 2006; Mirata & Emtairah, 2005). Some scholars note that improved productivity can be attained by detecting complementary activities among existing industries or by creating new systems based on resource sharing (Ashton & Chertow, 2004).

One of the most remarkable examples of an industrial symbiosis strategy is in the small city of Kalundborg, Denmark, where nine public and private enterprises, including a power plant, oil refinery, pharmaceutical plant, as well as farms, are inter-related. They share water, energy, and different by-products from their respective industrial processes, achieving in this manner, high resource efficiency and improved environmental outcomes (Jacobsen, 2006; Kalundburg Symbiosis, 2011). Other programs to support industrial symbiosis have been developed successfully in the UK (National Industrial Symbiosis Programme - NISP), China (National Demonstration Eco-Industrial Park Program) and South Korea (Eco-Industrial Park Development) (Paquin & Howard-Grenville, 2012; Park et al., 2008; Shi et al., 2012).

In the specific context of islands, industrial symbiosis can provide innovative strategies to deal with limited local resources and the assimilative capacity of wastes (Ashton &
Chertow, 2004; Deschenes & Chertow, 2004). It is also recommended as a sustainable development tool for developing countries, especially those where the pattern of resources flow is related to natural resources extraction and agricultural activities (Ramaswamy & Erkman, 2006). Specifically within the Cuban context, it is also suggested that, given its current political leadership, economic conditions, and pursuit of positive social outcomes, industrial symbiosis represents a useful alternative to drive sustainable industrial development (Adams & Cantafio, 2011).

2.3.5 Integrated Food and Energy Systems (IFES)

So far, the conceptual similarities between industrial ecology and agroecology can be seen in that both adopt an “eco-mimetic development” approach (Nielsen, 2007) for the management of agricultural and industrial systems. A wide range of tools and methods to operationalize those principles are proposed in both disciplines. From the agroecology discipline, many tools and methods focus on an efficacious use of resources (energy, water and nutrients) and in the design of a system that maximizes ecosystem services (e.g. nutrient cycling, fresh water). In the industrial ecology discipline, processes and products can be improved through tools such as design for the environment or life-cycle assessment. From a systems point of view, the analysis of material flows and characterizations of industrial food webs can provide the basis for the establishment of symbiotic linkages among different operations that can lead to improved resource use and avoid many of the environmental impacts of industrial systems.

An example to translate some of these measures and tools in the management of agricultural and industrial systems is the concept of IFES. Embraced by the FAO in 2010 in its report “Making integrated food-energy systems work for people and climate” (FAO, 2010a), it describes an approach where food and energy are produced simultaneously, through the efficient and effective use of biomass and by integrating novel productive activities that increase the ‘added-value’ of the entire production system. The main principle behind this concept is crop intensification through the ecosystem approach and simultaneous production of energy (FAO, 2010b).
IFES are described in two typologies. IFES type 1 exist where basic energy resources and food are produced on the same land, through multi-cropping or agroforestry techniques. IFES type 2, however, employs a system that integrates technology and processing/production techniques in a manner that optimizes resource efficiency and maximizes the total food and energy output of the system (FAO, 2010a). Based on this description, it is evident that methods emerging from both agroecology (multi-cropping or agroforestry) and industrial ecology (integration of processing technology) are used in IFES.

Previous concepts describing a similar approach to IFES have been termed as integrated farming/integrated biomass systems (Chan, 1985), integrated biosystems (RIRDC, 2002), sustainable biosystems (Nair, 2009), permaculture (Holmgren, 2002), among a few others. The main feature shared by all of these concepts and IFES (specifically type 2) is the integration of both agricultural and processing operations. Such systems can vary in size and complexity, and include experiences ranging from small farms engaged in permaculture-type operations to integrated livestock/agroforestry systems and fully industrialized agro-industrial operations (Ajayi & Place, 2012; Preston, 2010; Zabaniotou et al., 2010). Farms can integrate Type 2 alternatives along with Type 1 alternatives to maximize the efficiency in energy and food production systems through the implementation of suitably scaled agro-industrial technology and higher-order energy conversion systems such as anaerobic digestion (Chen et al., 2010; Ghimire, 2013).

2.3.6 Linking Eco-Mimetic Development to Local/Regional Development

It has been argued that sustainable development should be operationalized through integrative economic, social, and environmental policies, but that so far, local and regional policies lack such a holistic approach and are often seen as “marginal to more main economic development measures” (Gibbs et al., 2005, p. 172). As a response to these critics, one of the new approaches to ecological modernization and industrial policy is the turn towards a ‘place-based’ eco-economy and industrialization (Horlings & Marsden, 2011; Sepulveda, 2008). It is claimed that through this approach the various forms of ecological resources can be used in a more sustainable and ecological manner,
in economies that are more embedded in local or regional settings (Horlings & Marsden, 2011; Sepulveda, 2008). A similar approach focuses on increasing networking activities in a regional system, favoring the development of a ‘regional networking economy’ or ‘islands of sustainability’ (Wallner & Narodoslawsky, 1994). Particular attention has been paid to the development of rural agri-food webs and their contribution to the development of these ‘place-based’ eco-economies (Donald et al., 2010; Lawson et al., 2008).

Some of the desired features of the webs shaping a place-based eco-economy are the emergence of a new set of production and consumption chains and networks, reconfigured local eco-resources utilization ensuring their sustainability, and the ability to develop new institutional frameworks and to shape the governance of markets (Marsden, 2010).

Based on the characteristics of the ‘place-based’ eco-economy, it can be observed that the ‘eco-mimetic’ approaches offer a wide range of opportunities for the development of this new form of economy. Agroecology, as a science and movement, provides many insights for the development of agri-food networks specifically within small size, rural settings (Uphoff, 2001; Warner, 2007). Industrial ecology and industrial symbiosis offer a wide range of tools to facilitate the development of new networks based on the efficient and innovative use of eco-resources. Furthermore, several authors have made claims regarding the social benefits that can be gained from industrial ecology and industrial symbiosis-based initiatives (Cote & Cohen-Rosenthal, 1998; Dunn & Steinemann, 1998; Gibbs et al., 2005). One manner to achieve this is by developing new employment opportunities, and in particular those linked to the more efficient use and allocation of resources in previously struggling areas or in places where people can be drawn, based upon improving its appeal as an environment within which to work and live (Illesley et al., 2007). Another way is by involving the community in the decision-making process, especially in areas of higher poverty and unemployment (Gibbs et al., 2005).
2.4 REFERENCES

Note to reader: Cuban scholars or other Latin scholars cited in this thesis use two last names, e.g. Pérez Villanueva.


CHAPTER 3 METHODS

The methods of data collection and analysis employed in this research are based on a case study research design. As defined by Yin (2003), case study research “investigates a contemporary phenomenon within its real-life context” (p. 13) and utilizes a wide range of data sources, such as data gathered from fieldwork, documents, archival records, verbal reports and direct observations (Simon et al., 1996; Yin, 2003). It should be noted that this case study will inform the development of ‘eco-mimetic’ strategies, but most importantly it will identify opportunities that are particularly helpful for the region and the actors involved.

Based on Yin’s description of the case study research process, the following sections describe the steps followed to develop this research. It is important to note the iterative nature of this process, where after the initial data collection activities and field visits, new and different approaches were considered to build the research question, conceptual framework and research objectives. An illustrative figure of the methodological process is provided in Figure 3.1.

![Illustrative figure of the methodological process](image)

**Figure 3.1** Case study approach (Adapted from Harris, 2010).
3.1 PLANNING

During the planning phase, the main research question, the type of case study, the unit of analysis (area of study), and the various methods of data collection were defined. Also, the theories and concepts framing this research were explored.

The conceptual framework was built around the concepts of agroecology, industrial ecology and industrial symbiosis, and the integrative concept of IFES. The exploration of these concepts provided a better understanding of the possibilities offered by the ‘eco-mimetic development’ approach to the sustainable development of the region, specifically addressing food and energy self-sufficiency. This conceptual framework also provided guidance to elaborate the research objectives, to determine what data to collect and how to analyze it.

In designing case study-based research, it is important to define a case study research question to better determine the type of case study useful for the research purpose, i.e. explanatory/causal, descriptive and exploratory case study (Yin, 2003). Explanatory research is useful in causal studies, where the main questions to be answered are “how” and/or “why”; descriptive research usually provides a thoughtful articulation of a descriptive theory, while that exploratory research try to answer “what” questions (Mills et al., 2010; Yin, 2003). The research questions that this research is intended to answer are related to exploring the possibilities offered by the ‘eco-mimetic’ approaches to improve food and energy self-sufficiency in the area of study. As such, this case-study research can be defined as an exploratory case study.

As the unit of analysis of this research is the province of Santiago de Cuba, and as this province is of a size of 6 228 km² that it was impossible to cover in the timeframe of this research, it was necessary to choose one or more representative municipalities. Three municipalities were chosen due to their geographical proximity and accessibility, and because of their representativeness of the diversity of agricultural and agro-industrial
activities in the province, such as sugar or fruit processing industries. These included Santiago de Cuba (Capital of the province), San Luis and Songo-La Maya (Figure 3.2).

3.2 DATA COLLECTION

The data upon which this research is based were collected from different sources. It is worth mentioning that as a Spanish native speaker, I was able to collect many relevant data available only in Spanish.

These data informed four main aspects: a) an overview of Cuba and the province of Santiago de Cuba in terms of their economic activities, scarcities and needs, and main imports; b) the identification of key actors in the agriculture and agro-industry sectors, who represent potential members of an IFEPN; c) the flows of materials and energy of different agricultural and agro-industrial activities; and d) the opportunities and constraints for the development of an IFEPN in the province of Santiago de Cuba.
The specific sources of data are described below:

a) Literature: Available data were collected from peer-reviewed papers, newspapers and national statistics data.

b) Structured questionnaires: Six agro-industrial facilities from the three municipalities were identified as potential ‘anchor tenants’ and subsequently completed structured questionnaires, providing data regarding a) material inputs, outputs and flows within the facilities; b) waste management practices; c) any current value-added activities involving by-products or residuals; and d) the facility’s relationship with local economic activities in the region (Appendix A). It should be noted that another eleven facilities were identified; data related to these operations were collected from published sources (e.g. industry statistics) and discussions with industry experts, operators, and researchers.

c) Direct field observations: Guided visits to the six different facilities were performed in order to better understand their processes and waste utilization/management practices.

d) Consultations: Consultations with stakeholders were held to gain insight to the various factors to be considered regarding the development and implementation of potential IFEPNs (Appendix B). A total of ten stakeholders from academia, government, and industry were consulted in interviews ranging from 30 to 45 minutes in length. These consultations drew on a set of questions centered on the challenges of undertaking material exchanges and collaborative activities among members of the agro-industrial and agricultural sectors. Another set of questions was used to explore the opportunities for exchanges and collaborations based on their existing needs and scarcities, instances for collaboration within the institutional framework, and current policies. This information was complemented and validated with official Cuban

1 In the industrial ecology literature, an anchor tenant is a major facility, whose inputs and outputs provide foundational opportunities for the establishment of material exchanges with other facilities. Typical anchor tenants include thermal generation stations and pulp and paper mills (Lowe, 1997).
documents. It should be noted that questions were specific to the individuals’ professional position and dealt with professional practices, experience and knowledge. They were not subjects of ‘human-based research’.

Field data were collected during the months on June and July of 2012. The list of people consulted and visited facilities is included in Appendix C.

Potential sources of errors and bias are associated to the data gathered through the structured questionnaires and consultations. As the questionnaires were applied during the visits to each of the six facilities, much of the information was not readily available and only a portion of the data was provided. To complete this information, estimations also integrated data from available literature, Cuba statistics yearbook, and reports for each type of industry. The data for the other eleven facilities identified was estimated using only sources of secondary data. The consultations may be subject to bias since the professional point of view of each interviewed also respond to the official discourse of the Communist Party of Cuba.

3.3 ANALYSIS

The data gathered in this research allowed the identification of potential members of an integrated network from the agricultural and agro-industrial sectors, their associated flows of energy and materials (with a special focus on valuable by-products and residues), and also their organizational and administrative dynamics. Potential links were then initially established based on the utility of the exchange of residues and by-products, or the opportunity to develop new product streams. A focus was given to the potentiality for energy creation/generation; therefore, the energy potential of each material stream was calculated. When the energetic potential was not sufficient to support an exchange, alternatives were selected based on their potential to substitute inputs that are currently imported. Finally, literature and local representatives were consulted for insight related to alternatives whose utility may be unique to Cuba. In all cases, alternatives were developed through the lens of improving Cuba’s energy and food self-sufficiency.

The second part of the analysis involved the identification of the main barriers and
opportunities in Cuba to develop alternatives of integrated food and energy production. Information collection comprised two major parts: a) a literature review of relevant research, and b) consultations with stakeholders. The literature review was directed to research informing the main barriers and forces driving the implementation of renewable energy technologies in rural settings and diversified farming systems, with a special focus on developing countries. It also covered relevant research on the implementation of industrial symbiosis initiatives and associated theories. Once the main barriers and opportunities were identified, the specific Cuban situation was compared through information gathered from consultations, as well as from the literature and official Cuban documents, such as the economic and social policy guidelines (‘lineamientos’).

3.4 References


CHAPTER 4  FOSTERING FOOD AND ENERGY SECURITY THROUGH THE APPLICATION OF INDUSTRIAL SYMBIOSIS: STUDY OF THE PROVINCE OF SANTIAGO DE CUBA

Note to reader – this chapter was written as a ‘stand-alone’ article intended for journal publication.

4.1  INTRODUCTION

Regions facing food and energy insecurity are widespread in the world and are searching for effective and sustainable solutions (Godfray et al., 2010). Reasons for such insecurity are as varied as the countries that experience this challenge. In the case of Cuba, it faced dramatic transformations after the collapse of the Soviet Union, its most significant trading partner. Since that time, the lack of access to international credit and – more importantly – fossil fuels, has led to ongoing, widespread energy shortages and food scarcity. This is particularly acute in the Eastern region of the island.

With the demise of the Soviet Union, Cuba lost its major providers of oil, fertilizers, animal feed, machinery parts and technology, a situation that was exacerbated by the US economic blockade. This gave way to a profound economic crisis, an effect of which was the decapitalization of the productive base and a dramatic reduction in the efficiency of industry, particularly the agro-industrial sector (Mesa-Lago, 2006). The productive sector is still trying to recover from this ‘Special Period’, a goal not easily accomplished. Internal factors such as inefficiencies in a top-heavy, restrictive public sector, and external factors - such as the continuing US economic blockade and weather events unprecedented in their destructive impact on the island’s infrastructure and resource based sectors – have hampered the country’s attempts at improving their self-sufficiency in these areas (Sánchez Egozcue, 2012).

In an attempt to integrate more resilience into its economy, Cuba introduced a series of economic and social policy proposals during the 6th Congress of the Communist Party (Sexto Congreso del Partido Comunista de Cuba, 2011). The guidelines - or
‘lineamientos’ - are intended to be developed over both the short and long term, and address a broad range of socio-economic and political issues. These include new models of enterprise development and economic management at one end of the spectrum to policies aimed at addressing environment issues and resource availability at the other. The long-term solutions have a sustainable development focus, specifically addressing issues related to “food and energy self-sufficiency, an efficient use of human capital, a high competitiveness in traditional production, as well as the development of new goods and services of high added-value” (Sexto Congreso del Partido Comunista de Cuba, 2011, p. 10). Within this scenario, tools or concepts employed to try and achieve these long-term solutions must embody a special emphasis on the efficacious use of the island’s limited resources, as well as in their culture around solidarity and communal values.

A concept that could potentially contribute to this focus emerged in 2010 when the FAO first coined the phrase “integrated food and energy systems” (IFES) (FAO, 2010a). This describes an approach in which food and energy are produced simultaneously, through both an efficient and effective use of biomass, and by integrating novel productive activities that increase the ‘value-added’ of the entire production system. IFES are described in two typologies. IFES type 1 exist where basic energy resources and food are produced on the same land, through multi-cropping and agroforestry techniques. IFES type 2, however, employs a system that integrates technology and processing/production techniques in a manner that optimizes resource efficiency and maximizes the total food and energy output of the system (FAO, 2010a).

Examples of such systems range from small farms engaged in permaculture type operations (type 1) to integrated livestock/agroforestry systems and fully industrialized agro-industrial operations (Ajayi & Place, 2012; Preston, 2010; Zabaniotou et al., 2010). Farms can integrate type 2 alternatives along with type 1 alternatives to maximize the efficiency in energy and food production systems through the implementation of suitably scaled agro-industrial technology and higher-order energy conversion systems such as anaerobic digestion (Chen et al., 2010; Ghimire, 2013).
For the purposes of this research, we expanded the conceptualization of IFES with the aim of connecting these individual systems into broader networks of exchange and collaboration, based on the concept of industrial symbiosis (IS). Industrial symbiosis is focused on supporting the creation of industrial ecosystems where, often supported by the benefits of geographical proximity, disparate industrial actors develop a network for the purpose of exchanging materials, residues, by-products, energy and water, in order to improve the resource efficiency and sustainability of the overall system (as well as individually) (Chertow, 2000; Lombardi & Laybourn, 2012). Equally important to the biophysical networks are those exchanging knowledge and expertise among people and institutions (Ashton & Bain, 2012). A broader concept of industry has also been adopted in this study - based on its Latin etymology “diligent activity directed to some purpose”- to expand the definition of industrial symbiosis to more aptly include the agricultural sector.

