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Bioenergy in Ukraine: Sustainable Pathways for the Development of Ukraine's Agro-biomass Potential

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Furthermore, this thesis contains no materials previously written and/or published by another person, except where appropriate acknowledgment is made in the form of bibliographical reference, etc.

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ABSTRACT OF THESIS submitted by:
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Ukraine (UA) has significant potential for bioenergy. Biomass can supply 1 EJ per year (or 18% in the country's energy balance). The major part of this is formed by agricultural residues and energy crops. Annually nearly 175 PJ can be derived from straw, which is currently not used elsewhere.

At present the biofuels sector in UA is not institutionalised although a number of initiatives have emerged recently. Biomass supplies only 0.5% in UA's energy balance. The development of bioenergy is believed to help the country combat its significant energy security problem, contribute to the revitalisation of its agriculture and bring a number of other economic, social and environmental benefits. The dissertation explores pathways for the establishment of an agro-industrial bioenergy sector that not only offers tangible benefits to UA but has also a capacity to co-exist with the country's entrenched energy sector, which is following natural gas, coal and nuclear pathways.

The work highlights and defines key factors and organisational elements for the transformation of local agro-bioenergy systems in Western Europe (WE) (i. e. Sweden, Denmark and Spain) and UA, and structures them into five types of new agro-biomass frameworks for organisation and action (ABFs). ABFs are described, analysed and compared via in-case and cross-case study analysis of 23 initiatives on straw use for energy in listed countries with the application of a conceptual framework developed by the author. Rationalisation of the behaviour of farm-based entrepreneurs, which emerge from case studies, is performed. The developed frameworks are expected to become motivational tools for the actor involvement in bioenergy chains as their main purpose is to underpin and demonstrate a clear suite of benefits to key stakeholders once they engage in bioenergy initiatives.

All ABFs share key components but differ markedly according to the local context and resources, the nature of goals, the number of actors, complexity and degree of formalisation. They stream the work into: 1) identification of constraining and facilitating factors for the bioenergy development in Ukraine; 2) suggestion of the pathways for the country to follow in order to establish an agro-industrial bioenergy sector. Three major pathways delineated in this work include: 1) *'straw for local heating'*; 2) *'straw for district heating'*; 3) *'straw for combined heat and power'*.

A roadmap towards the expansion of Pathway 1 and establishment of Pathways 2 and 3 in UA is suggested and discussed. Pathway 2 is viewed as the most feasible for the country to undertake considering its currently exploited biomass resources and forecasted potentials. Recommendations for the target audience (i.e. policy makers, non-governmental actors, academia and researchers), who would like to move new bioenergy systems forward are suggested. Among other, a recommendation to construct a 5-10 MW demonstration straw-fired district heating plant is given. The outcomes of the study are transferable to various contexts on the condition that local specificities are taken into account.

This work accounts for different sides in discussions over bioenergy sustainability, which took place in academic and public circles within the last few years. Major concerns around biofuels include food versus fuel debate, greenhouse gas neutrality of biofuel production and use, and overall environmental impacts of biofuels at different stages in their lifecycles. Energy production from residual agricultural biomass (i.e. straw), which is studied within the scope of this work, avoids most of the general concerns on biofuel sustainability, however, has its own specific challenges, which need to be understood and managed appropriately.

Keywords: bioenergy management, biomass residues, sustainable biofuels, straw logistics, non-technical barriers to bioenergy, Ukraine, economies in transition

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List of Abbreviations

ABF - agro-biomass based framework for organisation and action
Bioenergy NoE – Bioenergy Network of Excellence
BtL – biomass-to-liquids
BWV – Babcock and Wilcox Vølund A/S
CEU – Central European University
CHP – combined heat and power
CMU – Cabinet of Ministers of Ukraine
CtL – coal to liquid
DBA – Danish Biomass Agreement
DEA – Danish Energy Agency
DH – district heating
DK - Denmark
DSSA - Danish Straw Supply Association
DTI - Danish Technological Institute
EBAP – European Biomass Action Plan
EiT – economy in transition
ES - Spain
EU – European Union
EUR – Euro
FM - framework
GHG – greenhouse gas
GIS – green investment scheme
GtL – gas to liquid
ha - hectare
HTU - Hydro Thermal Up-grading
IDEA – Institute for Energy Diversification and Savings (Spain)
IEA – International Energy Agency
IIIEE – International Institute for Industrial Environmental Economics
JI – joint implementation
kg - kilogramme
LLC – limited liability company
MSW – municipal solid waste
Mtoe - million tones of oil equivalent
NAER - National Agency on Effective Energy Use in Ukraine
NASU – National Academy of Sciences of Ukraine
NERC - National Electricity Regulatory Commission
NERCU – National Electricity Regulatory Commission in Ukraine
NUBNUU – National University of Bioresources and Nature Use of Ukraine
OJSC – open joint stock company
PJ - petajoule
REP – Renewable Energy Plan (Spain)
RES – renewable energy sources
RQ – research question
RsQ – research sub-question
SE - Sweden
SEC Biomass - Scientific Engineering Centre Biomass
SLU – Swedish University of Agricultural Sciences (Sveriges Landbruksuniversitet)
SRC - short rotation coppice crop
TIS - Technological Innovation System
TPES – total primary energy supply
UA - Ukraine

UAH – Ukrainian hryvnya
UN FCCC - United Nations Framework Convention on Climate Change
USD – United States dollar
VAT – value added tax
VRU – Verkhovna Rada of Ukraine
WE – Western Europe
WWTP - waste water treatment plants

1 Introduction

Chapter 1 defines research problem explored in this work and formulates research questions to be addressed. Section 1.1 presents background to the research problem by broadly discussing sustainability challenges faced by current energy systems and presenting ideas on how bioenergy development can potentially address these challenges in global and Ukrainian contexts. Section 1.2 maps research area and scope, frames research problem and questions, and identifies target audience for this study.

1.1 The nature of the problem

1.1.1 Traditional energy systems

Ensuring secure, affordable and environmentally sustainable supply of energy services is an important global challenge of the 21st century. However, existing energy systems are in most cases unsustainable.

Combustion of fossil fuels (i.e. coal, oil and natural gas) for energy production contributes to greenhouse gas (GHG) emissions, which are known to cause global climate change (UNFCCC 2010). Humans burn fossil fuels at much faster rates than the speed of their formation. In the 20th century the global mean temperature increased by about 0.74°C (UNFCCC 2010) while that in Europe – by more than 0.9°C (Fagernäs *et al.* 2006). Computer climate models predict the average global temperature increase by 1.8°C to 4.0°C during this century (UNFCCC 2010). Nuclear energy is GHG free, however, entails a number of other challenges in the areas of social and environmental sustainability. The problem of nuclear waste utilisation (IAEA 2010; IEA 2008) and the risk perceptions of nuclear safety are among the key ones (A. Cherp *et al.* 2006; IEA 2008; Kåberger 2004).