The aim of this research is to develop a better understanding of how integrated food and energy production networks could be specifically applied within the Cuban agricultural and agro-industrial sectors as an innovative approach to improve food and energy security. As one of the nation’s priority areas is sustainable development for Cuba’s Oriente (Eastern) region, the Province of Santiago de Cuba in SE Cuba was chosen to be the location of the study. Its existing operations, infrastructure, resource flows and scarcities, and actor relationships provided the basis of the data used for evaluation.

The first sections of this chapter describe the regional context and identify potential members of an agricultural and agro-industrial network in three municipalities of the province, along with the main residues and by-products of key facilities. A brief section follows that reflects on the various alternative uses for these resources identified within the literature. This will aid in developing the links that can be created to support symbiotic networks among the different actors and at the same time, address the specific needs and resource constraints identified (through this research) in the region. This will include descriptions of the various scales of networks that emerge to suit agriculture,
medium-size, and large-size agro-industries. A conceptual model for a regional network for integrated food and energy production is then provided based upon the development of these three scenarios. Finally, the main technical challenges and opportunities for the development of the networks are described.

4.2 BACKGROUND INFORMATION

The province of Santiago de Cuba is located in the south eastern region of Cuba and represents 5.6% of the country’s total area (6 227 km²). It has a population of just over 1 million inhabitants at a density of ~168/km² and is divided into nine municipalities: Contramaestre, Guamá, Mella, Palma Soriano, San Luis, Santiago de Cuba, Segundo Frente, Songo-La Maya, and Tercer Frente (Figure 3.1). The biggest municipality in size and population is Santiago de Cuba at 1 031 km² with ~490 000 inhabitants (ONE, 2011a). Most of the industrial activity takes place in this municipality, e.g. oil refinery, thermal power generation and cement production. The rest of the municipalities have a high rural population and their economic activities rely mostly on the agricultural and food industrial sectors (ONE, 2011a).

The bulk of the raw resources used within industrial operations (energy and materials) are imported. Energy generation is heavily dependent on fossil fuels; in Santiago de Cuba electricity is generated in thermal generation stations, either fueled by a mixture of fuel oil and Bunker C (called “power stations”) or by liquid gasoline or fuel oil alone (referred to as “power generators”) (Pérez, 2008). Fuel is either imported or produced on the island; however, domestic oil has a high sulphur content, which damages the generation infrastructure (Suárez et al., 2012). Imported oil reached a peak of 4 848 Mt in 2008; peak domestic production reached 3 003 Mt that same year (ONE, 2011b).

Despite the remarkable success in sustainable farming in the urban and suburban areas of the country, agricultural operations still largely follow a heavily industrialized model requiring high levels of external inputs (Altieri & Funes-Monzote, 2012). At this point, many of these inputs are imported, which creates increasingly problematic vulnerabilities. The dependence on imported fertilizers, for example, created a situation where there was
a 70% deficit between need and availability of fertilizers in the municipality of San Luis in 2011 (Suárez, 2012). In terms of food commodities, there is a pattern of dependence on vegetable oil, legumes and cereals (rice and wheat for human consumption, and corn and soy bean for animal feed), and powdered milk (FAOSTAT, 2009). Any reduction in food imports in recent years (for example 2012) can be characterized more so by the nation’s fiscal challenges rather than an increase in national agricultural productivity.

4.3 METHODS OF DATA COLLECTION AND ANALYSIS

Three municipalities from the province of Santiago de Cuba were chosen due to their geographical accessibility and because they represent the diversity of agricultural and agro-industrial activities in the province. These included Santiago de Cuba (Capital of the province), San Luis and Songo-La Maya (Figure 3.2). Field data were collected between June and July of 2012, using an asset mapping approach\(^2\) to identify key actors from the agricultural and agro-industrial sectors and characterize specific elements of their operations. Six agro-industrial facilities from the three municipalities were identified as potential anchor tenants and were subsequently involved in a process of structured enquiry using questionnaires to gather data regarding: a) material inputs, outputs and flows within the facilities; b) waste management practices; c) any current ‘value-add’ activities involving by-products or residuals; and d) the facility’s relationship with local economic activities in the region. Observations of the operational processes also helped characterize norms and typical practices within the facilities. Another eleven facilities were also identified and data were collected from published sources (e.g. industry statistics) and discussions with industry experts, operators, and researchers. Potential links were then initially established based upon the utility of the exchange of residues and by-products, or the opportunity to develop new product streams. In light of Cuba’s severe energy security issues, priority was given to those links that resulted in new opportunities for functionally valuable energy provisioning; and to this ends, the energy potential of each material stream was calculated. In addition, strong preference was given to linkages

\(^2\) A methodology originally developed by urban planners to investigate the communities resources’ that along with external resources, can drive a community’s redevelopment (Kretzmann, 1993). In this research, this methodology is adapted to investigate the particular needs and available resources of the province of Santiago de Cuba for the development of integrated food and energy production networks.
that could potentially result in input substitutions for resources currently imported. Finally, literature and local representatives were consulted for insight related to alternatives whose utility may be unique to Cuba. In all cases, alternatives were developed that could somehow respond to Cuba’s focus on improving energy and food security, and internal accessibility.

4.4 IDENTIFICATION AND CHARACTERIZATION OF APPLICABLE SECTORS

4.4.1 Agriculture

According to the National Office of Statistics of Cuba, agricultural activities are classified in two groups: sugarcane production and non-sugarcane production. Non-sugarcane production includes vegetables, legumes and cereals, citrus fruits, fruits, coffee, and tobacco (ONE, 2012a). In the province of Santiago de Cuba, the most intensively cultivated non-sugarcane agricultural crops are tubers and bananas, followed by vegetables, legumes and cereals (rice and corn). Fruits and citrus fruits are also important crops in the province; mangos and oranges being the most intensively cultivated (ONE, 2012a).

Livestock production is related to both meat and ‘other animal’ products. For example, most of the cattle-rearing is related to the dairy industry; the demand for meat for human consumption is met primarily through pork production, although the poultry sector does supply some meat. Egg production is the primary focus of poultry operations. Sheep and goat farms are much smaller in number and revolve around the production of meat and milk.

Main residues produced in agricultural activities are arable crop residues such as straw or husks, stalk and leaves, manure and slurries, and animal bedding such as poultry litter. The existing degree of waste management currently varies significantly from farm to farm. However, there is a wide network of farmers who are currently benefiting from sustainable farming techniques that, amongst other things, reduce input intensities by making better, more innovative use of agricultural residues (Machin Sosa et al., 2010).
Agricultural activities are managed by the state, the cooperative sector and by small farmers. State production is directed by agricultural and forestry state-enterprises, sugarcane agro-industrial complexes (CAI, *Complejos agro-industriales*) and other state entities that develop agricultural, livestock or forestry activities. Presently, the largest proportion of the land holding is in the hands of the cooperative sector. In Santiago de Cuba they also manage the largest portion of cultivated agricultural area (58% of the total agricultural land). The state manages 37% (ONE, 2012a).

The cooperative sector embraces three forms of cooperative entities: the *Unidades Básicas de Producción Cooperativa* (UBPC), *Cooperativas de Producción Agropecuaria* (CPA) and *Cooperativas de Créditos y Servicio* (CSS). While UBPCs, CPAs and CSSs share a cooperative underpinning, their history and functioning are different. CSSs were established in the 1960s with the objective of accessing credit and major equipment purchases collectively. However, each farmer independently owns his or her land and is free to leave the cooperative without losing his or her access to it (Nova González, 2011). CPAs were founded in the 1970s and represent a more socialized form of production, in which each farmer sells her or his land and means of production to the cooperative, becoming a collective owner and worker (Nova González, 2011). UBPCs were the last cooperative form to be founded in 1993, after the disaggregation of large state farms into smaller units of production. While the land is owned by the state, it is ceded to the cooperative via the use of ‘usufruct rights’ of undefined time (Peters, 2012b). At the last census (2011), there were 324 UBPC, 248 CSS and 97 CPA in the province of Santiago de Cuba (ONE, 2012a). UBPCs range in size from 228 ha to 1596 ha (Nova González, 2003), while CPAs have an average size of 460 ha (ONE, 2012a).

The operational infrastructure of a cooperative depends on the focus of their activities, e.g. sugarcane, coffee, fruits, tobacco, livestock farming, etc. For example, a typical sugarcane cooperative of ~1200 hectares will allocate its holding to sugarcane growth (74%), food crop production for its members (3%), livestock farming (3%), and land for housing or any other infrastructure (20%) (Royce, 1996). A 743 hectares dairy cooperative farm in the region, however, allocates 61% of its land to dairy farming; the
balance is used for animal forage growth (12%), sugarcane growth (2%), silvo-pastoral land (2%), food crops growth (6%), and housing/other infrastructure (17%). It is worth mentioning that neither animal forage nor food crops production meet the consumption needs of animals and members of the cooperative (Sanz Medina, 2006).

4.4.2 Food Processing Industry

4.4.2.1 Sugar

Sugarcane processing is overseen by the Ministry of Agriculture and managed through the state-enterprise “AZCUBA”, which has divisions in each of the provinces. Within the study area there is one sugar mill, “Paquito Rosales”, located in the municipality of San Luis (Figure 4.1). “Paquito Rosales” has an installed capacity to mill 2 700 tonnes of clean sugarcane a day. The facility, however, does not operate at capacity due to the low yields of sugarcane, as a result of, among other factors, the low content of nutrients and organic matter in the soil and the consequent need for fertilizers (Fernández Marquez & Pérez de los Reyes, 2009). The main products are cane sugar and thermally generated electricity fuelled by bagasse, a lignocellulosic residue generated during the first stages of the milling process. The thermal generation system also produces heat and steam for use on-site.

The other major residues from sugarcane processing include: a) molasses, which is sold to rum distilleries; b) filter cake, which is sold for fertilizer production; c) ash, which is currently disposed of in landfills; and d) wastewater, which is ideally treated in an oxidation pond before being released back to the environment.

Finally, several sugarcane cleaning facilities are associated with the sugar mill, where sugarcane crop residue (SCCR) - consisting of green and dry leaves and cane tops - are separated from the cane stalks. The current practice, however, is for the SCCR to be burnt in open fields where no energy recovery is possible.

4.4.2.2 Fruit and Vegetable Products
Fruit processing operations are overseen by the Ministry of Food Industry and managed by the state enterprise “Unión de Conservas de Vegetales”. Nine divisions across the country oversee the production of canned fruit and vegetables, compotes, jams, juices, etc. In Santiago de Cuba province two facilities were identified: a small plant in La Maya (Songo-La Maya municipality) and a large operation in El Caney (Santiago de Cuba) (Figure 4.1). During the harvest season (~May – Jul) the smaller facility process 16 t/day of fruit (mango, sapote or tamarind), its main products being fruit pulp (9 t/d), jam and concentrate. El Caney facility processes 80 t/day of fruit (mango); the main product is pulp. This pulp is used during off-season to produce compote (Alfaro Vives et al., 2001). Both facilities generate both solid waste (peel, coarse fibrous pulp and kernel) and liquid waste (wastewater). Currently, solid materials are typically used as pig feed; however liquid treatment varies. In La Maya the wastewater is treated in an oxidation pond, while the El Caney facility discharges untreated wastewater into the San Juan river (Alfaro Vives et al., 2001).

4.4.2.3 Coffee

Coffee processing operations are overseen by the Ministry of Agriculture and managed by local state-enterprises. Primary processing of the coffee cherry takes place in each of the decentralized farms and cooperatives where it is grown. The main residue from this on-site process is the coffee pulp/mucilage, which represents ~82% of the total weight of the coffee cherry and is high in sugars, pectin and related compounds. Currently, this material is typically left to sun dry and then be used as compost. The green coffee beans are sent to dry processing plants, which are usually centralized in small towns. The main residue of the drying process is coffee husk or parchment, a cellulosic layer that surrounds the coffee bean. Two small coffee dry processing plants were identified in the municipalities of Songo-La Maya and San Luis (Figure 4.1).

4.4.2.4 Meat
Animal slaughter and meat processing is overseen by the Ministry of Food Industry and managed by a state-enterprise (“Unión de la Carne, Aceites y Grasas Comestibles”), which has sixteen divisions across the country. A small-size beef slaughterhouse was identified in the study area (San Luis); a poultry operation is located in El Brujo (Santiago de Cuba) (Figure 4.1). In addition to a poultry slaughter facility, a rendering facility is co-located. Residues include offal, yellow tallow (fat) and wastewater rich in proteins and fats. None are utilized to any significant degree.

4.4.2.5 Dairy Products

Dairy operations in the country are overseen by the Ministry of Food Industry and managed by a state-enterprise (“Union Láctea”), which has divisions in each province. Santiago de Cuba division owns several facilities, where the most notable is located in El Caney (Santiago de Cuba) (Figure 4.1). Its main products are powdered milk, yogurt, and cheese. The main residue generated at this facility is wastewater, and significant amounts of waste heat are generated by the refrigeration system. Whey, another important by-product from the dairy industry, is not recovered at this facility. At present, all wastewater is discharged into the San Juan river. The negative impacts of this practice have been documented (Olivares-Calzado et al., 2012). It should also be noted that this facility is also capable of processing soy and produces soy milk and soy yogurt, in addition to its dairy products.

4.4.3 Wood Industry

Forestry activities are overseen by the Ministry of Agriculture and managed by local state-enterprises. In Santiago de Cuba province, the Forestry enterprise “Gran Piedra Baconao” manages both forestry activities and the sawmill in El Brujo (Santiago de Cuba). Two small sawmills were also identified in San Luis (“Chamarreta”) and Songo-La Maya (Figure 4.1). Wood chips and sawdust are the main residues from sawmilling.
Although the wood chips from “El Brujo” are used in a gasifier to generate electricity, the rest of this forest biomass is not meaningfully utilized.

4.5 IDENTIFICATION OF RESIDUES AND BY-PRODUCTS USE ALTERNATIVES

The bulk of the residues and by-products generated by the various activities identified above are organics with the notable exception of the ash generated in the sugar processing facilities. These organic waste streams include a wide variety of compounds that may have further use including lignocellulosic materials, polysaccharides, proteins, lipids, acids, and other potential plant and animal nutrients (e.g. vitamins, minerals, fibers) (Ajila et al., 2012a). Lignocelluloses are a component present in the structural parts of wood, fruits and vegetables, such as peels, straw, husks or bagasse, which in Cuba are typically discarded during harvesting and processing. Such materials retain their energy and nutritional values during processing and therefore can be utilized for alternative purposes. Ajila et al. (2012a), for example, identified five categories of use for these materials including: a) material ingredients for alternative food products and/or livestock feed; b) carbon source for microorganism growth (edible/medicinal fungi,
algae, etc.); c) high quality compost/soil amendment; d) direct fuel source or materials for biofuel production (e.g. biogas); and e) ‘other’ high value-added products.

Table 4.1 provides an overview of the material flow amounts and characteristics for each agro-industrial system present in the study area, and a list of potential uses for each material stream. The information is based upon inputs from literature, and the field data related to existing infrastructure, resource needs and available resources. It should be noted that where quantitative or analytical data do not exist or could not be calculated, qualitative descriptions are supplied, based on literature and field observation.

### 4.5.1 Source of Food/Feed Ingredients

Organic residues and by-products have been used as animal feed since the beginning of animal domestication; therefore, this alternative is deeply rooted in traditional knowledge (Dineley, 2006). One of its benefits is that it poses minimal risks to animals and is rich in nutrients. Livestock and poultry can be fed with food residues and by-products directly or after a modification process, such as fermentation. There is a wide variety of food residues and by-products that can be used as animal feed, each present different characteristics that must be considered separately in weighing risks and benefits, such as moisture and nutrient content, or the presence of physical and microbial contaminants and toxins (Ajila et al., 2012b). The primary advantages of using this material as animal feed is that it can help address the current scarcity of more traditional animal feeds in Cuba, such as grains and root crops. This reduces the economic strain on Cuba to purchase livestock feed from the international market and also increases the amount of arable land that can be dedicated to human food production (Steinfield et al., 2006). Some novel applications developed in Cuba to address the production of animal feed are the use of sugar industry residues and by-products. These applications include the use of wastewater and filter cake in the manufacture of animal feed (named “GARANVER”) to supplement up to 50% of cattle’s diet (Gil et al., 1994; Solano Silvera et al., 2003).
Table 4.1 Flows of residues and by-products of the identified facilities and their potential uses/possible value.