Unequal distribution of conventional energy sources, and thus power, creates highly centralised systems, which are at heart of international socio-economic confrontations and political conflicts (A. Cherp *et al.* 2006). These issues are of particular importance to the

European Union (EU), which imports at least 50% of its energy (Fagernäs *et al.* 2006), and to transition economies (EiTs) in Eastern Europe (e. g., Ukraine, Belarus, Moldova) (A. Cherp *et al.* 2006).

As such the share of energy imports in total primary energy supply (TPES) is 46% in Ukraine (IEA 2006), 86% in Belarus (Voytenko *et al.* 2009) and 95.7% in Moldova (Gavrilita & Druta 2009). What adds specific tension to the issue is that the major part of this is constituted by imports of natural gas from Russia. The situation is complicated with a high to very high energy intensity of the economies in all countries, a continuous increase in natural gas prices and disruptions in the gas supply (Voytenko *et al.* 2009). In addition, Russia is seeking for alternative routes to transport natural gas to Europe (IEA 2006) to reduce its dependence on current energy transit countries (i.e. Ukraine, Belarus and Moldova), reach new markets that are able to pay more and thus further increase its ability to demand higher prices from the EiTs. All of the mentioned factors can thus be expected to significantly affect transit business and have ongoing and perhaps serious implications for the energy security on local, national and regional levels.

A need for energy source diversification, improved local energy self-sufficiency and environmental quality, and better distribution justice are among the leading drivers for the development of sustainable indigenous energy sources including bioenergy.

1.1.2 Two sides to the bioenergy debate

Currently energy from biomass supplies 50 EJ out of 500 EJ in the global TPES (or about 10%) (Bauen *et al.* 2009), which corresponds to 80% of energy supplied from renewable energy sources (RES) (Peck *et al.* 2010). It is forecasted (Bauen *et al.* 2009) that bioenergy could sustainably contribute between a quarter and a third of global TPES in 2050.

The exploration of bioenergy opportunities for various types of economies, and for different socio-environmental contexts can be considered as a quite young research area with many unsolved problems and numerous initiated debates (Bauen *et al.* 2009). Important ones of the latter are trying to address the question whether the pursuit of biofuel production and utilisation is likely to improve the socio-economic conditions within a jurisdiction or not.

Issues within this area of inquiry include the "food versus fuel" debate, discussions on general socio-economic benefits of bioenergy, arguments about the environmental sustainability of biofuels, and first generation biofuels in particular (Sander & Skøtt 2007). Production of first-generation biofuels is argued to have negative implications for natural ecosystems such as soil degradation, water scarcity and contamination, clearing of tropical rainforests, natural habitat fragmentations and losses etc. as well as social implications (e. g., the displacement of subsistence land users) (Groom *et al.* 2008; Olmstead 2006). Excessive or uncontrolled removal of biomass residues entails concerns about impacts on the soil quality and its properties (Blanco-Canqui & Lal 2009; Lemke *et al.* 2009). All of these issues are scrutinised in detail in Section 2.3.

At the same time growing interest in bioenergy is linked to the potential for modern biofuel production activities to leverage micro- and macroeconomic co-benefits and forms of social betterment (Bauen *et al.* 2009; UN Energy 2007). The term "co-benefit" is used in this work to describe situations when agro-biomass crops, biofuels and the activities related to their production, offer tangible benefits that are additional to the direct economic revenues from the agricultural or downstream processing activities (Peck & Voytenko 2008).

General field of this dissertation covers bioenergy developments in Ukraine and selected Western European countries with a further possibility to generalise a number of its outcomes to other EiTs, and primarily to those that have similar climatic conditions and social trends.

1.1.3 Bioenergy co-benefits for Ukraine

Bioenergy can offer many co-benefits for the countries that develop their potentials. These opportunities include improved energy independence and diversification of energy sources as well as the potential for environmental and social benefits linked to biomass utilisation (Bauen *et al.* 2009; Dubrovin *et al.* 2004; IEA 2004; IEA 2006; Smeets *et al.* 2005; UN Energy 2007;

WBCSD 2007; Wordlwatch Institute 2006). All of these also have place in Ukrainian conditions.

Biomass being a local or at least indigenous source of energy supply contributes to the provision of energy security by reducing dependence on imported fuels, which is crucial for Ukraine. The country is heavily dependent on the imports of most energy sources. The main share of oil and gas, and all nuclear fuel is brought to Ukraine from Russia or passes through Russian territory. Net imports account for 46% in Ukraine's TPES (IEA 2006). This places Ukraine among those countries in Central and Eastern Europe that have the highest total energy dependency (Bossong 2006). It is projected (Bossong 2006) that if the current trends continue, Ukraine's total dependency on the imports of natural gas and oil could rise to 65-70% in 2020. In addition to all of the mentioned, natural gas prices have been increasing steadily since 2004 and resulting into sound debates over Ukraine's energy security (Sub-section 4.3.1).

Therefore a need for energy source diversification is one of the leading drivers for the development of RES and bioenergy in the country. Moreover, except for value adding to national economies from domestic use, energy derived from biomass also offers opportunities for export and thus creates advantages from macroeconomic perspective (IEA 2004; IER 2007; Wordlwatch Institute 2006; UN Energy 2007).

In addition to this, the development of bioenergy options can help revitalise the country's agricultural sector, which declined in the period of economic recession after the collapse of the Soviet Union (Dixon *et al.* 2001; Dolinski & Geletukha 2006; IEA 2004; IEA 2006; Smeets *et al.* 2005). The revitalisation can be pursued through the utilisation of significant amount of crop residues and vast territories of land with low or negative opportunity cost[1] (e.g. abandoned or degraded land) (Sub-section 1.1.4), and by mobilising the potential markets for agro-biomass and energy produced from it. Local use of biomass was also shown to

[1] Opportunity cost – the value of a product forgone to produce or obtain another product. Land of low opportunity cost implies that such land would not have much value, if it was used for agricultural practices.

contribute positively to rural development by the creation of new jobs (Geletukha 2000; Smeets *et al.* 2005; UN Energy 2007; WBCSD 2007; Wordlwatch Institute 2006).

Further, bioenergy is considered to be largely carbon neutral (Dolinski & Geletukha 2006; Dubrovin *et al.* 2004; IEA 2004). Plantations of dedicated energy crops such as short rotation coppice or perennial grasses in many cases have positive environmental implications as they contribute to ecosystem restoration, soil remediation, biological waste water treatment and favour maintenance of biological diversity (Groom *et al.* 2008; Rosenqvist *et al.* 1997; Rosenqvist & Dawson 2005; Rosenqvist & Ness 2003; UN Energy 2007).

Additional driving force for bioenergy development is formed by the possibilities for Ukraine to participate in Joint Implementation (JI) projects under Kyoto Protocol whereas bioenergy projects play a significant role (Geletukha *et al.* 2006). Attraction of foreign investors within JI projects is not only financially profitable but also provides access to new knowledge, modern technologies and contributes to the creation of an improved country image (Geletukha *et al.* 2006).

1.1.4 Biomass potentials in Ukraine

According to several studies conducted on the assessment of bioenergy potentials in different countries (Dolinski & Geletukha 2006; Geletukha *et al.* 2008; Ericsson & Nilsson 2006; Faaij *et al.* 2004; Smeets *et al.* 2005) Ukraine is considered to have substantial bioenergy potential for all types of biofuels. In the research by Ericsson and Nilsson (2006) bioenergy potential of Ukraine is estimated to be the highest among all studied countries. The most important component of this is comprised by the possibility to grow energy crops on large territories of land. Currently about 4.7 million ha of arable land in Ukraine is not utilised (Geletukha & Dolinsky 2009). Another significant part of total potential is comprised by agricultural residues.

The Institute for Engineering Thermophysics at the National Academy of Sciences (NAS) of Ukraine has estimated the total technical potential of biomass and peat at 36.23 million tonnes of coal equivalent (Mtce) (1.06 EJ) per year (Geletukha & Dolinsky 2009). Considering that TPES in Ukraine is about 140 million tonnes of oil equivalent (Mtoe) (5.86 EJ) per year (Geletukha *et al.* 2008), the total technical biomass potential in the country constitutes about 18% of TPES. However, the current share of biomass use in Ukraine is only 0.5% of the country's TPES (Dolinski & Geletukha 2010).

Biomass potentials by source are given in Table 1-1. Although these figures change with ongoing research in the field, potentials for agricultural residues and energy crops constitute the main share in the overall biomass potential of Ukraine. From Table 1-1 it can be calculated that the potentials of agricultural residues and energy crops together add to 738.55 PJ (or 69.5% in the country's overall biomass potential).

Table 1-1. Biomass and peat potentials in Ukraine

Fuel type	***Energy potential, PJ (2009)***					
	Theoretical	***% of total theoretical***	***Technical***	***% of total technical***	***Economic***	***% of total economic***
Agricultural residues including:	**628.06**	**42.9%**	**375.43**	**35.4%**	**226.84**	**28.4%**
Straw of grain crops	304.51	20.8%	152.69	14.4%	39.27	4.9%
Straw of rape	31.36	2.1%	21.98	2.1%	21.98	2.8%
Residues of corn production for grain	167.05	11.4%	116.94	11.0%	81.77	10.2%
Residues of sunflower production	125.14	8.5%	83.82	7.9%	83.82	10.5%
Energy crops (willow, poplar, miscanthus, acacia, alder)	**427.30**	**29.2%**	**363.12**	**34.2%**	**363.12**	**45.4%**
Straw from dedicated rapeseed plantations	**48.36**	**3.3%**	**33.70**	**3.2%**	**33.70**	**4.2%**
Wood	**62.43**	**4.3%**	**48.65**	**4.6%**	**43.38**	**5.4%**
Biogas including:	**171.16**	**11.7%**	**121.63**	**11.5%**	**65.06**	**8.1%**
Biogas from manure	95.84	6.5%	71.80	6.8%	22.27	2.8%
Liquid bio-fuels (biodiesel, 1st generation bioethanol)	**105.80**	**7.2%**	**105.80**	**10.0%**	**55.39**	**6.9%**
Peat	**22.57**	**1.5%**	**13.48**	**1.3%**	**11.72**	**1.5%**
TOTAL	**1465.68**	**100%**	**1061.81**	**100%**	**799.22**	**100%**

Source: Geletukha & Dolinsky 2009

1.1.5 Straw potential for energy in Ukraine

Straw deserves special attention here as it has the highest potential among all agricultural residues to deliver energy in Ukraine (i.e. nearly 175 PJ per year or 16.5% of total biomass potential (Table 1-1). Ukrainian agricultural sector produces about 6-8 million tonnes of straw annually, which can be utilised for energy without putting other competitive uses of straw (e. g., straw for bedding and fodder, straw as a natural fertiliser) under pressure (Geletukha *et al.* 2008; Dubrovin *et al.* 2004). The main regions with excessive straw production are located in Central and Eastern Ukraine (EBRD 2008; Grynyuk 2009; Radchenko *et al.* 2009; Smeets *et al.* 2005). In case the agricultural productivity in Ukraine increases to the average EU level, potentials of crop residues in general and straw in particular could increase by 2-3 times (Geletukha & Dolinsky 2009).

Researchers from the National University of Bioresources and Nature Use of Ukraine (NUBNUU) consider straw to be the most promising option as compared to other types of biomass used for energy (Dubrovin *et al.* 2004). Indeed, Ukraine's potential is significant. For example, in Denmark, which is a world leader in the production of heat and combined heat and power (CHP) from straw, only 1-1.5 million tonnes of straw is used annually for energy purposes (Hinge 2009; Hinge & Geletukha 2002; Holst 2007; Sander & Skøtt 2007). Straw potential in Denmark is assessed at 55 PJ (Sander & Skøtt 2007), which is almost three times less than that in Ukraine (175 PJ) (Geletukha & Dolinsky 2009).

In addition, straw is among the cheapest options for energy production as it does not require sophisticated infrastructure (at least on small scale) (Skøtt & Hansen 2000). The profitability of straw use for energy generation depends to a large extent on straw collection costs. Dubrovin *et al.* (2004) consider the collection of corn and sunflower stalks for energy unprofitable as the collection costs are 2.8-3.2 times higher than those for straw from grain crops and rape, and argue that it is better to plough these residues back to the soil. The cheapest option in Ukrainian setting is straw collection from winter wheat with its following baling (Dubrovin *et al.* 2004). Baled straw is also reported to have the lowest price (EUR 2.8

per GJ) among all solid biofuels in Ukraine (Table 4-1, Section 4.3.2) (Geletukha & Zhelezna 2010).

According to the action plan on the development of Ukraine's bioenergy potential by Scientific Engineering Centre (SEC) Biomass, it is deemed feasible to install 16 000 MW of 0.1-1 MW straw-fired farm boilers and 1400 MW of 1-10 MW straw-fired district heating (DH) plants in Ukraine by 2015 (Geletukha *et al.* 2008). The realisation of the proposed action plan requires investment of USD 2.3-2.6 million. The payback of straw-fired installations depends on their capacity and on fossil fuel prices. Overall, it is concluded (Geletukha *et al.* 2008) that even with the foreign manufacture of biomass equipment heat production from wood and crop residues is competitive with that from coal or natural gas.

Currently straw combustion for heat supply is carried out in about 25 boilers in rural areas in the country (Geletukha *et al.* 2008; Oliynyk pers.comm. 2010; Svintsitskiy pers.comm. 2009) (Section 6.1). Some agricultural producers install heat generators on their farms to run grain dryers and satisfy other energy needs (Melnychuk & Dubrovin 2007; Toropets pers.comm. 2009). However, straw use for energy in Ukraine is clearly not of industrial scale yet. There exist neither medium nor large DH plants, nor power plants, nor CHP plants that would use straw as the mainstream fuel or at least as a fuel blend. Hence straw use for energy is an emerging practice in the initial stage of its development, and straw-to-energy sector is not institutionalised in the Ukrainian setting yet.