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Facility</th>
<th>Residue</th>
<th>Unit of measurement</th>
<th>Flow</th>
<th>Characteristics</th>
<th>Alternative uses</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Luis</td>
<td>Sugarcane cleaning facility &quot;Santa Cruz&quot;</td>
<td>SCCR&lt;sup&gt;a&lt;/sup&gt;</td>
<td>t/harvest season</td>
<td>31,500</td>
<td>Heat content (MJ/kg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.2 <em>Electricity generation through combustion</em>; bioethanol production; animal feed (fodder, forage and silage); soil amendment; textile fiber</td>
<td>(Costa et al., 2013; Dawson &amp; Boopathy, 2007; Martin, 2009; Reyes Montiel et al., 2003; Sanomiya et al., 2006)</td>
</tr>
<tr>
<td></td>
<td>Sugar mill &quot;Paquito Rosales&quot;</td>
<td>Bagasse&lt;sup&gt;a&lt;/sup&gt;</td>
<td>t/harvest season</td>
<td>124,000</td>
<td>Heat content (MJ/kg)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8 Fuel for thermal electricity generation; bioethanol production; animal feed (bagasse pith/molasses/urea mixture); bioactive compounds production; composite packaging materials</td>
<td>(Alonso Pippo et al., 2007; Loh et al., 2013; Martin, 2009; Pandey et al., 2000a; Soccol et al., 2010; Solano Silvera et al., 2003)</td>
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<tr>
<td></td>
<td></td>
<td>Molasses&lt;sup&gt;a&lt;/sup&gt;</td>
<td>t/harvest season</td>
<td>11,400</td>
<td>Total fermentable sugars (%)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>45-55 <em>Bioethanol production</em>; animal feed production (molasses fresh or dry, molasses mixed with urea and minerals, mixed with torula yeast, fermented molasses); bioactive compounds production</td>
<td>(Martin, 2009; Meunchang et al., 2005; Soccol et al., 2006)</td>
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<tr>
<td></td>
<td></td>
<td>Ash&lt;sup&gt;a&lt;/sup&gt;</td>
<td>t/harvest season</td>
<td>512</td>
<td>Macronutrients and micronutrients content (ppm)&lt;sup&gt;f&lt;/sup&gt;</td>
<td>P: 110 Soil amendment; additive in cement and concrete</td>
<td>(Khan &amp; Qasim, 2008; Sales &amp; Lima, 2010)</td>
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<td></td>
<td></td>
<td>Wastewater&lt;sup&gt;g&lt;/sup&gt;</td>
<td>m&lt;sup&gt;3&lt;/sup&gt;/harvest season</td>
<td>8,100</td>
<td>COD content (mg COD/L)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19,735 <em>Biogas production</em>; balanced animal feed production (known as GARANVER in Cuba); soil amendment component (known as REINAZ in Cuba); fertirrigation</td>
<td>(Solano Silvera et al., 2003)</td>
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<td></td>
<td></td>
<td>Filtercake&lt;sup&gt;a&lt;/sup&gt;</td>
<td>t/harvest season</td>
<td>17,900</td>
<td>Volatile organic solids (g/kg)&lt;sup&gt;j&lt;/sup&gt;</td>
<td>48 <em>Biogas production</em>; balanced animal feed (known as GICABU and GARANVER); soil amendment component (known as REINAZ)</td>
<td>(Martin, 2009)</td>
</tr>
<tr>
<td></td>
<td>Small slaughter-house</td>
<td>Cattle offal (primarily protein, fats, bone)&lt;sup&gt;j&lt;/sup&gt;</td>
<td>t/year</td>
<td>128</td>
<td>Volatile organic solids (g/kg)&lt;sup&gt;j&lt;/sup&gt;</td>
<td>150-200 <em>Biogas production</em>; biodiesel production (from tallow); animal feed (hemolyzed, ruminal content)</td>
<td>(Martin, 2009)</td>
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<td></td>
<td></td>
<td>Cattle slaughter wastewater&lt;sup&gt;i&lt;/sup&gt;</td>
<td>m&lt;sup&gt;3&lt;/sup&gt;/year</td>
<td>2,630</td>
<td>COD content (mg COD/L)&lt;sup&gt;l&lt;/sup&gt;</td>
<td>5,100 <em>Biogas production</em></td>
<td></td>
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<tr>
<td>Municipality</td>
<td>Facility</td>
<td>Residue</td>
<td>Unit of measurement</td>
<td>Flow</td>
<td>Characteristics*</td>
<td>Alternative uses</td>
<td>Reference</td>
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<tr>
<td>San Luis</td>
<td>Tobacco factory</td>
<td>Midribs*</td>
<td>t/year</td>
<td>1.2</td>
<td></td>
<td>Natural pesticide; substrate for mushroom growth</td>
<td>(Rao, 2011; Reyes et al., 2004)</td>
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<td></td>
<td>Dry beneficio &quot;Cafetalera San Luis&quot;</td>
<td>Coffee husk*</td>
<td>t/harvest season</td>
<td>185</td>
<td>Heat content (MJ/kg)*</td>
<td>Briquettes/gasification; bioactive compounds production; substrate for mushroom growth; composting; production of particleboard</td>
<td>(Bekalo &amp; Reinhardt, 2010; Pandey et al., 2000b; Suárez et al., 2003)</td>
</tr>
<tr>
<td></td>
<td>Decentralized small farms</td>
<td>Coffee pulp*</td>
<td>Collective total (t/harvest season)</td>
<td>1,600</td>
<td>Sugar (%)*</td>
<td>Production of compost, aminoacids, cultivation of mushrooms</td>
<td>(Adams &amp; Ghaly, 2007)</td>
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<td></td>
<td>Protein (%)*</td>
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<tr>
<td>Santiago de Cuba-El Caney</td>
<td>Compotes factory &quot;El Caney&quot;</td>
<td>Solid wastes (peel, kernel)*</td>
<td>t/harvest season</td>
<td>2,400</td>
<td>Volatile organic solids (g/kg)* Pectin content*</td>
<td>Biogas production/animal feed (ensiled peels)/bioactive compounds production (pectin); composting; cellulose nanocrystals</td>
<td>(Guzmán et al., 2010; Henrique et al., 2013; Misra et al., 2003; Santana-Méridas et al., 2012)</td>
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<tr>
<td></td>
<td></td>
<td>Wastewater*</td>
<td>m³/harvest</td>
<td>15,000</td>
<td>COD content (mg COD/L)*</td>
<td>Biogas production</td>
<td>(Demirel et al., 2005; Siso, 1996)</td>
</tr>
<tr>
<td></td>
<td>Dairy processing facility &quot;El Caney&quot;</td>
<td>Wastewater*</td>
<td>m³/year</td>
<td>104,000</td>
<td>COD content (mg COD/L)*</td>
<td>Biogas production; bioethanol production;</td>
<td>(Demian, 2007; Siso, 1996)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whey*</td>
<td>m³/year</td>
<td>960</td>
<td>Protein content (%w/v)*</td>
<td>Animal feed (mixtures with molasses or soya flour); cheese production; bioactive compounds production</td>
<td>(Cai et al., 2013; Croan, 2000; Lesme Jaén &amp; Oliva Ruiz, 2010)</td>
</tr>
<tr>
<td></td>
<td>Sawmill &quot;El Brujo&quot;</td>
<td>Woodchips and sawdust*</td>
<td>t/year</td>
<td>11,600</td>
<td>Heat content (MJ/kg)*</td>
<td>Electricity generation through gasification/briquettes; substrate for mushroom growth; composite panel production</td>
<td>(Cai et al., 2013; Croan, 2000; Lesme Jaén &amp; Oliva Ruiz, 2010)</td>
</tr>
<tr>
<td></td>
<td>Pig farm</td>
<td>Manure*</td>
<td>t/year</td>
<td>1,730</td>
<td>Volatile organic solids (g/kg)*</td>
<td>Biogas production; soil amendment (compost)</td>
<td>(Cantrell et al., 2007; Martin, 2009; Misra et al., 2003; Thien Thu et al., 2012)</td>
</tr>
<tr>
<td></td>
<td>Poultry farm</td>
<td>Manure*</td>
<td>t/year</td>
<td>1,740</td>
<td>Volatile organic solids (g/kg)*</td>
<td>Biogas production; soil amendment (compost)</td>
<td>(Cantrell et al., 2007; Martin, 2009; Misra et al., 2003; Thien Thu et al., 2012)</td>
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<tr>
<td>Municipality</td>
<td>Facility</td>
<td>Residue</td>
<td>Unit of measurement</td>
<td>Flow</td>
<td>Characteristics*</td>
<td>Alternative uses</td>
<td>Reference</td>
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<tr>
<td>Fruit pulp mill</td>
<td>&quot;Ponupo&quot;</td>
<td>Solid wastes (peel, kernel)</td>
<td>t/harvest season</td>
<td>480</td>
<td>Volatile organic solids (g/kg)</td>
<td>Biogas production/animal feed (ensiled peels)/bioactive compounds production (pectin); soil amendment; cellulose nanocrystals</td>
<td>(Cantrell et al., 2007; Martin, 2009; Misra et al., 2003; Thien Thu et al., 2012)</td>
</tr>
<tr>
<td>Wastewater</td>
<td></td>
<td>m³/harvest season</td>
<td>3,000</td>
<td></td>
<td>COD content (mg COD/L)</td>
<td>Biogas production</td>
<td></td>
</tr>
<tr>
<td>Dry beneficio</td>
<td>&quot;Café La Maya&quot;</td>
<td>Coffee husk</td>
<td>t/harvest season</td>
<td>22.5</td>
<td>Heat content (MJ/kg)</td>
<td>Briquettes/gasification; bioactive compounds production; substrate for mushroom growth; composting; production of particleboard</td>
<td>(Bekalo &amp; Reinhardt, 2010; Pandey et al., 2000b; Suárez et al., 2003)</td>
</tr>
<tr>
<td>Decentralized small farms</td>
<td>Coffee pulp</td>
<td>Collective total (t/harvest season)</td>
<td>200</td>
<td>Sugar (%)</td>
<td>14.4</td>
<td>Production of compost, aminoacids, cultivation of mushrooms</td>
<td>(Adams &amp; Ghaly, 2007)</td>
</tr>
<tr>
<td>Sawmill</td>
<td>&quot;La Maya&quot;</td>
<td>Woodchips and sawdust</td>
<td>t/year</td>
<td>250</td>
<td>Heat content (MJ/kg)</td>
<td>Electricity generation through gasification/briquettes; substrate for mushroom growth; biobased composite panel production</td>
<td>(Cai et al., 2013; Croan, 2000; Lesme Jaén &amp; Oliva Ruiz, 2010)</td>
</tr>
<tr>
<td>Tobacco factory</td>
<td>Midribs</td>
<td>t/year</td>
<td>1.2</td>
<td></td>
<td>Nicotine and cellulose content</td>
<td>Natural pesticide, substrate for mushrooms growth</td>
<td>(Rao, 2011; Reyes et al., 2004)</td>
</tr>
</tbody>
</table>

* Qualitative and quantitative characteristics included. Highlighted alternatives are those selected for the establishment of the exchange networks.

**Estimates and data sources:**
- Estimate from questionnaire data and cane sugar literature, assuming operation at full installed capacity (Allen & Campbell, 1997; Contreras et al., 2009; Renouf et al., 2011)
- At 50% moisture (Aguilar et al., 2008)
- At 48% moisture (Chauhan et al., 2011)
- On a dry weight basis (Delgado & de Armas Casanova, 2001)
- Yadav and Solomon (2006)
- Jamil et al. (2004)
- Estimate from questionnaire data and cane sugar literature (Solano Silvera et al., 2005)
- Fonte Hernández (1999)
- Estimate from questionnaire data and midrib weight (Davis and Nielsen, 1999)
- Estimate from literature (Adams & Ghaly, 2007) and Suárez (2012)
- Suárez et al. (2003)
- At 82% moisture (Adams & Ghaly, 2007)
- Alfaro Vives et al. (2001)
- Anhuradha and Mullai (2010)
- Berardini et al. (2005)
- Sánchez Camps et al. (2001)
- Guerrero-Haber et al. (2011)
- Questionnaire data
4.5.2 Carbon Source for Microbial Cultivation

Residues and by-products can be used to grow microorganisms and then make use of either the enriched microbial biomass or any metabolite produced by the microorganisms. Residues and wastewaters are used as growth media and/or as a carbon source for different microorganisms producing metabolites of varied utility based upon the type and characteristic of the residue and the microorganisms in question. Microbial biomass, e.g. *Saccharomyces cerevisiae*, is usually enhanced in terms of protein content and is used in the production of food for human consumption as well as animal feed (Bacha et al., 2011). Edible fungi are usually grown using a wide range of wastes-based substrates, such as coffee pulp, coffee husk or sawdust (Croan, 2000; Pandey et al., 2000b). Metabolites can include catalyzing enzymes, organic acids (e.g. lactic acid), flavour and aroma compounds, or pigments, which are valuable compounds for the manufacture of foods, chemicals, drugs and cosmetics (Ghaly et al., 2003; Singh, 2011). Such compounds are particularly useful in Cuba as they are difficult and expensive to import directly.

4.5.3 Soil Amendment

Organic residues and by-products can be used as soil conditioner or fertilizer. This can be done through the direct application of specially mixed ‘recipes’ - such as chicken bedding mixed with coffee pulp (Adams & Ghaly, 2007) - or applied after undergoing a composting or digestion process. To guarantee that the final output meets the requirements to be applied to the soil, certain parameters must be monitored, such as moisture content, biological oxygen demand (BOD), minerals, carbon:nitrogen (C:N) ratio, fat and oils, odors, pathogens, pH, and toxicity (Gupta, 2003).

In Cuba, the economic crisis of the nineties led to an 80% decrease in mineral fertilizer use. At present, the use of fertilizers is prioritized to certain crops, such as sugarcane, potatoes, bananas and rice. Since the fertilizer industry in Cuba is no longer operational, all mineral fertilizers are imported, creating vulnerability within the agricultural sector (FAO, 2003). The production of organic fertilizers from residues and by-products could
help to alleviate the demand for imported nitrogen, phosphate and potassium. The sugar industry provides various residue streams for fertilizer production. Ash for instance, has both potassium and phosphorus content. A novel application has also been designed using a mix of filtercake and wastewater (named “REINAZ”), containing nitrogen, potassium and phosphorous (Solano Silvera et al., 2003).

4.5.4 Use for Energy Production

Organic residues and by-products can be used to obtain three types of biofuels: bioethanol, biogas and biodiesel. In bioethanol production, one of the main advantages of using this kind of substrate is that alleviates the demand for energy crops, such as corn, which require extensive use of land, nutrients, and energy that could otherwise be used for food crops production (Kim & Dale, 2004). Currently, the most common industry by-product used in ethanol production is sugar molasses, although sugar bagasse has the highest potential to be utilized for this purpose (Soccol et al., 2010).

Another proven alternative to obtain energy from residues and by-products is anaerobic digestion (AD), where the main product is biogas, with a composition around 55-65% methane (Balat & Balat, 2009). Biogas can be used as fuel for internal combustion engines to produce heat and electricity; as a direct fuel for domestic uses such as cooking; or purified and upgraded use as vehicle fuel (Akinbami et al., 2001; Weiland, 2003). The other product of the AD process is digestate, a moist slurry that can be applied directly into soil as biofertilizer (Al Seadi & Lukehurst, 2012; Thien Thu et al., 2012). It can also be dewatered producing a liquid and a solid fraction, the latter of which can be applied as fertilizer (Balat & Balat, 2009). A further demonstrated innovation is to use the liquid fraction as an input to an aquaponics system, in which wastewater nutrients support a multi-trophic chain of algae, zooplankton, and fish, generating a still nutrient-rich effluent that can irrigate and fertilize a hydroponic production system (Graber & Junge-Berberović, 2008; Klee, 1999). In this manner, fish and some vegetables are produced for human consumption, and other hydroponic plants such as duckweed provide animal feed.
4.5.5 Recovery of Value-Added Products

Food, chemical, pharmaceutics and cosmetics industries are big consumers of substances such as antioxidants, carbohydrates, dietary fibers, fats and oils, and pigments and proteins, which can be isolated from different organic residues and by-products (Santana-Méridas et al., 2012). Lignocellulosic by-products, because of their high content of fibers of cellulose and hemicelluloses, are valuable resources for the manufacture of paper, paperboards, building materials, textiles and biopolymers (Loh et al., 2013). Renewable sources of fiber in Cuba could substitute imported materials such as paper and cardboard (ONE, 2012b), which affects the delivery of basic products to the population.

4.6 Potential Integrated Networks within the Province of Santiago de Cuba

Based on the data collected regarding the type and availability of agricultural and agro-industrial residues and related by-products, as well as a better understanding of the resource constraints and needs within the region, a number of potential ‘integrated systems’ are proposed. These networks were designed to better utilize available resources in a manner that is particularly suited to the Cuban socio-economic and technological context, rather than simply using an economic or carbon lens which is a more typical approach for evaluating the utility or benefit of entering into an IS relationship (Jacobsen, 2006). Three scenarios are suggested representing a particular scale and type of operation: agriculture, medium-size, and large-size agro-industry. It should be noted that the intent is that these different scales can be further integrated with each other and this will be discussed further in later sections.