1.1.6 Challenges for bioenergy

Despite all potential advantages, the pathway towards the development of a bioenergy sector in Ukraine may turn out to be quite challenging. As a number of theoretical studies have shown (Aldrich & Fiol 1994; Bergek *et al.* 2008; DiMaggio & Powell 1991; Jacobsson & Bergek 2004; Jacobsson & Johnson 2000), the diffusion of a new emerging industrial sector faces many barriers in the broad institutional environment. The indications of such barriers could be seen in case studies from other countries including Sweden (Hillman *et al.* 2008;

Jacobsson & Bergek 2004; McCormick 2007; Rosenqvist *et al.* 2000; Roos *et al.* 1999); Rosenqvist *et al.* 2000; Roos *et al.* 1999), the Netherlands (Hillman *et al.* 2008; Jacobsson & Bergek 2004), Austria (Roos *et al.*. 1999), Poland (K. Ericsson & L. J. Nilsson 2006; McCormick 2007), the USA (Roos *et al.* 1999), etc.

According to Aldrich and Fiol (1994), cognitive legitimacy of business options meaning the knowledge about and the understanding of a new venture and its product chain by general public, and their socio-political legitimacy within the policy community, political circles and existing norms and laws are crucial to the viability of the growth of such industry. However, an entirely new activity begins, by definition, with low cognitive legitimacy (Aldrich & Fiol 1994). As a new business, such arguments are held here to apply to bioenergy. In other words, the levels of understanding of bioenergy systems and their "perceived value" in the eyes of political actors who have the capacity to push such systems, are of great importance (Aldrich & Fiol 1994; Bergek *et al.* 2008; Jacobsson & Bergek 2004).

Bergek *et al.* (2008) recognise legitimacy as a necessary precondition "for resources to be mobilised, for demand to form and for actors in new technology innovation systems (TISs) to acquire political strength". They view legitimacy as "a prerequisite for the formation of new industries and new TIS". Based on these considerations, it is anticipated that the institutionalisation of bioenergy in Ukraine above all will require legitimisation of its options.

The support of new business activity by stakeholders is crucial. Such support has both direct market related economic implications, as well as broader social and policy linked implications (Jacobsson & Bergek 2004). In regards to the latter aspect, areas where modern bioenergy impinges include agricultural and forestry policies, stimulation of rural and agriculture based economies, energy security issues, environmental and land-use implications, GHG emissions reduction strategies, etc.

The enhancement of legitimacy of bioenergy systems, which are currently in their formative phase in Ukraine (Bergek *et al.* 2008), is anticipated to help overcome difficulties on the way towards bioenergy sector establishment and development. Thus strategies to enhance the legitimacy of bioenergy in Ukraine form a rationale for this study.

Not least important, the role of collectives is viewed as one of the determining factors that might foster the institutionalisation of bioenergy sector in Ukraine. As it is postulated by neoinstitutional theorists (Aldrich & Fiol 1994; Bergek*et al.*2008), it is collective action of organisations that facilitates industry's socio-political approval and the reshaping of industries and institutional environments. Co-benefits of bioenergy are more likely to be achieved once small-scale producers are organised in groups (UN Energy 2007). That is why existing and potential collaboration between bioenergy stakeholders is scrutinised in this work.

1.2 Problem definition

1.2.1 Research area, scope and delimitations

The general area of this inquiry covers the transformation of energy sector to bioenergy and the emergence of bioenergy systems in the context of transition economies (Fig. 1-1). Data collection and field research are conducted in several EU countries (i.e. Sweden (SE), Denmark (DK), and Spain (ES) and in Ukraine (UA). Research outcomes are targeted at UA but are also transferable to other EiTs, and primarily to those that have similar to Ukrainian climatic conditions and socio-economic trends. Specific value of this work is in its potential use for those actors who deal with the challenges of transition of energy and agricultural sectors towards bioenergy, and converting biomass into a commercial energy carrier.

This research focuses on the delineation of pathways for the development of Ukraine's agro-biomass potentials. Agro-biomass within the scope of this inquiry refers to plant biomass from which energy can be obtained. It includes mainly crop residues and, where relevant for the discussion, agricultural biomass dedicated for energy (i.e. herbaceous energy crops). Other agricultural by-products such as biogas streams from animal manure are outside of the scope of this research.

In this study energy crops are referred to crops that are grown with specific intention of energy yield as heat and/or power. This work's main focus is on straw use for energy, however, wherever relevant, it also discusses the possibilities to grow perennial grasses such as miscanthus, reed canary grass, hemp, switchgrass, etc. Perennial grasses are expected to provide future feedstocks for straw based bioenergy systems, and thus are considered to be the "next step" options in the development of straw-to-energy supply chains. They can also be used as alternative fuels in existing straw-based energy systems and thus enhance the security of fuel supply at such installations (Hinge 2009; Lerga pers.comm. 2009).