4.6.1 Agricultural Scenario

A typical IFES model designed for a small-scale (or agriculture-scale) operation in Cuba (Figure 4.2) must be characterized by a high degree of diversification in terms of crops and/or livestock, as this has proven to be one of the enabling factors for food productivity and energy efficiency (Agostinho & Ortega, 2012; Funes-Monzote et al., 2011). Opportunities for crop diversity in Cuba are considerable; crops ranging from vegetables to tropical fruits and medicinal plants flourish. Diversified farms in Cuba can
simultaneously grow sugarcane, cassava, sweet potatoes (*boniato*), taro (*malanga*), bananas and plantain, pumpkin, onion, garlic, beans, corn, rice, sorghum, soy, and tropical fruits such as mango, guava and coconut (Monzote et al., 2005). Such crops are grown for human consumption. With the proper management, however, animal feed can also be produced by integrating growth of grass and legumes (Villar-Delgado & Montano-Martínez, 2011), but more importantly, modifying crop residues to make them suitable as fodder. It is also important to reintroduce sustainable farming methods that were largely replaced by mono-culture, ‘green revolution’ style farming - e.g., multi-cropping techniques and agroforestry systems, as well as soil conservations practices, such as green manure/cover crops (FAO, 2011).

The two main mechanisms for introducing energy into the system are through small-scale/rudimentary gasification systems (thermo-chemical conversion) and/or anaerobic digestion (biochemical conversion). Gasification technology has been successfully demonstrated in small-scale settings, in this case fed by sugarcane bagasse and forage residues and producing 100 kWh/day of energy (Preston, 2010). In addition, gasification research and technology development is actively pursued by Cuban researchers; as such ‘in-country’ expertise is increasingly available, mitigating to a great extent the challenges and issues faced by solutions that depend on ‘technology transfer’ from other industrialized nations.

Anaerobic digestion of most materials containing volatile organics will produce biogas. Small-scale biodigesters have been proven to be appropriate technology in many rural settings such as China and Vietnam, as well as Cuba (Chen et al., 2010; Ghimire, 2013; Suárez, 2012). Depending on the different activities being developed in the farm, the biodigesters can be fed with livestock manure slurry from beef or pig rearing. In mountain farms where coffee is grown, another biodigester can be fed with wastewater from coffee pulping and grey wastewaters from households. Coffee pulp, which has a reasonably good C:N ratio can be composted and/or used as a growth medium for mushrooms, where the spent substrate can be used as soil amendment, off-setting fertilizer and facilitating moisture retention and reduced erosion (Adams & Ghaly, 2007).
As previously described in section 4.5.4, the other valuable product from the anaerobic digestion process is digestate, which can be applied directly to soils as a biofertilizer or be dewatered producing a liquid and a solid fraction. By using the liquid fraction in an aquaponics system, additional products such as fish and vegetables, and other hydroponic plants for animal feed, can be obtained. A successful example of the application of this system in a more rural, small-scale setting was developed at the Montefort Boys school in Fiji, using digestate from an on-site AD system run by the school’s students (Klee, 1999).

Under the actual model of agricultural production in Cuba, the IFES model could be adopted at the small farm level to further create symbiotic networks with other small farms and/or among cooperatives. For instance, linkages could be created to operate centralized composting operations, anaerobic digesters or gasifiers to achieve economies of scale; this could allow an easier integration of other related systems such as aquaponic operations or processing practices needing heat energy, for example, dairy pasteurization. Cooperatives that are specialized in certain types of crops could also establish symbiotic relationships among them to improve food and energy production.

Figure 4.2  Potential IFES model in the agricultural scenario.
4.6.2 Medium-size Agro-Industrial Scenario

As previously noted, a number of medium-size agro-industrial facilities were identified in the three municipalities of the study area. In a process similar to the one discussed above, consideration was given to the resources, infrastructure and needs of the region when evaluating the network options at the medium-scale. One of the main features of this network is the necessity of a conscious focus on appropriate/optimal energy production, given the marked energy security issues faced by both industrial operations and society in general. As such, the digestion of agricultural and agro-industrial residues to produce bioenergy (in the form of biogas) and the optimal use of available energy are key considerations. Anaerobic digestion technology is commonly used to digest municipal wastewater sludge, the organic fraction of municipal solid waste, or cattle manure with different co-digestates such as sawdust, or agro-industrial/agricultural residues. The additional supply of nutrients and an improved C:N ratio result in (typically) higher and richer (more methane) biogas production. Furthermore, it facilitates an efficient use of equipment and cost-sharing by involving multiple partners/suppliers (Alatríste-Mondragón et al., 2006).

Figure 4.3 presents a potential system that directs existing manure and crop residues into an anaerobic digester co-located with local agro-industrial operations with high concentration of wastewater outputs such as slaughtering facilities, rendering plants, dairy operations, and fruit processors. The solid residues from such systems can also be co-mingled, depending on the utility of the materials for other purposes. Anaerobic digestion systems can be coupled to an aquaponics system (Section 4.5.4), to fully utilize the nutritional content of the liquid digestate and to produce both animal feed and food. Solid digestate can be composted and returned to the agricultural fields as fertilizer. The produced biogas may be utilized for the production of heat and electricity. In localities such as El Caney or La Maya, heat could be used for the pasteurization of dairy and fruit products, or to supply energy for new operations such as fruit drying, which is currently only done on a small-scale basis using primarily solar drying options.
Figure 4.3 Potential symbiotic networks in the medium-size agro-industrial scenario.

Fruit processing residues can also provide the basis for pectin production, extracting it from high pectin-containing materials such as mango peel. Pectin is an important emulsifier, thickener and stabilizer used in the food industry, and is currently an input needed for the fruit processing industry in the province that is typically imported from other jurisdictions nationally and internationally. Whey, an output from dairy processing, is rich in nutrients and bioactive peptides (Ajila et al., 2012a). Whey could be used as pigs feed (without pre-treatment), be processed to extract valuable nutrients that are used in enhanced animal feed, or be used in the manufacture of different types of cheese and or edible protein products (Demian, 2007).

Gasification systems can be supplied with solid residues such as sawdust and woodchips, coffee husk, and any other source of fibrous residual biomass. An operational example (albeit at a demonstration scale) exists already within the sawmill “El Brujo”, based on woodchips.

An alternative to supply fuel energy to the population would be to use sawdust and coffee husk in the manufacture of energy briquettes. These can be either fed into the gasifier or used as a fuel source in bakery furnaces, and other local systems needing a more sustainable fuel source, which currently depends on specifically sourced firewood.
(Suárez et al., 2003). It should be noted, however, that sawdust and coffee husks can also be successfully used as a growth substrate for edible mushrooms. Mushrooms have a high protein content which can be integrated into protein deprived diets, or at least integrated into livestock diets and substitute existing edible crops fed to livestock herds, particularly pigs (Pandey et al., 2000b).

Each local network will have different configurations in size and components based on the specific material flows and local scarcities or shortages. Administratively, an option is to begin with a size of 6 km² where a cluster of medium-size facilities is operating, such as in the locality of “El Brujo” (Figure 4.1). It could also be expanded through the consejo popular, the smallest administrative unit in each municipality, from 20 to 50 km², to reach a higher extension with a larger number of agricultural and agro-industrial activities. One or both configurations could apply for the operations identified in Songo-La Maya (Figure 4.1). In the municipality of Santiago de Cuba, whose population is 90% urban, medium-size food and energy production networks could be arranged around agro-industrial activities and urban or suburban farms, such as in the locality of “El Caney” (Figure 4.1).

The geographic scale and specific linkages will be somewhat limited by transportation infrastructure and resources. As such, local networks must be developed to also restrict transportation activities to only those that deliver the greatest return in terms of contribution to food and energy security.

4.6.3 Large-size Agro-Industrial Scenario

The theoretical foundations for a large-scale system were developed around the industrial ecology concept of an ‘anchor tenant’ (see footnote in Section 3.2). For the purpose of discussion, the example of the sugar mill in the municipality of San Luis will be used. The mill has several residues and by-products whose value can be enhanced through processes both inside and outside the mill, thus creating a broader system of beneficial exchanges founded on the effective and efficient use of the mill’s by-products (Figure 4.4).
Molasses has historically been used in Cuba as a raw material for the production of rum (Miller et al., 2009). At present, molasses from this sugar mill are transported to rum distilleries situated significant distances from the source. There is increased interest, however, in using it as feed stock for bioethanol, which could be produced in systems co-located with the actual sugar mill, where energy for the distillation process could be developed out of other system by-products. This avoids transportation costs and creates a source of biofuel for the municipality, which could offset fossil fuels. Moreover, this partnering of sugar processing and ethanol distillation is more resource efficient from an energy perspective than operating the two systems in isolation. For example, distillery residues, such as wastewaters, can be treated in an anaerobic digester along with filter cake and wastewater from the cane sugar distillery. This provides the scale of AD system needed to provide a significant portion of the necessary energy for the distillation process as well as supplement the heat and energy requirement at the mill. This overcomes a significant issue regarding the energy balance for ethanol production, given the energy inputs resulting from the processing of waste materials that would have otherwise been released to the environment and provided no resource benefit in the best case scenario, or, more likely, had a negative environmental impact.

As noted, the liquid digestate coming from the anaerobic digester can be in part diverted for ferti-irrigation in nearby farming systems or to an aquaponics systems, as described in previous sections. The solid digestate, along with yeast from the distillation process, and ash from the cane sugar refinery, can be combined to achieve an appropriate C:N ratio and produce a rich fertilizer/soil amendment to be deployed either in sugarcane fields or any other agricultural operation. It should be reemphasized that soil fertility is a particular issue in the eastern region, which lacks the finances to source such resources even at a rudimentary level. As such, any soil amendments or related products that can be developed utilizing locally available, affordable inputs respond directly to regional resource scarcity issues. Such products can augment existing systems and enrich agricultural fields that are currently degraded or idle. Alternatively, the solid digestate could be pasteurized using the produced biogas. Such digestate then becomes an ideal substrate for mushroom cultivation.
Other sources of organic residues, such as manure, can be sourced from livestock production as well as from pig breeding, an activity that takes place in many households of the municipality. The small slaughterhouse and households are also important producers of organic residues. These sources of organic waste could be either co-digested in the centralized anaerobic digester in the sugar mill, improving the overall productivity of biogas, or in decentralized anaerobic digesters spread over the municipality. For example, under the concept of ‘energy farms’, developed in Brazil, electricity is produced at the household level for individual consumption, while the remaining electricity is connected into the local grid (Global Methane Initiative, n.d.).

Biomass residues generated in sugarcane harvesting and processing represents another aspect of the network, where different actors can participate. At present, bagasse is already used as a fuel for co-generation of electric power and steam to supply the energetic demand of the sugar mill. Sugarcane crop residues generated in the sugarcane cleaning facility are currently burnt in open spaces. A useful way to take advantage of its calorific value is to use it as a fuel for co-generation of heat and power. The same strategy can be adopted with the sawdust and woodchips generated in the sawmill located approximately 20 km away. As previously described in section 4.6.2, another alternative for the utilization of these residues is the manufacture of energy briquettes, which can be used as a local fuel source.

4.7 **INTEGRATION OF THE VARIOUS SCALES**

The three models discussed above require the development of relationships and integration of activities both internal to existing operations and among different actors. Each of them relies on utilization of residues and by-products as well as on the input of local natural, human and cultural resources in order for such systems to be successful (Adams & Ghaly, 2006). These three models can be further integrated with each other to form a broader network for regional production of food and energy (Figure 4.5). This system is based on a network of small farms and cooperative farms that produce a diversity of crops and forage, allowing food self-sufficiency of their members and the
Figure 4.4  Potential symbiotic networks in the large-size agro-industrial scenario.

feeding of livestock and poultry. Furthermore, it could produce enough energy to satisfy their energetic needs and ideally permit the remaining energy to be sold to the energy grid.

This broader agricultural network could provide sufficient raw materials for food processing industries, both at the medium-size level or large-size, but does not pre-empt small farms or cooperatives from also processing food. For example, due to the high
production of tropical fruits, especially mango, small-scale, on-farm processing methods such as sun-drying or jam production, are suitable opportunities for product development in these smaller communities, especially in cases where there is too much product for existing large-scale processes to manage. For example, currently mangos are often left to rot on the trees as there is more supply than demand from the processing operations, and due to limited transportation networks and resources, it is not possible to get the fresh fruit to larger markets in other parts of the country or internationally. As such, the support of small-scale operations through the supply of locally available resources such as energy resources can help alleviate this resource inefficiency. A stronger agricultural sector is a key factor in providing food security in the region and in fostering a more resilient economy in the country. For instance, by providing enough sugarcane to the sugar mills, and by developing a diversified and integrated sugar industry, the economy is strengthened and is better able to face challenges such as fluctuations in sugar prices.

Agro-industries need to be interconnected with surrounding farming operations through the transformation of waste materials and by-products into products and resources of use to the farming community as well as those with additional ‘market’ value. These arrangements also support a cooperative and more efficient use of processing technologies, such as anaerobic digestion and thermo-chemical conversion of biomass (gasification or combustion), by receiving inputs from the surrounding farming operations rather than depending solely on their own residuals. The main outputs of these processes, fuel and/or heat and electricity, can be utilized to fulfill the energetic demand of their operations and the remaining energy can be diverted appropriately, such as supplying excess electricity to the grid or supplying additional fuel sources (briquettes) into local markets. It can also allow the development of new processing systems, such as decentralized pasteurizing systems based on biogas fuel to support access to locally produced food. Other by-products generated by these technologies can enable the agricultural network to provide fertilizers, animal feed and fish for human consumption.
In this manner, a network between agricultural producers and agro-industries can be achieved and benefit the region in many forms. It should be noted that the operation of such an integrated agro-industrial network can offer additional employment and consequently, attract a younger and well educated population (Zhu et al., 2007). This is particularly an opportunity for rural development in Cuba, which is often affected by younger population migration to bigger cities (Wolfe, 2004). Other benefits are associated with the provision of inputs that are currently imported, such as fertilizers, or inputs for the agro-industry, such as pectin. Additionally, the quality of the food can be improved substantially by reducing the use of pesticides and other agrochemicals, through the implementation of the use of sustainable management practices and the use of natural pesticides.

### 4.8 Technical Challenges and Opportunities

The development of the models described in this chapter face a number of challenges that should be addressed in order to bring about the expected results in terms of food and energy provision. Some of these challenges are related to the technical complexity of implementing and operating new productive systems and technologies, which will be reviewed in this section. A further discussion around the challenges and opportunities to develop the IFEPNs will be covered in Chapter 5.

The integration of activities within existing operations and among different actors requires the intensive and sustained use of a new set of knowledge and technical skills. At the farm level, growing a larger number of crops and rearing more animals implies an
even greater set of abilities. The operation of technologies also means that technical capacity is needed. In this sense, the network of farms and the cooperation among agro-industries can provide an opportunity for knowledge sharing and support.

Opportunities within Cuban agriculture exist for overcoming these constraints. On one hand, a large part of the population has received formal education at the university or technical (65%) levels or has participated in some sort of formal training (26.9%) (Vidal Alejandro et al., 2010), which facilitates the understanding and creation of new knowledge and skill sets. On the other hand, networks of farmers have disseminated different positive experiences involving a more sustainable use of their resources and residues and by-products through a farmer-to-farmer approach (Rosset et al., 2011). As a result, the cooperative sector and small farmers are developing new farming techniques to produce foods that are currently imported, such as legumes and cereals. At the same time, new techniques for growing rice, an important cereal in the Cuban diet, have been integrated into a CSS from the eastern province of Granma using sustainable agricultural methods, achieving an average yield of 7.3 t/ha (Almarales Frías et al., 2007). This is a relatively high yield compared with the global average yield of 4.4 t/ha (IRRI, 2013) and demonstrates the potential opportunities on this front as well.

The operation of biomass conversion technologies is a significant challenge, especially when medium- and large-size technologies are adopted. First, the blend fed into the system must be studied and monitored carefully in order to create a favourable environment for methane production, avoiding inhibition by ammonia or lipid degradation products (Mata-Alvarez et al., 2011). Digestibility of the co-substrates also depends on factors such as the type of sorting (manual or mechanical), the diet of the livestock in case manure is used, and particle size of farm residues among other factors (Alatriste-Mondragón et al., 2006). Therefore, the implementation of co-digestion technologies demands a series of prior studies at the laboratory and pilot-scale levels, and further vigilant real-time monitoring of AD inputs.
In the case of thermo-chemical conversion of biomass, such as gasification or combustion, difficulties are associated with biomass pre-treatment, necessary for transportation and further processing (Santana-Méridas et al., 2012). For instance, SCCR has a large particle size (between 200-700 mm), high moisture (40-60%) and low density (20-30 kg/m³), which make necessary its transformation and reconditioning for direct use (Aguilar et al., 2008). These processes may include drying, grinding, and compression, which are highly energy-consuming. Cuban researchers have proposed that the transformation and reconditioning of SCCR should take place in the sugarcane cleaning facilities distributed near the sugar mills, by modifying the actual technology of sugarcane cleaning (Aguilar et al., 2008).

Despite the technical challenges associated with the implementation of AD or thermochemical conversion technologies, the country possesses a large amount of scientific and technical expertise, as well as experience in developing these kinds of technologies. For instance, the country has a significant experience in the utilization of bagasse as a fuel for thermally-generated electricity. Furthermore, the country has recognized in the ‘lineamientos’ the importance of continuing to use sugarcane residues, and forestry and agricultural residues for the generation of electricity (Lineamiento No. 246 – Appendix D). Research centres in Santiago de Cuba, such as the Centre for Energy Efficiency and the Centre for Solar Energy Research have a considerable experience in the study of these technologies.

A political willingness also exists for the production of high value-added products. The ‘lineamientos’ explicitly expresses the will to expand exports of high added-value products, such as food or animal feed ingredients, valuable bioactive compounds, and natural medicines (Lineamiento No. 221 and No. 222 – Appendix D). In this sense, the high level of education and research centres of biotechnology (e.g. Center of Industrial Biotechnology in Santiago de Cuba) can provide the necessary expertise to develop these industries.
4.9 **CONCLUSION**

The models of development in Cuba provide the opportunity to integrate economic and environmental considerations with existing beneficial social constructs. To do so, the Cuban Congress has agreed to attain long-term solutions under a sustainable development approach, which must be facilitated by the adoption of novel strategies and innovations. The aim of this research was to show such strategies through the application of an eco-industrial development approach informed by two concepts, IFES and IS. The findings of this research indicate that the application of this approach could help to address some of the primary shortages faced in the country i.e. local and renewable sources of energy, as well as local sources of fertilizers and inputs for agriculture.

The opportunities for the adoption of IFES within the agricultural sector in the province of Santiago de Cuba can rely on the existing diversity of crops, livestock and poultry, and the sources of traditional knowledge and extension farmers’ organizations that can assist the transition from the ‘green revolution’ model to one of integrated farming systems. The organization of agriculture into small farms and cooperatives is particularly helpful for the development of symbiotic networks among farmers and cooperatives, especially to operate centralized composting operations, anaerobic digesters, gasifiers or aquaponic systems that can better utilize available resources and maximize the overall food and energy output of the system. Furthermore, the experience of Cuban researchers and technicians in technology development is an asset that can mitigate some of the challenges of the ‘technology transfer’ often needed to implement these systems. Particularly aligned with the scarcities and needs of the province, the networks can be designed to increase food and animal feed production. Presently, most of the animal feed is produced from imported soybean and corn; therefore, IFES could, if need be, integrate these crops along with others, while optimizing food and animal feed production.

Opportunities also exist for symbiotic networks based upon the exchange of agro-industrial by-products and residues, which can be recovered for energy production or to support and/or produce added-value products. The energy content of all the identified residues and by-products (Table 4.1), plus the additional energy content of bioethanol
from a potential distillery and the associated biogas produced from wastewater, is equivalent to 1 463 203 GJ. In case this energy is transformed into electricity and assuming transformation efficiencies of 15 to 20%, it could provide 63 GWh of electricity per year. Greater contributions could be possible if the energy were used more directly and thereby with greater conversion efficiency. Other residues and by-product streams can be recovered to produce food-industry inputs such as pectin, natural pesticides for agriculture, or used as growth substrate for edible mushrooms or other microorganisms to then extract valuable bioactive compounds. The intention of this research, however, is not to be prescriptive, and the specific use for each by-product and waste stream will depend ultimately on the material flows, local scarcities and resources availability, transportation infrastructure, and the specific needs, capabilities and priorities of the communities involved.

The articulation of these agricultural and agro-industrial networks into a regional IFEPN represents an opportunity for improved resource use efficiency and efficacy without affecting the environment adversely. This could facilitate the development of a more diversified and resilient economy emerging from local scarcities and needs, therefore benefiting the communities in a more direct way. The regional network can also offer additional employment for the younger and educated population of the region, and specifically for the rural population that often migrates to urban settings in search of better job opportunities. Overall, this regional network can offer what is often called a ‘win-win-win’ situation for the economy, the environment, and society. Considering the unique opportunity that Cuba is facing today to update its economic model, the adoption of IFEPNs in a local and more regional scale represents a concrete opportunity to drive the sustainable development that the country has decided to pursue.

4.10 REFERENCES

Note to reader: Cuban scholars or other latin scholars cited in this thesis use two last names, e.g. Pérez Villanueva.


CHAPTER 5  FACILITATING INTEGRATED FOOD AND ENERGY SYSTEMS AND INDUSTRIAL SYMBIOSIS IN CUBA – CHALLENGES AND OPPORTUNITIES

Note to reader – this chapter was written as a ‘stand-alone’ article intended for journal publication.

5.1  INTRODUCTION

Around 870 million people, representing 12.5% of the world population, were estimated to have lived in undernourished conditions during the period 2010-2012, affecting mostly people in developing countries (FAO-WFP-IFAD, 2012). In Cuba, even though there is no “chronic hunger”, particular segments of the population present some degree of anemia and scarcity of micronutrients (Grogg, 2009; PMA-IPF, 2001). In terms of food production, inefficient agricultural systems have resulted in a pattern of import dependence for basics such as vegetable oil, legumes, cereals (rice and wheat for human consumption, and corn and soy bean for animal feed), and powdered milk (FAOSTAT, 2009). The challenge for countries like Cuba is to boost food production and reduce imports in a manner that is both sustainable in the long term and economically feasible in the short term. Mainstream approaches have tackled this through the augmentation of crop yields by means of agricultural intensification and biotechnology, e.g. GMO crops (Holt-Giménez & Shattuck, 2011). However, in many instances these methods have shown detrimental effects on the environment and rural farming communities (Basu & Scholten, 2012). These methods negatively impact biodiversity, and require high inputs of agrochemicals that are not accessible to Cuba for a variety of reasons.

A challenge closely related to food security is energy security, considered as a basic requirement to satisfy lighting, heating, and cooking needs, as well as to provide education and health services, among other products and services. Today, nearly three billion people rely on unsustainable biomass-based energy sources (Kaygusuz, 2011). In Cuba, the access to energy services is particularly difficult in rural areas, and the lack of resources has a direct impact on energy imports and infrastructure improvements (IAEA-CUBAENERGIA-UN, 2008).
An alternative model that can potentially address both of these issues is one that relies on an intensification of crop production and utilization through an ecosystem approach, where efficiency is captured through ecosystems services and management (FAO, 2010b). This ecosystem approach to augmenting food production can also be developed to create inputs and resources for energy generation, where the use of renewable sources is the key. To operationalize these ecosystem principles, different approaches have emerged, ranging from those that apply to the individual farm level to those implemented at more regional scales involving a network of multiple actors (Chan, 1985; Nielsen, 2007; Rhodes, 2012). For this research, we have brought together two concepts with the aim of developing such strategies; both can be applied to this spectrum and address the production of food and energy under ecosystem principles: integrated food and energy systems (IFES) and industrial symbiosis (IS). The former addresses simultaneously food and energy production with a focus on small farms in developing countries (Bogdanski, 2012; FAO, 2010a). Industrial symbiosis supports the building of relationships among disparate industrial operations to improve their efficiency and sustainability through the exchange of residues and by-products, as well as knowledge and information, in spatial scales ranging from eco-industrial parks to wider regions (Lombardi & Laybourn, 2012; Lombardi et al., 2012). Even though both approaches typically occupy different niches, both are built on ecosystem principles. The integration of both concepts can provide strategies for a wider local or regional network made up of small farmers, agricultural cooperatives and agro-industries producing food and energy, as well as other social and economic benefits. These networks are identified under various names such as: agro-industrial symbiosis network (Ometto et al., 2007); eco-industrial networks, industrial networks and industrial ecosystems (Chertow & Ehrenfeld, 2012); and agri-food webs (Marsden, 2010). For the purpose of this chapter, and as a result of the blending of the concepts IFES and IS, the term integrated food and energy production networks (IFEPNs) will be used to describe the underlying conceptual framework developed as part of the research.

Within IFEPNs the ecosystem approach is employed at the farm level through methods such as agroforestry, rotation of crops and intercropping, and crop diversification (Funes-
Energy for productive activities is captured through renewable sources, such as wind, solar, the thermal combustion of biomass, or creating more advanced biofuels through the biological alteration of organic residues (Preston, 2010). At the network level, the creation of synergies among agro-industries and/or farming operations is generally developed through residue and by-products exchange, to generate energy, create new products, or offset the input of raw or virgin materials (Sokka et al., 2011; Zhu et al., 2007). As suggested, different biomass to energy technologies can be used, such as thermo-chemical conversion technology (gasification, combustion or pyrolysis) or biochemical conversion technology (anaerobic digestion or fermentation).

The development of these kinds of networks, however, is not straightforward, and even the operation of IFES in small farms implies many challenges and constraints. Cuba is no exception. Therefore, the key question is how to facilitate the implementation of integrated food and energy production at both the farm and agricultural level and agro-industrial level, and the further symbiosis among all the actors involved in a potential network. The bodies of knowledge regarding both IFES and IS have identified common challenges and difficulties that must be addressed, as well as some of the enabling factors that can facilitate the development of the networks.

The main objective discussed in this chapter is the identification of both the barriers and the often uniquely Cuban strategies to address them related to forwarding the development of IFEPNs. This will include an assessment of the literature as it pertains to the primary obstacles typically encountered elsewhere that hinder the development of the IFES networks, as well as enabling factors and recommendations. Following that, the specific barriers and opportunities in Cuba, as well as next steps and recommendations for the facilitation of IFES and IS in the country, will be discussed, supported by a review of the literature, as well as insight developed through consultations with various Cuban stakeholders. The output will inform a framework for investigating the enabling factors for any other region looking to improve food and energy security using this ‘integrated’ ecosystems approach. Finally, several conclusions on the future of IFEPNs in Cuba will be offered.
5.2 METHODS

As noted, in order to understand the potential barriers to the development of an IFEPN in Cuba and the opportunities to overcome them, two sources of information were utilized: a) scholarly literature and b) the outputs of consultations with stakeholders involved in various aspects of Cuban agriculture and agro-industry in the Oriente region. A literature review focused on initiatives that share the main features of these networks: the implementation of renewable energies and integrated farming systems. The related bodies of knowledge were explored for the main barriers and enablers influencing the implementation of these initiatives, placing an emphasis on developing countries. The IS literature provided insight to the barriers and opportunities for collaborating and establishing networks among disparate industrial actors.

Consultation with knowledge holders within the regional industrial operations, academia and government were conducted during field work within the province of Santiago de Cuba. The focus of one set of questions was to understand the current challenges of undertaking exchange and collaborative activities among members of the agriculture and agro-industry. Another set of questions focused on the opportunities originated by the current needs and scarcities, actual mechanisms for collaboration within the institutional framework of the country, and opportunities made possible by new policy implementations. This information was complemented and validated with official Cuban documents, such as the guidelines for economic and social policy ('lineamientos') (Sexto Congreso del Partido Comunista de Cuba, 2011), national databases, and statistical information.

5.3 CHALLENGES TO THE DEVELOPMENT OF AN IFEPN

Challenges associated with the development of integrated food and energy production networks (IFEPNs) at both the farm level and agro-industrial level are related with technical, operational and organizational constraints, as well as with institutional and policy limitations. In this section the most common challenges in the development of
IFEPNs at both the farm and network level among members of the agriculture and agro-
industry will be reviewed.

5.3.1 Constraints to the Development of IFEPNs at the Farm-Level

A diversified and integrated farm implies that a large set of skills is required to grow a 
larger diversity of crops and to raise a larger diversity of animals - in addition to the 
technical skills to operate biomass to energy conversion technologies or any other 
renewable energy technology. This represents a potentially significant challenge for small 
farmers. Even though this type of technology (e.g., small-scale biodigesters) is typically 
not complex and has been successfully implemented in rural settings elsewhere (Ghimire, 
2013), its installation and maintenance require a sustained commitment on the part of 
farmers. Therefore, access to knowledge and training should be guaranteed when starting 
an integrated food and energy production initiative and throughout the development of 
the system. This challenge is even greater when a wide range of technologies is used as 
even more knowledge is then required. Usually, when the technical support comes from 
the government or NGOs, or when the technologies are imported, the system is much 
more exposed to unforeseen vulnerabilities that can impact on its viability in the long 
term (Alam Hossain Mondal et al., 2010).

Making a decision towards a technological choice is another challenge, since many 
factors regarding its operation, efficiency, and cost should be considered. Again, 
accessing the information is crucial to the decision-making process. The spatial and 
social configuration of the farm, however, will also influence this choice. For instance, 
bigger farms or a network of farms can operate a centralized anaerobic digestion (AD) 
plant, which is more efficient in terms of inputs required and outputs obtained. In 
addition, the costs of transporting feedstock can be minimized (Mistry et al., 2007). Due 
to the simplicity and reduced costs of smaller digesters, however, many farmers, 
especially in developing countries, prefer the loss of efficiency in lieu of lower 
maintenance technologies (FAO, 2010a).
Perhaps one of the main challenges facing farmers when they are deciding on alternative use for their residues is the potential conflict of competing uses (e.g. animal feed, energy production, value-added products, etc.). Crop residues, forestry, and livestock residues have an ecosystem function when left on, or integrated into the soil. These functions avoid the use of external inputs such as fertilizers and soil amendments; consequently, it is important to find a balance between the amount of residue that can be taken for energy or animal feed purposes and the amount of residue that should be left on the field or composted and reintroduced to the field, to maintain soil quality (Power, 2010).

The operation of a diversified and integrated farm also requires more intensive labour, a significant challenge considering that this type of work does not appeal to the younger generation who prefer to migrate to cities, a longstanding phenomenon threatening the rural population (Azaola, 2012).

Another challenge is related to access to financial mechanisms to purchase new technologies or any other necessary input for the operation of integrated food and energy production systems. Usually, transaction costs are not worth it when small farmers are accessing financial mechanisms, which makes the procedure difficult (Cull et al., 2009).

Additionally, the development of integrated production systems has to face the challenges imposed by the institutional framework, policies and access to markets. The institutional framework determines how decisions are made at the local level and therefore influences the delivery of factors needed for integrated food and energy production, such as financial opportunities, access to information, training, etc. Policies also have a direct impact on the decisions taken by farmers (Winter, 1996). For example, when policies support subsidies for intensified forestry or agriculture, it shifts farmer attention and interest away from an integrated systems type of operation. Similarly, disconnected policies and legal frameworks focused on a more silo’d approach to agricultural productivity and ecosystem management eclipse the potential for the integration of food and energy production (Iles & Marsh, 2012; Russell et al., 2011).
5.3.2 Constraints to the Development of IFEPNs at the Agro-Industrial Level

An agro-industrial symbiotic network also faces many of the constraints mentioned in the development of integrated food and energy production in the agricultural setting. In cases where larger amounts of residues are exchanged for energy production, or when new products are produced, complex technology may be necessary. Therefore, accessing knowledge and training for selecting or implementing appropriate technologies and for maintenance is a challenge.

The potential conflict of competing uses, financial constraints and the influences of the institutional framework and policies can pose significant challenges that are exacerbated by the scale and number of actors potentially involved. In this case, more complex technology is often required, but there is potentially greater access to financial resources, which can counteract the transaction costs. Similarly, competing uses are less conflictive in the agro-industry since process residues have lower competition challenges (Bhattacharya et al., 2005). Transportation, however, is an ongoing challenge to the development and operation of such networks, especially when fuel availability is limited and road infrastructure is weak. Institutional frameworks and policies can interfere with more ‘sustainably-minded’ decision-making in the agro-industrial setting; for example when surplus renewable energy is legislated to be sold to the grid, at the same time as subsidies to non-renewable energies exist. This is particularly so if prices paid to producers are too low (Lucia, 2013).

5.4 Opportunities to Overcome the Challenges

Despite challenges, various alternatives exist to overcome the technical and economic barriers associated with the development of IFEPNs at the farm level and agro-industrial level, as well as in settings to integrate the two scales. Some can be initiated independently at the farm or facility level, while some others necessitate the streamlining of institutional and organizational arrangements among different stakeholders (FAO, 2010a). In addition, appropriate policies need to be promoted to overcome the challenges and pave the way towards the development of an IFEPN.
Interestingly, however, in a number of cases the types of mechanisms that can be implemented to address these challenges need to include the participation and collaboration of those at the centre of the issue. In this sense, IS literature has an important body of knowledge on how to facilitate collaboration among actors that have a poor historical relationship or a complete absence of any. As such, this literature is helpful and applicable to the development of the relationships necessary for the implementation of IFEPNs in a practical sense.

5.4.1 Approaches to Overcome Technical and Financial Challenges

Technical and financial challenges need to be addressed locally as well as at the broader institutional level. Much of the knowledge, technical skills, training, labour and access to financial mechanisms can be facilitated by institutional arrangements among farmers in an agricultural network, and among facilities in an agro-industrial network (Wilkinson et al., 2011).

The conflict of competing uses for residues in the agriculture and agro-industries can be approached by accepting the trade-offs and by looking for win-win situations. Each situation will depend exclusively on local factors such as the residue’s structural and chemical characteristics, environmental conditions, and the current use of the residue (USDA, 2006). To decide whether or not, or to what extent, residues can be removed, these various considerations should be evaluated; first and foremost is the necessity to ensure soil health; all other resource allocations can then focus on addressing the specifics of the regional scarcities such as the creation of animal feed and bioenergy-based energy generation systems. Win-win situations refer to technologies that can produce more than one output, such as energy and fertilizer, thus diminishing and alleviating the pressure on soil health. Such practices include anaerobic digestion, green manuring, aquaponics, and thermochemical conversion technologies such as pyrolysis and gasification (FAO, 2011; Graber & Junge-Berberović, 2008; UNEP, 2009; Weiland, 2010).
Diversification and integration in small farms could be difficult to achieve, mainly because there are few farmers who would invest the time or be willing to learn how to grow more crops or how to operate a new technology (Below et al., 2010). In these cases, an agricultural network made of numerous small-scale farms, a cooperative, or specialized enterprises (that could also be part of the cooperative) could deliver these services.