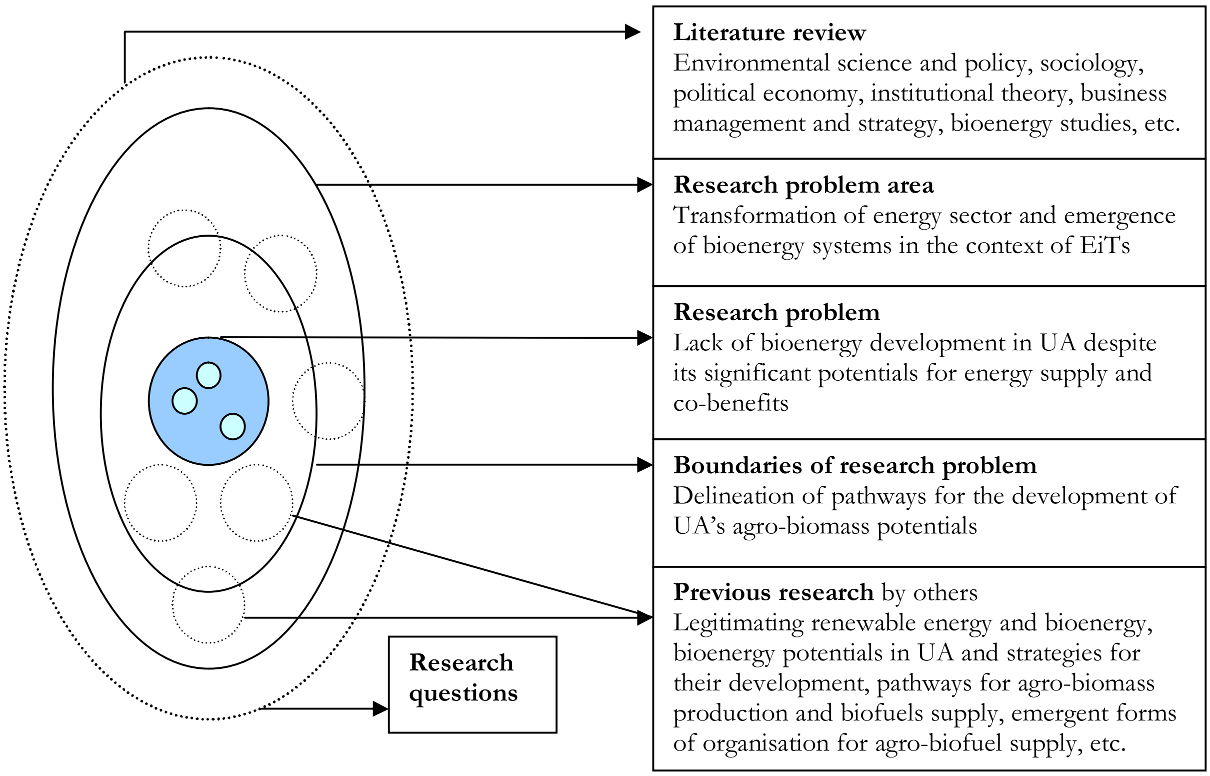

Figure 1-1. Relationship between research area, problem and questions

Source: After Perry 1995

Coppice crops such as willow and poplar are primary sources of woody feedstock in biomass supply chains, and thus are outside of the scope for this research. Other industrial crops (that are in essence food crops) such as wheat, barley, maize and rape – particularly those that are 'converted' to first-generation liquid biofuels - are not intended to be of key focus here but remain relevant to some extent for the discussion. The possibility to grow perennial grasses on lands with zero or negative opportunity cost rather than on farm lands, which are suitable for agricultural production, is one of the promising research areas but is not scrutinised here.

There are a few major reasons for narrowing the research scope to straw and crop residues. First, potentials for agricultural residues constitute the dominant share in total technical biomass potential in UA (375.43 PJ or 35.4%) (Table 1-1). Every year about 5-8 million tonnes of straw can be used for energy needs of Ukrainian farmers (Dubrovin *et al.* 2004; Geletukha *et al.* 2008). Second, straw is among the most promising, the cheapest and the easiest biomass options for energy production (Dubrovin *et al.* 2004; Geletukha & Dolinsky 2009). Third, and most important, the feedstocks within the scope of this work have prospects for their utilisation in the production chains of future generation biofuels, which are obtained through more sophisticated processes of solid biomass into liquid and gaseous fuels (Morris & Ahmed 2009; Wordlwatch Institute 2006). The latter fact is likely to ensure the relevance of this research over the next decades.

The study focuses on the production of energy from agro-biomass, and discusses key elements of and factors around such production systems. Bioenergy co-benefits and sustainability implications of energy from biomass are acknowledged by the author as important areas and are considered during research justification and data collection. However, they are not in the main focus in the discussion as the work targets rather the architecture of straw-to-energy production systems.

1.2.2 Research problem and questions

As Brown and Tandon (1983) put it, "problem definitions influence the data collected, the results apprehended, the solutions proposed, and the responsibilities assigned for the problem itself". Hence research problem formulation is a key precondition for a meaningful scientific research.

Although UA has substantial bioenergy potentials (Ericsson & Nilsson 2006; Faaij *et al.* 2004; Geletukha *et al.* 2008; Smeets *et al.* 2005), previous studies (Geletukha *et al.* 2008; Voytenko 2007) provided a clear evidence that the country did not have a significant established commercial bioenergy sector. Bioenergy initiatives in UA were found to lack support and legitimacy not only in the eyes of governmental leaders (socio-political legitimacy) but also in the eyes of other bioenergy stakeholders and general public (cognitive legitimacy) (Aldrich & Fiol 1994; Geletukha *et al.* 2008; Voytenko 2007). Moreover, work by the author (Voytenko 2007; Voytenko 2009) revealed that Ukraine faced numerous barriers to the diffusion of bioenergy options and to their further institutionalisation.

Considering all of above the research problem can be framed as follows:

Despite significant potential benefits for economic, social and environmental contributions to Ukraine from bioenergy development and large biomass potential, biomass is not currently established as a commercial energy carrier in the country.

Hannigan (1995) provides theoretical evidences that ensure successful construction of environmental problems. If a problem has clear notions of the factors outlined in the first column of Table 1-2, it can be argued as a desirable for research. The problem put forward within this inquiry is analysed along the framework by Hannigan (1995) (Table 1-2), and in this way supported with arguments on why it can be worth studying.

From the research problem two overarching research questions guiding this query follow:

1. Why is biomass not established as a commercial energy carrier in Ukraine?

2. How can Ukraine leverage agro-biomass for energy use?

The first research question (RQ 1) looks into the nature of the research problem and helps to better understand it. The answer is sought via deep analysis of the current situation in Ukraine's energy and agricultural sectors, and detailed examination of existing conflicts, constraints, drivers and facilitating factors for bioenergy development in the country (Chapters 4, 6 and 7).

Table 1-2. Factors ensuring successful construction of environmental problems

Factor	***Relevance to the research problem***
Scientific authority for and validation of claims	Science of sustainable versus unsustainable biofuel initiatives is growing
Existence of 'popularisers' who can bridge environmentalism and science	CEU, IIIEE, Swedish University of Agricultural Science (SLU), Bioenergy Network of Excellence (NoE), IEA Bioenergy, researchers and business people in Ukraine (SEC Biomass, NUBNUU), etc.
Media attention in which the problem is 'framed' as novel and important	Media frequently targets negative aspects of biofuel production. In UA the issue of natural gas dependence and increase in its price is often articulated. Co-benefit options from bioenergy development are not highlighted sufficiently enough
Dramatisation of the problem in symbolic and visual terms	Environmental and bioenergy NGOs critique severely the underestimated role of RES and biomass in the state Energy Strategy of Ukraine to 2030 and suggest alternative ways for the country's energy sector development. Absence of legitimacy of biomass as energy carrier contributes to the discussions about the construction of 22 nuclear power reactors in UA.
Economic incentives for taking positive action	Economic incentives are established (research scholarship, participation in conferences and workshops, possibilities for research and travel grants, etc.)
Institutional sponsor who can ensure both legitimacy and continuity	Local scientific (SEC Biomass, NUBNUU, etc.) and agricultural bodies, interested farmers and boiler manufacturers (UTEM) ensure legitimacy and continuity

Source: Hannigan 1995

The second research question (RQ 2) seeks to clarify which pathways exist and in which direction they are desired to be developed in order to establish a meaningful agro-industrial bioenergy sector in Ukraine. The answer to it involves a thorough analysis of both existing Ukraine's institutional capacity (Chapters 4 and 6) and that of the EU countries with advanced bioenergy sectors (Chapter 5). Projections on how positive EU experience can be translated into Ukrainian and EiT settings are also made (Chapter 7).

Research questions are broken down into five sub-questions that guided the design of this study. These "design" questions with delivered outcomes and methods that were used to answer them are summarised in Table 1-3.