One idea would involve different farmers (in these networks) specializing in different types of crops and livestock, while others could be in charge of the biomass-to-energy conversion technologies or any other renewable energy technology. Processing and commercialization of the agricultural products could be then networked with agro-industrial partners in the local IFEPN. In the same way, some of the agricultural residues could be co-processed along with agro-industrial residues, which allow for greater efficiency in terms of output delivery, knowledge and technical skills sharing, and facilitated access to financial mechanisms.

In terms of knowledge transfer and development, there are several participatory approaches that do not depend exclusively on NGOs or government training, such as farmer field schools, farmer to farmer movements and success case replication (Feder et al., 2004; Hellin, 2012; Orsini, 2000; Rosset et al., 2011). All of these approaches are based upon peer-to-peer knowledge transfer and ensure a sustained source of knowledge and support.

The institutional framework and policies should explicitly be developed to support the implementation of IFEPNs, incorporating: the promotion of R&D; improved rural infrastructure; incentivized technology transfer; the promotion of renewable energy markets; and access to credits and loans (Fox & Porca, 2001; Lal, 2008; Morris & Winter, 1999; Prasertsan & Sajjakulnukit, 2006). Overall, these policies should capture sound environmental management and social equity, and guarantee the benefit of small farmers and rural communities (Kumar, 2002). Regulations are also used as a type of policy instrument; however, their purpose cannot be fully accomplished when developed
without community participation. Related regulations, therefore, should be developed and coordinated in conjunction with stakeholder/community involvement (Vayssières et al., 2011).

5.4.2 Approaches to Facilitate Organization and Collaboration

The practical implementation of local IFEPNs is a challenge in and of itself. It requires coordination, access to inputs and markets, technical support and finance, and good regulatory frameworks. For an appropriate and meaningful articulation it must be people-centered and participatory, with a holistic perspective. Working in partnerships and cross-sectorally is key to success (FAO, 2010a).

The structure where engaged actors participate in relationships that emphasizes trust, cooperation, and repeated interactions, is called a social network or social structure. The resources shared by this network are named social capital, and are used collectively in the achievement of goals. The process whereby actors become increasingly involved in these social networks is called social embeddedness (Granovetter, 1985). During this process, actors interact repeatedly, creating shared norms that influence their behaviour and how decisions are made. Therefore, enabling social embeddedness to happen is the key factor in the creation and organization of these social networks. In practical and procedural terms, however, it is necessary to understand how social embeddedness can be built among a number of actors. This ‘social process building’ can be understood under the concept of institutional capacity building (Healey, 1998; Spekkink, 2013).

Institutional capacity building, social embeddedness, and social networks have been studied in IS experiences, and even though agricultural scenarios and farmers’ participation have not commonly been included, several facilitation strategies are useful.

Industrial symbiosis development has been observed to evolve mainly under three schemes: self-organized, planned, and facilitated. In these three models the role of social networks is crucial, and consequently, institutional capacity has to be built. These three models of IS have been the basis for the elaboration of evolutionary theories of IS (Baas
& Boons, 2004; Chertow & Ehrenfeld, 2012), and strategies for the facilitation and development of integrated networks can be designed.

The work by Chertow and Ehrenfeld (2012) offers a theory of the evolution of IS in a discontinuous three-stage model. In the first stage, known as ‘sprouting’, actors in a local or regional context begin to interact and exchange resources driven by a series of factors, such as economic efficiency, response to regulatory pressures, resource scarcities, rising costs of waste disposal, etc. These exchanges can bring positive net private benefits, but then continuity is not guaranteed. When the benefits are recognized and voiced to the public sphere, it is said that the network has moved to the ‘uncovering’ stage. This process allows the incipient institutionalization of the network and can lead to further additions by new actors. The third stage is ‘embeddedness and institutionalization’, where the expansion of the network is facilitated by an institutional framework that ties actors together and facilitates the growth and utilization of social capital.

Given the point of view of institutional capacity building, the evolution of IS requires a set of enabling factors. According to Boons and Spekkink (2012), such enabling factors have three dimensions: relational, knowledge and mobilization. Relational factors enable actors to engage in relationships that can be beneficial; knowledge factors enable actors to collect information about feasible exchanges; and mobilization factors enable actors to connect with other actors to create further symbiotic exchanges, to influence policies and regulations, and to attract external resources necessary for the continuation and strengthening of the network. This same research found that mobilization factors are the most correlated with the decisions taken by actors in the network, or in other words, successful symbiotic exchanges will be mostly determined by the ability to mobilize actors (Boons & Spekkink, 2012).

Other insight offered by Paquin and Howard-Grenville (2012) contributes to the understanding of IS evolution and institutional capacity building by stating that network evolution is influenced by both ‘serendipitous’ (or self-organizing) and ‘goal-directed’ (or planned) processes. In a serendipitous process, linkages among actors and processes
occur in a decentralized and self-organized fashion, while goal-directed processes are controlled and organized by stakeholders or by a coordinating organization (Kilduff & Tsai, 2003). According to Paquin and Howard-Grenville (2012), serendipitous processes tend to predominate in the early stages of development of IS, and as institutionalization and embeddedness progress, goal-directed processes dominate. Further maintenance and renewal of existing and new symbiotic linkages will require an appropriate balance of goal-directed and serendipitous processes (Paquin & Howard-Grenville, 2012).

5.5 CONSIDERATIONS FOR THE APPLICATION OF IFEPNs IN CUBA

Cuba presents many of the constraints outlined in previous sections to implement integrated food and energy production in the agricultural and agro-industrial sector and to implement broader networks of collaboration among farms and agro-industries. Moreover, many challenges are much more visible due to the economic constraints that the country has faced since the collapse of the eastern socialist block. During the recent years, however, Cuba has embarked on a number of structural transformations to revitalise its economy. A series of policy proposals known as the ‘lineamientos’, approved in 2011, contain different guidelines to drive these transformations (Sexto Congreso del Partido Comunista de Cuba, 2011). The objective of increasing food production and reducing imports is a hallmark of the ‘lineamientos’, and many of the guidelines provide opportunities for the development of IFEPNs.

In this section the main constraints faced by the agricultural and agro-industrial sectors in Cuba will be reviewed, as well as the opportunities to address them, identifying the enabling factors described in the previous section.

5.5.1 IFEPNs at the Farm Level

Cuban agriculture exhibits many opportunities to overcome the most common challenges associated with the development of integrated farming systems. Institutional arrangements such as cooperatives are the backbone of the agricultural structure in the country, which cultivate 64% of the agricultural land of the country (ONE, 2012c).
Cooperative arrangements in Cuba exist in three formats: CSS, CPA and UBPC (Peters, 2012b). The cooperative sector promotes a decentralized and autonomous form of production and the continuous learning of farmers, stimulating local and autonomous decision-making on use of resources (Fernández Domínguez et al., 2007). The presence of grassroots organizations, such as the National Association of Small Farmers (ANAP, Asociación Nacional de Agricultores Pequeños), the Cuban Association of Animal Production (ACPA, Asociación Cubana de Producción Animal), and the Cuban Association of Agricultural and Forestry Technicians (ACTAF, Asociación Cubana de Técnicos Agrícolas y Forestales), have allowed the collection and systematization of traditional knowledge as well as innovations, triggering a movement of learning and action throughout the country (Leitgeb et al., 2011). For instance, ANAP has led a national movement involving more than 14,000 participants in 155 municipalities of the country, known as the Farmer-to-Farmer movement (Rosset et al., 2011). To sum up, cooperatives in Cuba provide mechanisms to overcome knowledge transfer and training provision challenges, and can facilitate access to financial mechanisms.

As was mentioned in section 5.3.1, diversification is difficult to attain at the single farm level, so networking among small farms is a logical alternative to solve this constraint. The cooperatives in Cuba can facilitate this transition, and indeed, a few positive experiences have resulted from arrangements of this type. The experiences compiled by Fernández Domínguez and collaborators (2007) show the economic and social success of four cooperatives that have applied a diversification strategy and successful combination of agriculture and livestock, using technologies based on organic and sustainable principles.

Regarding the competing use of agricultural residues, soil health, animal feed, and energy production are all critical to Cuban agriculture. The condition of animal feed production is dependent on cereal imports (soy bean and corn), and pasture and forage availability is highly influenced by climate (Funes, 1979). In this sense, any opportunity to produce animal feed from residues and by-products represents a locally available solution that requires simple and manageable technologies (Ajila et al., 2012b). Therefore, win-win
solutions facilitated by integrated food and energy production methods provide opportunities to satisfy, to a certain extent, the various input needs of Cuban agriculture.

The most common constraint for rural development in Cuba has been rural population migration (Wolfe, 2004). Opportunities to reverse this situation can be found in the measures of land re-distribution promoted by the government, where unused state land is transferred in usufruct to small farmers. In addition, the government has fostered the creation of new small, urban and suburban farms, thus creating job opportunities for younger generations and to people who have decided to leave urban settlements (Cuba Debate, 2012).

Cuban ‘lineamientos’ support the adoption of sustainable agriculture practices, such as crop diversification, rotation, and intercropping to enhance agricultural yields (Lineamiento No. 187 – Appendix D) and encourage the use of organic fertilizers and biopesticides. Despite the clear intentions of the ‘lineamientos’ to support sustainable farming, there is a lack of specific policies and measures that reflect the political will to adopt sustainable agriculture. As noticed by Altieri and Funes-Monzote (2012), a contradictory phenomenon has been observed in Cuba: when the financial condition of the country improves, conventional agriculture based on high external inputs systems is encouraged; in contrast, sustainable agriculture is fostered only in scenarios of economic scarcity. For this reason, to move forward into the development of integrated farming and IFEPNs, a series of policies should be clearly implemented to really encourage farmers and cooperatives to get involved in more long-term sustainable systems.

5.5.2 IFEPNs at the Agro-Industrial Level

As previously noted, the development of symbiotic networks among agro-industries involves a higher degree of complexity due to the technical and operational requirements of implementing larger agro-industrial technology (Section 5.3.2). Especially in Cuba, the lack of financial resources and access to basic capital is a major concern. Technologies such as anaerobic digestion, however, can mitigate this issue by making efficient and collaborative use of the equipment, and by allowing cost-sharing among the different
facilities involved. For instance, biogas yield from sole substrate digestion, such as manure, does not justify the investment. As such, it is much more cost effective to invest in technology that can operate with various organic feedstocks (Mata-Alvarez et al., 2011).

Transportation is the other major challenge to be considered in the operation of the networks, due to fuel shortages and limited infrastructure in the country. Usually, a distance of no more than 10 km is covered in the transportation of high moisture content feedstock, and 40 km for agro-industrial residues (Dagnall et al., 2000). This reinforces the need for local production and distribution systems, supporting a more regionally-focused integrated symbiotic network. An interesting approach to transform transportation constraints into an opportunity is to ensure vehicles are capable of shipping various products and thereby capitalizing on back-hauling scenarios (Carlsson & Rönnqvist, 2007).

Within the policy environment, the ‘lineamientos’ supports the concept of IFEPNs in principle as it recognizes that the agro-industrial sector must be organized under a more systemic approach, comprising all of the actors involved in the production and commercialization of the products (Lineamiento No. 185 – Appendix D). Furthermore, ‘lineamiento’ No. 186 (Appendix D), seeks to improve the linkages among agricultural production centers with processing industries to ensure self-sufficiency. This represents an opportunity to further elaborate policies and planning tools that embrace the concept and models of the IFEPNs.

One of the main measures contained in the ‘lineamientos’ is the granting of enhanced power to public enterprises and support of new forms of non-state management. Cooperatives, for instance, are being promoted as a socialist form of collective property in different productive sectors, such as construction, transportation, waste disposal and agricultural markets (Puig Meneses & Hernández, 2013). This kind of measure offers the opportunity for the entrance of new actors who can provide services to enrich and support a symbiotic network.
5.5.3 Organizational Challenges and Opportunities

In Cuba, as a result of its culture and the economic constraints faced during the last decades, cooperation is seen as the key factor in overcoming existing challenges. In some scenarios, it is the only way to do it. It was revealed during the consultations, however, that the main challenge at the moment for solving collective problems and implementing new resources management measures is the lack of awareness and lack of agreement among the actors involved. This could certainly be remediated by building institutional capacity and social embeddedness.

Often, lack of awareness is caused by the excessive dedication, in time and resources, to the achievement of the productive goals of the industry or the farm. In terms of awareness around resources use, residues and by-products management practices are often associated with the need to comply with environmental legislation more than with resources use efficiency. In order to overcome this challenge, new spaces must be offered to learn and recognize the value of the resources and the opportunities for resource efficiency in the system, and as a result, create the knowledge capacity necessary to move forward into the evolution of a collaborative network.

Training programs as well as pilot demonstrations are two key strategies recommended by the stakeholders to increase awareness. Training programs should involve the participation of all the members of the enterprise or cooperative, from directors to workers and farmers. This process is considered a central leveling and awareness-gaining opportunity, since all the actors involved can better understand the possibilities offered by the network, as well as learn the importance of their individual role in it. Additionally, training provides time to think outside of the box of daily production, allowing the elaboration of new ideas and strategies, and the further development of social embeddedness.

The presence of a demonstrative experience is recognized as an important awareness – raising enabler as well as a dissemination means for new initiatives and innovations,
particularly when the demonstration is conditioned to local realities and to geographic and climatic factors. For instance, in the province of Santiago de Cuba, and specifically in the head municipality, a successful experience has been carried out in the sawmill “El Brujo”. As part of a national project involving the development of renewable sources of energy, the sawmill is producing energy through gasification of wood residues; the energy produced supplies part of the electricity demand of the enterprise. Although still on a pilot scale it has served as a demonstrative center for other enterprises in the region, and it has confirmed a fruitful relationship between industry and academia.

Through training programs and demonstration, the opportunity to increase the productivity and resource efficiency of the industry or the farm can be explained and disseminated. As was mentioned above, actors in the industry are generally focused solely in accomplishing the productive plans, and any other initiative regarding residues management is seen as a regulatory condition that must be complied with. Therefore, it is important to remark that the IFEPNs are not only a means to reduce the environmental impacts of their residues, but to also improve resource efficiency and productivity.

One of the challenges that previous collaborative experiences have faced was a lack of communication and agreement on common interests among actors. It was reiterated throughout our engagement with the various stakeholders that the feasibility and success of any collaboration project rests in the communication among the actors involved. As many have different interests and duties, it was recognized that it is important to identify and agree on a set of shared interests and objectives to keep the network functioning successfully. In particular, the specific needs, weaknesses and strengths of every actor must be identified such that appropriate contribution can be determined. In other words, relational capacity should be built to develop trust and shared norms of interaction, which lead to a mutual understanding of each other’s problems, interests, capabilities and willingness to participate.

The political and administrative system in Cuba offers several opportunities to build on knowledge capacity as well as relational capacity. Several instances exist where actors
can meet and share knowledge and interests, and further create shared norms. The most important venue is the Assembly of the *Poder Popular*, held at the local, municipal, provincial and national level. In these assemblies, members from the government, directors of public enterprises, among other stakeholders, meet together in commissions, e.g., environment, energy, transportation, among others, to discuss and coordinate different activities and promote new initiatives. The space to discuss initiatives also exists at the level of the state enterprises in the units of environmental management.

Another type of venue, the forum of science and technology, allow the discussion of innovations in industry and agriculture. This movement originates at the local level, and from there spreads successful initiatives up to the national level. This type of initiative represents an opportunity for the dissemination of integrated food and energy production initiatives. In addition, some universities play a role in creating spaces of knowledge transfer and interaction with different stakeholders. Municipal university centres (CUM, *Centro Universitario Municipal*) are located in some municipalities and facilitate the direct relationship between academia and local governments, supporting them in the decision-making processes. Moreover, as part of the changes in the economic policy of the country, the government has indicated the training of local government boards. Even though the main topics covered in training sessions are related to public administration and enterprise management, the stakeholders consulted in this research recognize that resource efficiency and environmental themes could also be included.

All of these instances represent an opportunity for further design, dissemination, and institutionalization of the potential networks, allowing their transition towards the ‘uncovering’ and ‘institutionalization and embeddedness’ stages proposed in the evolutionary theory of Chertow and Ehrenfeld (2012). It should be emphasized, however, that the successful evolution will depend mostly on the ability of actors to interact in a manner that ensures the leverage of resources and policies necessary for the strengthening of the system (mobilization capacity).
Table 5.1 provides an overview of the main barriers and opportunities for the development of further IFEPNs, ranging from the techno-economic to the organizational aspects of the networks.

Table 5.1  Techno-economic and organizational challenges and opportunities for the development of IFEPNs.