1.2.3 Research assumptions

The main assumption behind this research can be stated as follows:

Energy from agricultural biomass may offer real potential for benefit to Ukraine

Table 1-3. Coherence between research sub-questions, outcomes and methods for data collection and analysis

#	Research sub-question (RsQ)	Outcome and output	Methods for data collection and analysis
1	*How can biomass from agriculture deliver energy service in a manner that avoids problems and leverages gains?*	Sustainability of bioenergy, bioenergy co-benefits (EU, EiTs, UA)	Documentary analysis (biofuel sustainability, bioenergy co-benefits, EiT realities)
		3 conference papers; 3 oral presentations; 1 poster; Chapters 1, 2; a journal article (planned)	Participation in bioenergy events (UA and EU) (Annex I)
			Site visits to bioenergy facilities (EU. UA); in-depth interviews with bioenergy actors
2	*What will be the main characteristics and desirable parameters of key potential agro-biomass based frameworks for organisation of energy service delivery?*	Conceptual framework	Documentary analysis of theoretical sources and bioenergy case studies
		Chapter 3	Site visits to bioenergy facilities in the EU; in-depth interviews with bioenergy experts
3	*What are the facilitating and constraining factors for agro-bioenergy development in Ukraine?*	Trends, drivers and constraints for bioenergy in UA	Documentary analysis and "desktop" research of current state of bioenergy sector in UA
			Review of bioenergy related policies in UA
		A paper and presentation for UN FAO; Chapter 4	Participation in bioenergy events and review of related documents
			Pilot study of Drozdy case (UA)
			In-depth interviews with Ukrainian bioenergy experts
4	*How are the key parameters of an agro-biomass system business set up organised in Western Europe and Ukraine?*	Empirical frameworks for sustainable commercial use of agro- biomass for energy in EU and UA	Site visits to bioenergy facilities
			In-depth interviews with bioenergy actors (WE and UA)
			Documentary analysis of straw-for-energy in DK
		2 conference papers; 2 posters; 3 oral presentations; a journal article (submitted to Biomass & Bioenergy); Chapters 5, 6	Documentary analysis of case study related documents
			Participation in bioenergy events and review of related documents
			Case conceptualisation and structuring
			Cross-case analysis
			Farm entrepreneur rationalisation
5	*How can existing, emerging and potential constraints to agro-bioenergy in Ukraine be circumvented to facilitate the rise of a sustainable supply and utilisation of agro-biomass for energy in the country?*	Pathways for straw use for energy on medium and large scale in UA	Analysis of constraining and facilitating factors for agro-bioenergy in UA
			Comparison and contrast of contexts in UA and EU
		Chapters 7, 8	Analysis and discussion of agro-biomass frameworks (ABFs) that are missing in UA as compared to EU

This assumption is based on the evidences presented in Section 1.1, i.e.: 1) agricultural biomass has significant potentials in Ukrainian setting; 2) the use of agricultural biomass for energy might deliver a number of co-benefits for the country; 3) heat production from agro-biomass is economically feasible and competitive with that from conventional energy sources.

To ensure symmetrical outcomes (i.e. account for both sides of the bioenergy debate) the work will also highlight areas where the pursuit of bioenergy may not be a reasonable strategy from sustainability perspective.

Key assumptions, which evolve under the main hypothesis, include the following:

1. Agricultural biomass production and bioenergy conversion activities have a potential to deliver tangible benefits to Ukraine's economic, social and environmental development (Dubrovin *et al.* 2004; IEA 2004; IEA 2006; Smeets *et al.* 2005; UN Energy 2007; WBCSD 2007; Wordlwatch Institute 2006);
2. Bioenergy can become legitimate energy source in Ukraine's setting (Dolinsky 2008; Geletukha 2008; Geletukha 2009; Geletukha *et al.* 2008; Geletukha & Dolinsky 2009; IEA 2006);
3. A pathway towards development of agricultural bioenergy sector in Ukraine can turn out to be quite challenging due to a number of institutional (i.e. political, economic, organisational, technological and cognitive) barriers (Geletukha & Dolinsky 2009; Voytenko 2007; Voytenko 2009);
4. Any form of collective action requires relevant forms for organisation to move forward (Aldrich & Fiol 1994).
5. Existing and well-known agricultural practices may facilitate the legitimisation of bioenergy activities once they become parts of biomass supply chains (Aldrich & Fiol 1994; Alsos *et al.* 2003).

1.2.4 Target audience

The outputs of this work are to be applied in future studies of different actors and in various contexts – in particular, the extension of bioenergy schemes eastwards from Europe into the transition economies of Central and Eastern Europe. The results are expected to be of direct use for policy makers, municipal leaders, business managers, researchers and other actors seeking for the transformation of local energy systems towards bioenergy (Fig. 1-2). Although the work is based on examples from Western Europe and Ukraine, its outcomes can be transferable to other contexts on the condition that local specificities are taken into account. Since this research is carried out towards the accomplishment of a doctoral degree at Central European University (CEU) with co-supervision from the International Institute of Industrial Environmental Economics (IIIEE) at Lund University, academia communities of both institutions are among its primary audience. In addition, professional knowledge exchange has been pursued via joint seminars and workshops within the research process with bioenergy groups at Swedish University of Agricultural Science (SLU), CEU Business School and United Nations Food and Agricultural Organisation (UN FAO). Not of least interest is this study for academia representatives in Ukraine and other EiTs who both pursue research in the field and develop educational curricula for university courses on environmental sciences and policy, renewable energy technologies, sustainability driven business strategies, etc.

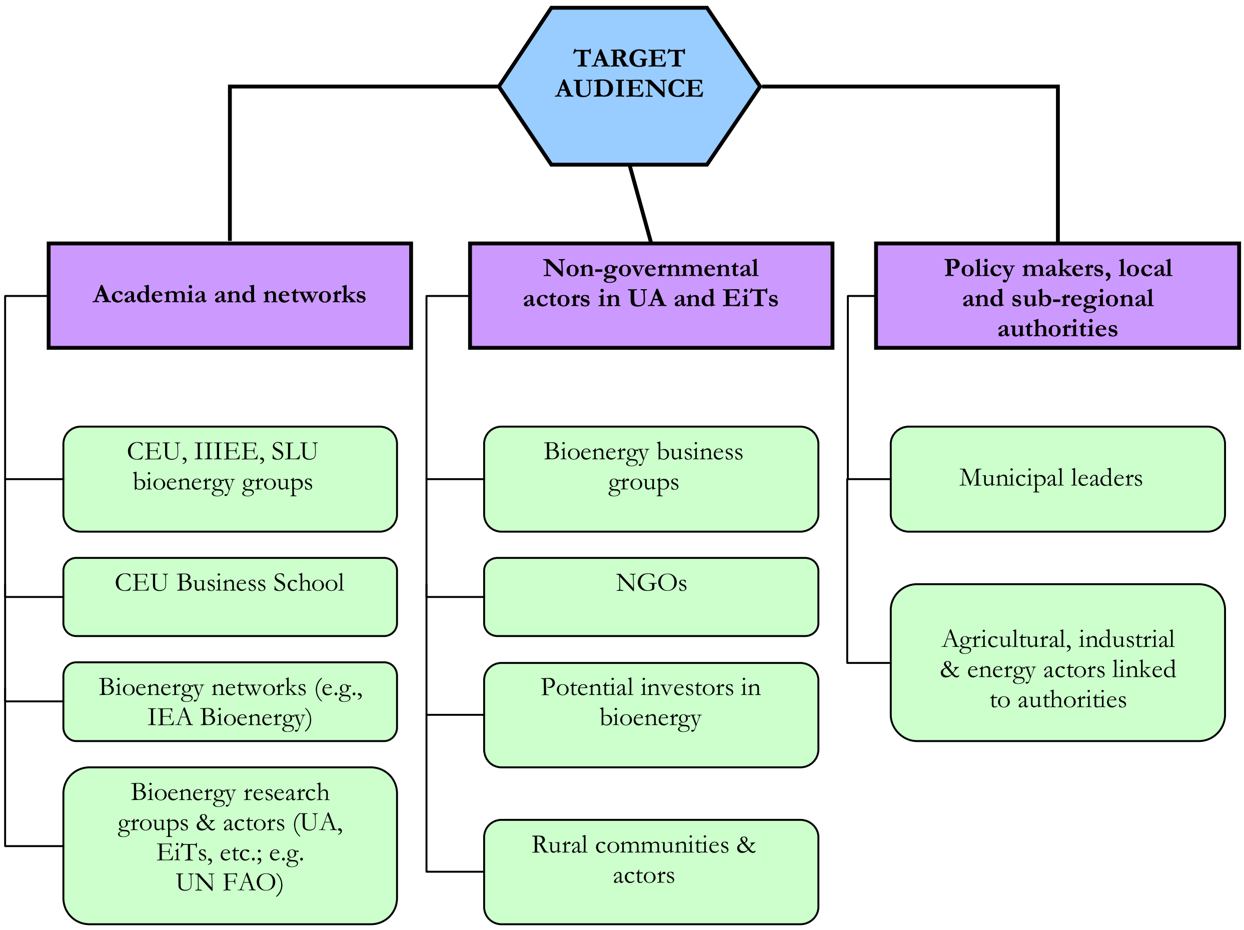

Figure 1-2. Target audience

Bioenergy research networks such as the former Bioenergy Network of Excellence (NoE), LU Biofuels, International Energy Agency (IEA) Bioenergy (primarily its *Task 43 "Biomass Feedstocks for Energy Markets"* and *Task 40 "Sustainable International Bioenergy Trade - Securing Supply and Demand"*), etc. can expand their knowledge about bioenergy systems and on specifics of bioenergy expansion in Eastern European context.

This work can also contribute to the knowledge and understanding of other non-governmental actors in UA and EiTs including bioenergy business groups (e.g., equipment manufacturers, bioenergy and environmental consultants, potential investors in bioenergy activities, etc.), NGOs (primarily those interested in renewable energy and energy security), farmers and rural development audiences who seek to diversify their incomes by producing energy from agricultural biomass, etc.

Not least important target group of this work includes local and sub-regional authorities and related to them agricultural, industrial and energy actors, who are important participants in and contributors to the policy-making process.

1.2.5 Thesis outline

The dissertation constitutes of eight chapters. Chapter 1 introduces research problem and identifies key prerequisites of a sound scientific research in the application to this work.

Chapter 2 reviews documentary sources on sustainability of biofuel production and use, describes biomass conversion pathways and a variety of biomass products. It outlines practicalities and sustainability implications of straw use for energy. It also presents and highlights theoretical considerations underpinning this study.

Chapter 3 outlines research steps undertaken, and describes research methods applied to collect and analyse data for this study as well as accounts for their limitations.

Chapter 4 provides an overview of the bioenergy sector in Ukraine and presents data on the existing support schemes for bioenergy production in the country, market environment and potentials, and outlines general requirements to start bioenergy production in the country.

Chapter 5 aggregates and describes the experiences of straw use for energy in Sweden, Denmark and Spain, presents an agro-biomass framework for organisation and action (ABF) for each case study and rationalises the behaviour of Western European farm-based entrepreneurs.

Chapter 6 aggregates and describes Ukrainian straw-to-energy initiatives, presents an ABF for each case study and classifies Ukrainian farm-based entrepreneurs.

Chapter 7 analyses, compares and discusses five types of new ABFs of straw-based energy systems in Western European and Ukrainian contexts. It also identifies facilitating and constraining factors for the expansion of straw-for-energy production in Ukraine, establishes their contributions to the functions of an agro-bioenergy system, and concludes with proposed pathways for the development of agro-bioenergy sector in the country including a specific set of recommendations for the target audience to this study.

Chapter 8 concludes the dissertation presenting major findings, core research contribution to knowledge and theory and implications for future research.

Bioenergy provides us with an extraordinary opportunity to address several challenges: climate change, energy security and development of rural areas. Investments, however, need to be planned and managed carefully to avoid generating new environmental and social problems, some of which could have irreversible consequences. Measures to ensure sustainability of bioenergy include matching of crops with local conditions, good agricultural management practices and development of local markets that provide the energy poor with modern energy services.

Achim Steiner, Executive Director of UNEP

2 Energy from biomass: theory and practice

Chapter 2 presents a literature review of bioenergy options (Sections 2.1-2.4), theories applied in the work (Section 2.5) and forms of organisation for bioenergy (Section 2.6). It outlines the present and the future of bioenergy (Section 2.1), describes existing bioenergy routes and conversion technologies distinguishing between different biofuel generations (Section 2.2) and discusses sustainability of biomass-to-energy options (Section 2.3). Sustainability implications addressed here include socio-economic (i. e. energy security and economic flexibility, cost competitiveness, production scale, rural development and poverty, job creation and employment, food security, health and gender issues) and environmental implications (i. e. air emissions and net GHG balance, impacts on soil, water and biodiversity from bioenergy expansion). Section 2.4 addresses peculiarities and challenges of straw conversion to energy via combustion and describes specific sustainability implications of straw as a fuel. Section 2.5 presents theories relevant to this work and their applicability to data analysis. Section 2.6 reviews different forms of organisation for bioenergy, which were encountered in the literature. Definitions of key terms and concepts, which are used in this work and are narrowed down in line with its scope, are given in Box 2-1.

2.1 Present and future of bioenergy

Energy from biomass is the fourth important fuel in global energy supply (Dubrovin *et al.* 2004). Bioenergy sector has grown substantially in recent years with biofuels for transport facing the most significant growth among all energy end uses (Bauen *et al.* 2009). Currently it supplies 50 EJ out of 500 EJ in the global TPES (or about 10%) (Bauen *et al.* 2009). This corresponds to 80% of energy from renewable energy sources (RES) (Peck *et al.* 2010). About

Box 2-1. Key terms and concepts

Agricultural biomass

Agricultural biomass includes harvest residues (e. g., straw of cereal crops, maize residues, sunflower stalks and husk, etc.), conventional energy crops (e. g., maize, sugar-beet, sugar-cane, rapeseed, oil palm, soybeans, etc.) and lignocellullosic energy crops (e. g., willow, poplar, miscanthus, switchgrass, reed canary grass, hemp, etc.) (Bauen *et al.* 2009). Animal manure (dung) is also referred to agricultural biomass whereas it has a potential for biogas production. Within the scope of this work agricultural biomass includes straw and "straw producing" energy crops (perennial grasses) unless other is specified.