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Techno-economic</strong></td>
<td></td>
</tr>
<tr>
<td>Lack of financial mechanisms to implement and operate new technology.</td>
<td>Agricultural cooperatives and emergent non-agricultural cooperatives organized into IFEPNs allow shared use of technology and facilitate access to financial mechanisms.</td>
</tr>
<tr>
<td>Knowledge transfer and training provision challenges - implementation of new farming methods.</td>
<td>Grassroots organizations allow peer-to-peer transfer of traditional knowledge as well as innovations. Political willingness to adopt sustainable agriculture practices.</td>
</tr>
<tr>
<td>Competing use of agricultural and agro-industrial residues.</td>
<td>Adoption of win-win technologies to obtain food and energy or fertilizers and energy simultaneously.</td>
</tr>
<tr>
<td>Lack of rural population.</td>
<td>Land re-distribution measures plus additional sources of employment offered by potential IFEPNs to attract rural population.</td>
</tr>
<tr>
<td>Transportation and poor transportation infrastructure.</td>
<td>Improved local networks and back-hauling alternatives to make better use of the existing resources.</td>
</tr>
<tr>
<td><strong>Organizational</strong></td>
<td></td>
</tr>
<tr>
<td>Lack of agreement.</td>
<td>Spaces to meet and agree on common interests: Assemblies of the <em>Poder Popular</em>, state enterprises’ environmental management units, forum of science and technology, municipal university centers, potential new spaces created to look for potential exchanges and networks.</td>
</tr>
</tbody>
</table>
5.6 MOVING FORWARD

In order to move forward with the development of IFEPNs in Cuba it is necessary to evaluate the current agricultural and agro-industrial operations within a determined region, and evaluate potential networks based on the actual needs of the region. The network opportunities identified as part of this research were based on the consideration of the needs of food and energy provision in the eastern province of Santiago de Cuba. A more detailed study can be conducted to evaluate the potential of a specific municipality or locality. As was described previously, the challenges associated with the development of integrated systems, at the on-site level and the network level, require the understanding of technical and economic aspects, as well as institutional and social conditions. To avoid inadequate decision-making in these dimensions, it is necessary to identify priorities and the assets available to develop the networks. The assets mapping should include information about material flows (inputs, outputs, residues, by-products), infrastructure (transportation, facilities), skills sets, and social networks. It is also important to identify the institutional framework and current policies that underlay decision-making processes.

As it was recognized by the stakeholders consulted in this research, once the potential networks are identified, any decision regarding the operation of the networks should be supported by a detailed assessment in terms of material exchanges and any other resource that is going to be required, especially transportation. This assessment will lead to the elaboration of an appropriate contract, the element that, as stated by stakeholders, can sustain the relationship among the participants of the network. This contract should contain all the responsibilities of the actors involved.

Regarding the facilitation of these cooperative systems and how to drive the process, it is recommended to adopt a mixed approach between goal-directed and serendipitous actions. In such a process, the government provides the policies and policy instruments that deliver objectives and incentives for the actors involved in the network; the different actors are then free to provide solutions. During this process it is important to have feedback mechanisms among all the actors involved and the government so that adequate
interventions can be identified (Costa & Ferrão, 2010). Events are often hosted by the local governments or by a leading organization to allow the interaction among actors (Costa & Ferrão, 2010; Paquin & Howard-Grenville, 2012).

Cuban stakeholders consulted in this research agree on the role of the government to establish general guidelines, prioritize measures, and monitor and evaluate the impacts. They also recognize the importance of incorporating all the actors involved, especially the communities and the universities as assistance and support bodies. It is also noted that the specific knowledge owned by every actor, will greatly contribute to the design and implementation of the networks.

The current spaces for meeting and discussion in Cuba, such as the assemblies of the poder popular, the science and technology forums, or the municipal university centres can be the spaces for interaction among the members of the potential networks. Special events, however, could also be organized by a leading organization, university or by the local governments, where actors can dialogue, share knowledge and look for mutually beneficial networks.

Cuban institutionality is characterized by being highly goal-directed and bureaucratic. As such, space for serendipitous interactions might not be easy to reach so some of the measures promoted by the government need to facilitate this process. For instance, the new management models that seek to give greater autonomy to the producers to encourage greater productive efficiencies, additionally seek to gradually decentralize decision-making processes towards local governments. Certainly, this could also allow a better identification of local needs as well as the search for solutions that best adapt to local realities, as recognized by the stakeholders consulted in this research.

5.7 CONCLUSION

The development of new economic management models in Cuba offers the possibility to introduce new strategies for food and energy production – two of the main priorities of the country. The strategy analyzed in this chapter is based on the adoption of two eco-
mimetic concepts, IS and IFES, to support the emergence of local and regional IFEPNs. The development of these networks implies challenges both at the on-site operational level (mainly technological constraints) and at the network level (mainly organizational constraints). Such challenges include the need for new skills sets and knowledge, the provision of technical support and training supply, lack of rural labour, inadequate access to finance, and the influence of the institutional framework and policies on the delivery of the factors necessary to trigger the new integrative and collaborative activities.

The opportunities in Cuba to face these challenges are mostly associated with the cooperative organization of agriculture and the incorporation of new non-agricultural cooperatives that are encouraged by the social and economic policy guidelines of the country. Cooperative arrangements can facilitate the creation of networks among farmers, agricultural cooperatives and agro-industries for an efficacious use of the resources (raw materials, residues and by-products), the shared use of the necessary technology, and the access to financial mechanisms. The development of these networks relies on the ability of its members to organize, collaborate and make use of the social capital. In a resource-constrained country such as Cuba, collaboration is most often the only way to get things done, so in a sense the development of IFEPNs is a new way of organizing the collaborative efforts of the Cuban population to this end. It requires increased institutional capacity should be built, where spaces for learning, training, and demonstrative experiences can facilitate knowledge capacity building and at the same time provide spaces for communication. This allows for a sharing of values and builds consensus, supporting improved relational capacity. Both aspects can increase the capacity of the collaborative endeavour to leverage resources and policies necessary to the strengthening of the system. The facilitation of the integrated networks and the necessary institutional capacity building that must occur concurrently can be a product of both goal-directed and serendipitous actions. Some of the economic and social policy guidelines are intended to give greater autonomy to the producers and to local governments, factors that can enable serendipitous actions in a country that has long been characterized for its centralized decision-making and excessive bureaucracy.
By adopting the strategies for integrated food and energy production, Cuba has the opportunity to reinforce its socially focused economy without threatening the vulnerability of its environment and natural resources. Through an adequate interpretation of the ‘lineamientos’ and by taking advantage of the collaborative underpinning of the population and institutions, Cuba has the opportunity to prove a sustainable alternative that can benefit the economy, society and the environment.

5.8 References

Note to reader: Cuban scholars or other latin scholars cited in this thesis use two last names, e.g. Pérez Villanueva.


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CHAPTER 6 CONCLUSIONS

6.1 SUMMARY OF RESULTS AND MAIN CONCLUSIONS

The history of Cuba during the last twenty three years of revolution is marked by a constant experimentation in structural policies to drive the country's economy. The collapse of the USSR and the reinforcement of the economic blockade in the early 1990s have prompted Cuba to implement policies that on the one hand, preserve the social and political ideology of the country, and on the other, provide economic stability to the country.

Particularly since Raúl Castro assumed the presidency in 2006, a series of more market-oriented reforms have shaped the transformation of the country. The authorization of the ‘cuentapropistas’ (self-employment) has changed the physiognomy of the Cuban cities; small snack bars keep multiplying in every street, “for sale” signs appear in houses and car windows, and self-employed vendors sit on their buildings doorways selling everything from hair accessories to music CDs. In the countryside, 1.4 million hectares of idle state land have been transferred to small farmers as a measure to augment agricultural production (Peters, 2012a). The challenge for Cuba is to ensure that these transformations do not attract the major ills of capitalism, i.e. social inequalities associated with the accumulation of wealth, and environmental degradation.

This research emerged in light of this challenge and set out to investigate specific opportunities for an eco-industrial development model that can improve food and energy production, conceptualized by IS and IFES. In order to investigate these opportunities a set of questions were posed to know a) current needs and scarcities in the country; b) the existing assets in terms of materials (residues and by-products) and energy flows, infrastructure, and skills sets (research questions 1 and 2); c) the potential linkages and networks among members of agriculture and agro-industry sectors (research question 3 and 4); and d) the current challenges and opportunities that can counteract and favor the development of the IFEPNs (research question 5). The findings of this research around these four topics can be summarized as follows.
a) Cuba is a country heavily dependent on imports for local production of energy and food. Fertilizer production ceased after the ‘Special Period’, and after several decades of agricultural production based on the ‘green revolution model’, the soils are affected by deficiencies in organic matter and nutrients, which generates a situation of dependency on fertilizers. The use of imported mineral fertilizers is prioritized to crops of economic importance such as sugarcane, bananas, potato and rice. The agricultural output is still low, however, and there is a pattern of dependence of imports of vegetable oil, legumes and cereals (rice and wheat for human consumption, and corn and soy bean for animal feed), and powdered milk. Therefore, the outputs of the IFEPNs should be centered in the production of energy through local and renewable sources, and the production of organic fertilizers, animal feed and main staples of the Cuban diet.

b) A set of assets in agriculture and agro-industry can allow the development of both IFES and IS systems. In agriculture, the diversity of crops and animals currently grown and reared provides the basis for both better utilization of this diversity in terms of the design of the farms and better use of residues and by-products. The rural population in Cuba is an educated population. Furthermore, farmers’ organizations exist to disseminate knowledge related to the implementation, operation, and improvement of new practices and technologies, facilitating in this manner the transition towards diversified and integrated farms. The organization of the agricultural sector in small farms, non-state cooperatives (CSS and CPA) and state cooperatives (UBPC), is particularly helpful for the development of symbiotic networks between farmers and cooperatives, especially to operate centralized composting operations, anaerobic digesters and gasifiers, or aquaponic systems that can better utilize available resources and maximize the overall food and energy output of the system.

In the agro-industry, there are several activities generating considerable amounts of by-products and residues that are mostly not utilized to any significant degree. With appropriate management and treatment further value can be recovered from or added
to these materials through energy production or production of new or existing value-added products. The energy content of all the identified residues and by-products (Table 4.1), plus the additional energy content of bioethanol from a potential distillery and the associated biogas produced from wastewater, is equivalent to 1,463,203 GJ. If this energy is transformed into electricity and assuming transformation efficiencies of 15 to 20%, it could provide 63 GWh of electricity per year. Other materials can be recovered to produce value-added products such as pectin, natural pesticides for agriculture, or be used as growth substrate for edible mushrooms or other microorganisms to then extract valuable bioactive compounds. The large set of human capital and research centres existing within the country and the province can provide further assistance to investigate the basic requirements to adapt and operate the necessary biomass to energy technology and value-added products production methods. The intention of this research is not to be prescriptive, and the specific use for each by-product and waste stream will depend ultimately on the material flows, local scarcities and resources availability, transportation infrastructure, and the specific needs and capabilities of the communities involved.

c) The set of assets described above offer the opportunity to develop IFEPNs that can range from the small farm, the cooperative, a network of cooperatives, a network of agro-industries, and up to a network of cooperatives and agro-industries. The priority of these networks is to reinforce the production of crops that provide food for human consumption and crops for animal forage. Equally important is to generate animal feed and forage from crop wastes. The most important feature of these networks is the integration of technology and processing/production techniques in a manner that better utilize available resources and maximizes the total food and energy output of the system. An example of this is anaerobic digestion, where the outputs are not only in the form of energy (biogas), but also as a source of organic fertilizers (solid digestate) and wastewater that can further be used to cultivate fish and plants for animal feed (aquaponics system). It is important to remark that these networks can also produce value-added products, which can replace inputs for agriculture (natural pesticides) or agro-industry (pectin), or to diversify the industry and obtain more
revenue. It is important to note that even though these integrated systems and networks are intended to maximize food and energy self-sufficiency, it does not mean that they are isolated. In the same manner they can provide outputs they can also receive external inputs. The configuration of these networks in size and components will vary according to the specific material flows and local conditions. A variable that limits the extension of the networks, however, is transportation infrastructure and resources. Therefore, local networks should be developed to maximize output production while minimizing transportation.

d) The challenges to develop integrated networks of food and energy production in the province of Santiago de Cuba can be classified into techno-economic constraints and organizational constraints. In the first group, the main challenges are the incorporation of new skills sets and knowledge, the provision of technical support and training, supply of rural labour, access to finance, and the influence of the institutional framework and policies in the delivery of the factors necessary to trigger integrative and collaborative activities. In the second group, the main challenges are the lack of awareness and lack of agreement among actors involved. Opportunities to overcome the techno-economic challenges are found in the cooperative arrangements of the agricultural sector and the incorporation of new non-agricultural cooperatives that are promoted by the social and economic policy guidelines of the country. Cooperative arrangements can facilitate the efficacious use of resources (raw materials, residues and by-products), the shared use of necessary technology, and the access to financial mechanisms. Cooperative arrangements, along with grassroots organizations that allow a peer-to-peer knowledge transfer, can facilitate sustained technical support. The job opportunities offered by the integrated food energy production networks, along with the measures of un-used state land transfer, can boost rural labour supply. The organizational barriers can be overcome by building up institutional capacity through the opportunities offered by the Cuban institutions in providing spaces for learning and knowledge transfer, and spaces for communication and agreement on common interests. The measures contained in the ‘lineamientos’ to give greater autonomy to the producers and to local governments, can enable
serendipitous actions to emerge and to complement goal-directed actions supervised by the government. This mixed approach can facilitate the evolution of the IFEPNs.

Overall, the results of this research show the potentiality of the region to embark in new economic management and production models that can generate what is often called a “win-win-win” situation, where the society, the economy and the environment are benefited. The concept of the ‘eco-economy’ for instance, remarks on the direct benefits to local communities when a myriad of networks of economic activities make use of local resources (particularly eco-resources) in a more sustainable and ecological manner, in a way that generates new activities, new products, transactions and networks (Marsden, 2010). Consequently, the IFEPNs discussed in this research can be perceived as drivers for the development of an ‘eco-economy’ and for the emergence of local and regional sustainable development (Chatterton, 2002; Kitchen & Marsden, 2009).

Even though industrial ecology and industrial symbiosis are considered a weak approach for local and regional sustainable development and ecological modernization (Horlings & Marsden, 2011; Pike et al., 2006), the results of this research provide examples of the ecological underpinning of these concepts through the design of systems and networks that make and efficient, and most importantly, effective use of limited resources. The debate, which is not extended in this research, should be focused on how the political and social trends - neoliberal, reformist, progressive, and radical, as identified by Holt-Giménez and Shattuck (2011) – make use of the concepts and technologies. In this sense, Cuba is in a privileged condition; besides being physically isolated it is also isolated from dominating supra-national organizations, and therefore it can adopt and adapt current concepts and technologies to its own local needs.

Despite the opportunities offered by the eco-mimetic development approach and the specific benefits of the networks presented in this research, and despite the favorable conditions found within the institutional framework and policy proposals, the Cuban government shows some contradictory behaviours and mild responses to the implementation of long-term sustainable solutions. As Lane (2012) has pointed out, Cuba
is strong in red ideology, but weak in green ideology and green economy, and even though some hints for a green economy are included in the ‘lineamientos’, they do not guarantee it. Also, as Altieri and Funes-Monzote have argued (2012), the greener initiatives, such as sustainable farming, are left behind when the economy of the country improves or when a new allied country offer its supports.

6.2 Recommendations

Implementation strategies for IFEPNs can be drawn by using the methods used in this research as well as from the recommendations compiled from the literature. This research was based on an assets mapping approach to identify potential networks. The organizations, universities, or government bodies in Cuba that will eventually develop these networks could adopt a similar approach. This approach is based on understanding the actual needs and scarcities of a determined region, to further evaluate the actual and potential networks based on the existing material flows (inputs, outputs, residues, by-products), infrastructure (transportation, facilities), skills sets and social networks. The potential networks should be accompanied by a detailed techno-economic assessment to fully understand their benefits and requirements.

It is recommended to adopt a mixed or middle-out approach to facilitate the further implementation of the networks, where planned or goal-directed, and self-organized or serendipitous actions drive their development. This means that the distinctive top-down directives of the Cuban government should be alternated and complemented with bottom-up spontaneous initiatives from the actors participating in the network. For this process to be fruitful and meaningful for both the government and the actors and communities involved, it is recommended that strong feedback mechanisms exist so better and less restrictive interventions can be made.

6.3 Research Opportunities

As this is exploratory research, there are myriad opportunities to better understand the potential of the eco-development approach in Cuba and specifically in the province of Santiago de Cuba. Further opportunities exist to investigate the whole province in detail,
and even the whole country to estimate how it could benefit from this eco-economic model. In the opposite direction, the investigation could be focused in one municipality or one specific locality. For example, the locality of El Brujo (Santiago de Cuba municipality) is the place of operation of several facilities, where the sawmill ‘El Brujo’ has a demonstration gasification plant. The opportunities for symbiotic networks in this locality could be further explored to expand the demonstrative operations and take advantage of the social networks already-created through the gasification experience. In addition, the networks with neighbouring agricultural cooperatives could be investigated.

This research was mainly focused on the opportunities in the agriculture and agro-industrial sectors, nevertheless the province of Santiago de Cuba and its head municipality is an important industrial center (power station, oil refinery, cement plant), which represents another aspect of the productive spectrum that could be investigated. Also, the municipality of Santiago de Cuba has a 90% urban population, therefore another research opportunity exists to investigate the opportunities in a more urban and sub-urban setting, and the linkages and symbiotic networks that can be established among the urban, suburban and rural interfaces.

A useful method to enrich this type of research is through the utilization of Geographical Information Systems (GIS). Through a GIS-assisted mapping of all the types of assets, a further geographical analysis can be performed to better understand the potentialities of the selected province or municipality and inform the development of potential networks. Particularly important is the investigation of transportation infrastructure and how the local networks can optimally adapt to such infrastructure. In this sense GIS analysis is the ideal tool.

An additional research opportunity is the study of the techno-economic variables affecting the development of the integrated networks. In these assessments, the study of suitable technologies is particularly relevant since many geographical and climatic conditions are unique to the Cuban-tropical context. Related to this topic is the investigation of other renewable sources of energy that can be added to the system to
increase the energy efficiency and to not depend exclusively on biomass. In this sense, the ‘lineamientos’ acknowledge the importance of incorporate non-renewable sources of energy (Lineamiento No. 247 – Appendix D). The country and the province have a vast trajectory in the study and application of these technologies, even though they do not represent more than 0.6% of the total energy output of the country (ONE, 2011b).

Local community needs have been mentioned more than once throughout this thesis, and it is therefore a significant research opportunity. Many of the problems associated with community projects and technology transfer are associated with the lack of or limited participation of the involved communities. Therefore, an assessment of the local community needs and capabilities is highly desired. Equally important is the insight from the involved stakeholders in the locality and in direct contact with the communities, such as members of the local government, agricultural cooperatives administrators, and delegates of the municipal agricultural delegation, among others.

The research opportunities presented here, as well as the overall results and conclusions of this thesis, are particularly useful for current initiatives being developed in ‘Oriente’ region, such as the Canadian International Development Agency (CIDA) project for local economic growth and food security. The main objectives of the project are to increase the capability of local governments and local officials to implement new strategies for local development, and to increase the capability of small farmers to involve in new productive activities. Therefore, the insights provided by this thesis can be adopted and further adapted by the project coordinators in Canada and Cuba to fit into the different stages of the program, and help to achieve the expected results.

6.4 Final Thoughts

After the collapse of the USSR, the severe economic crisis, and the massive exodus of Cubans to the U.S., not many believed that the fierce resistance of the Cuban regime to capitalism would last for so many years. More than 20 years after, however, the “Revolution” keeps on track, demonstrating two things that I am still not able to decipher,
a) that the Cuban regime and ideology is so strong that it prevents any attempt of re-revolution, or b) that the Cuban people are really very resilient. Maybe my response is a mixture of both. What this research has shown me is that Cuba can be again the small, revolutionary, and influential country that it was previously. Cuba can still give us a lesson, an inspirational model as it did it in the sixties, as it did it in the Chile of Salvador Allende. Cuba can show us a model towards sustainable development, where our existence as human beings does not compromise the existence of other species, where the biophysical resources that support us are not threatened by our very own existence. But as Cubans say in their day-to-day, *no es fácil* (is not easy), and the solution is only in them, in the Cuban people.

6.5 REFERENCES


REFERENCES


river San Juan de Santiago de Cuba associated to a focus of industrial pollution").

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APPENDIX A QUESTIONNAIRE
DATA COLLECTION FORM

A) Facility information

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of employees</th>
<th>Main products</th>
<th>Water sources</th>
<th>Energy sources</th>
</tr>
</thead>
</table>

B) Materials, energy, and water inputs and outputs (weight, energy consumption and volume)

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
<td></td>
</tr>
<tr>
<td>Energy consumption</td>
<td></td>
</tr>
<tr>
<td>Water consumption</td>
<td></td>
</tr>
<tr>
<td>Main products</td>
<td></td>
</tr>
<tr>
<td>By-products</td>
<td></td>
</tr>
<tr>
<td>Residues (wastewater, solid wastes, atmospheric emissions)</td>
<td></td>
</tr>
</tbody>
</table>

C) Management

<table>
<thead>
<tr>
<th>Strategies for:</th>
<th>Yes/No</th>
<th>Frequency</th>
<th>Description (technologies, amounts, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water use optimization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid waste management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wastewater treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capture and use of waste heat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycled materials use</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D) Distance from suppliers, buyers, facilities involved in any kind of exchange or any other facility in the proximity

<table>
<thead>
<tr>
<th>Suppliers, buyers, facilities involved in any kind of exchange or any other facility in the proximity</th>
<th>Distance (km)</th>
</tr>
</thead>
</table>
ORIGINAL QUESTIONNAIRE IN SPANISH

FORMULARIO DE RECOLECCIÓN DE DATOS

A) Información de la industria

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nombre</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Número de empleados</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lista de productos principales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Origen de las fuentes de agua:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Origen de las fuentes de energía:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B) Entradas y salidas de materiales, energía y agua (peso, consumo energético y volumen)

<table>
<thead>
<tr>
<th>Descripción</th>
<th>Cantidad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materias primas</td>
<td></td>
</tr>
<tr>
<td>Consumo de energía</td>
<td></td>
</tr>
<tr>
<td>Consumo de agua</td>
<td></td>
</tr>
<tr>
<td>Productos principales</td>
<td></td>
</tr>
<tr>
<td>Sub-productos</td>
<td></td>
</tr>
<tr>
<td>Residuos (aguas residuales, residuos sólidos, residuos atmosféricos)</td>
<td></td>
</tr>
</tbody>
</table>

C) Gestión

<table>
<thead>
<tr>
<th>Estrategias para:</th>
<th>Sí/No</th>
<th>Frecuencia</th>
<th>Descripción (tecnologías, volúmenes, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eficiencia energética</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eficiencia en la gestión del agua (ej: reutilización del agua)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gestión de residuos sólidos</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tratamiento de aguas residuales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Captura y uso de pérdidas de calor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uso de materiales reciclados</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D) Distancia desde proveedores, compradores, industrias con las que exista algún tipo de intercambio u otros centros productivos cercanos

<table>
<thead>
<tr>
<th>Proveedor, comprador, industrias con las que exista algún tipo de intercambio u otros centros productivos cercanos</th>
<th>Distancia (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B CONSULTATIONS

Theme: Specific needs

1. What are the scarce resources that have impacted the productivity of the industry and/or agriculture sector?
2. What other resource needs does the industry and/or agriculture sector have? Have you considered other alternatives or investigated how you could work with other industries to address this?

Theme: Potential areas for exchanges and collaboration

3. What kind of wastes or by-products do you produce? Have you ever investigated who could use these resources or what else they could be used for?
4. Have you ever identified wastes or by-products from other facilities that could be used in your processes? Has anyone ever come to you with such an idea?
5. Have you identified any new technologies, processes, and synergies that you feel could help improve productivity and efficiency in the industry and/or agricultural sectors if you had access to it?

Theme: Inter-organizational cooperation and key factors for the development of the network

6. What do you think could be some important aspects for determining the suitability for potential resource exchanges? Distance between facilities?, transportation?, available technologies?, inter-organizational relationships?, personnel?, autonomy (power in decision-making)?
7. Do you actively develop relationships or maintain contact with those in other industries, such as through industry networks or groups, annual meetings, etc.? Have you exchanged materials, ideas or other resources with other industries or facilities?
Theme: Challenges, barriers and drivers

8. What are the obstacles and challenges that you see to exchange wastes or by-products with other facilities?

9. How could these difficulties and barriers be overcome?

10. How could this type of relationships be driven and through whom or which agencies, municipalities, NGOs, universities, ministerial agencies?

11. If you were asked to participate in a materials’ exchange network what concepts or policies would need to be supported in order for it to be of interest to you?

Theme: Expectations or benefits of the project

12. Do you think being a part of a material exchange network could benefit your facility? If so, how?

Theme: Implications for participants and capabilities

13. What would be the characteristics of the network members that would favour (help with) it development and successful operations?

14. What do you think would be (could be) your significant contribution to such a network (there can be more than one contribution)?

15. What kind of knowledge and/or managerial resources would you need to support your participation in such a network?

16. What risks do you see by participating in such a network?

Theme: Next steps

17. What are the next steps that you think could be taken to start the development of such a network?
Tema: Necesidades

1. ¿Cuáles son los recursos escasos que han limitado la productividad del sector industrial y/o agrícola?
2. ¿Qué otro tipo de necesidades de recursos tiene el sector industrial o agrícola? ¿Ha considerado otras alternativas para satisfacer estas necesidades, o ha investigado cómo podría trabajar con otras industrias para abordar este problema?

Tema: Áreas potenciales de intercambio y colaboración

3. ¿Qué tipo de residuos o sub-productos se generan en esta industria? ¿Ha investigado quiénes podrían usar estos recursos o en qué otra cosa podrían ser utilizados?
4. ¿Usted ha identificado alguna vez residuos o sub-productos de otras industrias que podrían ser útiles en sus procesos? ¿Alguien le ha propuesto tal idea?
5. ¿Usted ha identificado nuevas tecnologías, procesos, y/o redes de intercambio de materiales que usted cree podrían mejorar la productividad y eficiencia en los sectores industriales y/o agrícolas, en caso de que usted tuviera acceso a ellas?

Tema: Cooperación inter-organizacional y factores clave para el desarrollo de la red

6. ¿Qué aspectos cree usted que podrían ser claves en la factibilidad de potenciales intercambios de recursos? ¿Distancia entre las industrias?, ¿transporte?, ¿tecnologías disponibles?, ¿relaciones inter-organizacionales?, ¿personal?, ¿autonomía (poder en la toma de decisiones)?
7. ¿Usted desarrolla activamente relaciones o mantiene contacto con otras industrias, a través de por ejemplo, grupos o redes de industrias, reuniones anuales, etc.? ¿Usted ha intercambiado materiales, ideas u otros recursos con otras de estas industrias?
Tema: Desafíos, barreras y conducción

8. ¿Qué tipo de dificultades y barreras ve usted en intercambiar residuos o sub-productos entre los miembros de una red sinérgica?
9. ¿Cómo podrían ser superadas estas dificultades y barreras?
10. ¿Cómo se podría conducir este tipo de relaciones y a través de quién o qué organismos, municipios, ONGs, universidades, agencias ministeriales?
11. ¿Si a usted le preguntaran participar en una red de intercambio de materiales, qué conceptos o políticas cree que debieran ser apoyadas para que usted se interesara en participar en ella?

Tema: Expectativas o beneficios del proyecto

12. ¿Cree usted que siendo parte de una red de intercambio de materiales su industria podría beneficiarse? Si es así, cómo.

Tema: Implicancias para los participantes y capacidades

13. ¿Cuáles serían las características de los miembros de la red que podrían favorecer su desarrollo y ser exitosa en sus operaciones?
14. ¿Cuáles cree usted que podrían ser sus mayores contribuciones a la red? Por ejemplo, proveer de medios de transporte, silos de almacenamiento, u otra infraestructura, servicios o personal calificado.
15. ¿Qué tipo de necesidades específicas de conocimientos y/o recursos administrativos requeriría usted para apoyar su participación en tal red?
16. ¿Qué riesgos ve en la participación en tal red?

Tema: Siguientes pasos

17. ¿Cuáles son los pasos siguientes que usted cree deben tomarse para comenzar el desarrollo de tal red?
APPENDIX C

LIST OF VISITED FACILITIES

Municipality of Santiago de Cuba:
1. Sawmill “El Brujo”

Municipality of San Luis:
2. Sugar mill “Paquito Rosales”
3. Sugarcane cleaning facility “Santa Cruz”

Municipality of Songo-La Maya:
4. Fruit processing plant “Ponupo”
5. Sawmill at La Maya
6. Tobacco factory at La Maya

LIST OF PEOPLE CONSULTED

1. José Suárez: Coordinator of the Group of Industrial Symbiosis. Professor at the Faculty of Mechanical Engineering, University of Oriente, Santiago de Cuba.
2. José Alfredo Motito: Chemical engineer. Oversight Committee of the Ministry of Science, Technology and Environment (CITMA), Santiago de Cuba delegation.
3. Luis Blanco Dominguez: Director of Industrial Plants of the Sugar Company of Santiago de Cuba.
4. Hipólito Carvajal: VC of Research and Post-graduate studies, University of Oriente, Santiago de Cuba.
5. Alfredo Ferrer: Professor at the Centre of Energy Efficiency, University of Oriente, Santiago de Cuba.
6. Ofelia Pérez: Director at the Centre of Coastal Multidisciplinary Studies, University of Oriente, Santiago de Cuba.
7. Orlando Alfaro Vives: Deputy Director of the Centre of Solar Energy (CIES-CITMA), University of Oriente, Santiago de Cuba.
8. Telvia Arias Lafargue: Professor at the Faculty of Chemical Engineering, University of Oriente, Santiago de Cuba. Former member of the group “Bahía” for the integrated management of the bay of Santiago de Cuba.


10. Manuel Falcón Hernández: President of the Poder Popular Municipal Songo-La Maya.
Lineamiento No. 185: Organizar la producción agropecuaria en aquellas actividades generadoras de ingresos externos o que sustituyan importaciones, aplicando un enfoque sistémico o de cadena productiva que comprenda no solo la producción primaria, sino todos los eslabones que se articulan en torno al complejo agroindustrial. Estas cadenas se desarrollarían con los propios recursos del sistema, a partir de los ingresos netos por exportaciones o de los ahorros por sustitución de importaciones. En la organización de la producción del resto de las actividades, deberá predominar, sobre todo, un enfoque territorial, dirigido al autoabastecimiento a ese nivel, con énfasis en la ejecución del programa de la agricultura suburbana, que deberá extenderse a todo el país.

Guideline No. 185: Organize agricultural production around external income-generating activities or activities that replace imports, applying a systemic or chain production approach that includes not only primary production, but all the links that are built around the agroindustrial complex. These chains would be developed using the own resources of the system, through net export income or savings gained through import substitution. In the organization of the rest of the productive activities, a territorial approach should predominate, aimed at providing the territory self-sufficiency, with emphasis on the implementation of the suburban agriculture program, which should be spread throughout the country.

Lineamiento No. 186: Vincular adecuadamente los polos productivos agropecuarios y la industria procesadora, a fin de garantizar el abastecimiento a las grandes ciudades, a la exportación y al mercado interno en divisas.

Guideline No. 186: Adequately link agricultural production centers with the processing industry in order to ensure supply to large cities, export and domestic market in Cuban convertible peso (CUC).
• **Lineamiento No. 187:** Continuar reduciendo las tierras improductivas y aumentar los rendimientos mediante la diversificación, la rotación y el policultivo. Desarrollar una agricultura sostenible en armonía con el medio ambiente, que propicie el uso eficiente de los recursos fito y zoogenéticos, incluyendo las semillas, las variedades, la disciplina tecnológica, la protección fitosanitaria, y potenciando la producción y el uso de los abonos orgánicos, biofertilizantes y biopesticidas.

Guideline No. 187: Continue to reduce unproductive land and increase yields through diversification, rotation and multicropping. Develop sustainable agriculture in harmony with the environment, which encourages the efficient use of plant and animal genetic resources, including seeds, plant varieties, technological disciplines, plant protection, and promoting the production and use of organic fertilizers, biofertilizers and biopesticides.

• **Lineamiento No. 221:** Consolidar la industria farmacéutica y biotecnológica como una de las actividades de mayor capacidad exportadora de la economía, e incorporar nuevos productos al mercado nacional para sustituir importaciones.

Guideline No. 221: Strengthen the pharmaceutical and biotechnology industry as one of the activities of major export capacity of the economy and bring new products to national market to substitute imports.

• **Lineamiento No.222:** Desarrollar la industria de suplementos dietéticos y medicamentos naturales, a partir de insumos nacionales, para el consumo y la exportación.

Guideline No. 222: Develop a dietary supplements and natural medicines industry from domestic inputs, for both internal consumption and export.

• **Lineamiento No. 246:** Fomentar la cogeneración y trigeneración en todas las actividades con posibilidades. En particular, se elevará la generación de electricidad
por la agroindustria azucarera a partir del aprovechamiento del bagazo y residuos agrícolas cañeros y forestales, creándose condiciones para cogenerar en etapa inactiva, tanto en refinación como en destilación.

Guideline No. 246: Promote co-generation and tri-generation in all possible activities. In particular, electricity generation will be increased by the sugar industry from the use of sugarcane bagasse and agricultural and forestry residues, creating conditions for co-generation during the off-season, both in refining and distillation.

- **Lineamiento No. 247:** Potenciar el aprovechamiento de las distintas fuentes renovables de energía, fundamentalmente la utilización del biogás, la energía eólica, hidráulica, biomasa, solar y otras; priorizando aquellas que tengan el mayor efecto económico.

Guideline No. 247: Promote the use of various renewable energy sources, primarily the use of biogas, wind, hydro, biomass, solar and other, prioritizing those with the greatest economic impact.