Agro-biomass based frameworks (ABFs) for organisation and action

ABFs are forms of organisation and entrepreneurship, which serve as motivational tools for individual and collective action between bioenergy stakeholders. The main purpose of new frameworks is to demonstrate a clear suite of benefits to key actors once they engage into bioenergy practices and bring a structure for their activities. The full operationalisation of this concept and identification of its forms underlines the essence of the work.

Agro-industrial bioenergy sector

The existence of such can be reported once bioenergy initiatives become integrated in the national economy, and the related processes and activities are carried out by or are of relevance to agricultural and industrial stakeholders in the country.

Bioenergy co-benefits

These include situations when agro-biomass crops, biofuels, and activities related to their production and use may offer tangible benefits that are in addition to direct economic revenues from the agricultural or downstream processing activities (Peck & Voytenko 2008a). Arguments on bioenergy co-benefits are supported with the framework developed following Porritt's (2007) Five Capitals Model of sustainable development, which guided the ways to leverage positive and negative implications of biofuels in the context of EiTs (Peck & Voytenko 2008a; Peck & Voytenko 2008b).

Bioenergy stakeholders

Bioenergy stakeholders in the scope of this work include individuals, firms and organisations that are directly or indirectly engaged in agro-biomass supply chains.

Energy sector

In the scope of this work the energy sector is considered when it intersects with the emerging agro-industrial bioenergy sector. Such instances include pricing of conventional fuels, policy support mechanisms and economic incentives for RES, impact factor of incumbent energy technologies (i.e. natural gas, nuclear and coal in Ukraine's case), a market niche for bioenergy within the energy sector, etc.

Institutionalisation of biofuels

This term refers to the establishment of a legitimate commercial bioenergy sector with well-developed and mature markets. An overall purpose of this study is the suggestion of development pathways for the institutionalisation of such sector in Ukraine via actors' engagement into structured frameworks for organisation and action.

Legitimacy of bioenergy options

Legitimacy is a "generalised perception or assumption that the actions of an entity are desirable, proper or appropriate within some socially constructed system of norms, values, beliefs and definitions" (Suchman 1995). The level of legitimacy of bioenergy options in Ukraine and EU countries under study is discussed on the basis of theoretical considerations and definitions by Aldrich and Fiol (1994) (Sub-section 2.5.1).

Phase of industry/market development

These are identified in the literature on technology lifecycles and industrial change and include three main phases of evolution: a formative phase, an intermediate development phase and a mature industry phase (Bergek *et al.* 2008; Williamson 1975). The formative (incipient) phase is characterised by high degree of uncertainty around a new product or technological system, and a more rapid entry and exit of firms (Peck *et al.* 2009). The intermediate phase is identified by a refinement of manufacturing techniques and sharpening of market definitions (Jacobsson & Bergek 2004; Peck *et al.* 2009; Van de Ven & Gerud 1989).

97% of this comes from solid biomass (mainly wood), and the most of it is used in the residential sector for heating and cooking (Peck *et al.* 2010). Biofuels for transportation account only for 2% in total biomass use for energy, and 1.5% of total road transport fuel consumption (Bauen *et al.* 2009). While in the industrialised countries bioenergy contributes to about 3% of TPES (Bauen *et al.* 2009), developing countries cover from 22% (Bauen *et al.* 2009) to one third (Sander & Skøtt 2007) of their energy needs from biomass, and in the poorest countries bioenergy constitutes up to 90% of energy supply (Bauen *et al.* 2009).

It is forecasted (Bauen *et al.* 2009) that bioenergy could sustainably contribute between a quarter and a third of global TPES in 2050. Global biomass use for heat and industrial energy is forecasted to double by 2050 under business-as-usual scenarios, while that for electricity is expected to grow from its current share of 2.4% in total power generation to 3.3% by 2030 . Production of biofuels for transport is projected to increase by a factor of 10 to 20 by 2030 as compared to current levels (Bauen *et al.* 2009). The major factors determining future bioenergy crop availability were identified by Bauen *et al.* (2009) and include: 1) agricultural modernisation and agro-technology development (including productivity increases); 2) biomass yield levels and crop choice; 3) the efficiency of feedstock logistics; 4) sustainability constraints; and 5) population growth and resulting food demand.

Bioenergy receives more and more attention from various interested parties and on different levels. Many countries have introduced supportive biofuel policies not least as a means to diversify their agricultural sectors (Bauen *et al.* 2009). These include Argentina, Australia, Canada, China, Colombia, Ecuador, India, Indonesia, Japan, Malawi, Malaysia, Mexico, Mozambique, the Philippines, Senegal, South Africa, Thailand, USA, Zambia, etc. (UN Energy 2007). Targets to develop renewable energy sources (RES) in the European Union are specified in the *EC Directive on Renewable Energy 2009/28/EC* (EC 2009), which sets a requirement on each EU Member State to enhance its use of RES so that an overall EU share of 20% is reached by 2020. At the end of 2005 the European Biomass Action Plan (EBAP) was introduced, and proposed measures for the increase of biomass use for heat production, electricity generation and transportation (EC 2005). Governments in Member States set relevant targets too, and accept policies and programmes to achieve them. The level of compliance with these targets is being reviewed and assessed on a continuous basis.

As discussed in Sub-section 1.1.3, further deployment of bioenergy could provide a number of co-benefits including significant GHG emission reductions and other potential environmental advantages, improvements in energy security and trade balances, opportunities for rural economic and social development, waste streams valorisation, etc (Bauen *et al.* 2009). These are discussed in detail in Section 2.3.

However, the issue of bioenergy expansion has to be taken with precaution as a lot of concerns in regards to the overall sustainability of biofuels are expressed. As bioenergy sector grows, public scepticism about the potential GHG savings and possible adverse social and environmental impacts from bioenergy development is noted (Bauen *et al.* 2009). The majority of sustainability challenges linked to modern bioenergy are complex and largely context specific (i.e. highly dependent on local circumstances - climatic, agronomic, economic, and social) (Bauen *et al.* 2009). Hence they need to be analysed for specific conditions in a particular country or region, and this is the reason why any generalisations should be drawn with a continuous cross-check for their validity (UN Energy 2007). Sustainability challenges that remain relevant should be addressed before or while bioenergy options are being developed.

2.2 Bioenergy routes and conversion

2.2.1 Bioenergy feedstocks and routes

Bioenergy is energy derived from biomass, which comprises a wide range of biologically produced hydrocarbons (Dolinski & Geletukha 2006). Solid biomass along with liquid and gaseous fuels (e. g., bioethanol, biodiesel, biogas, etc.), which are obtained from it, can be used for energy production (Bauen *et al.* 2009; Dubrovin *et al.* 2004). Bioenergy is utilised for heating and cooling, electricity generation and transportation (Bauen *et al.* 2009; IEA 2004; UN Energy 2007).

There is a wide range of biomass feedstocks that can be converted to energy. These include (Bauen *et al.* 2009; Dubrovin *et al.* 2004; Wordlwatch Institute 2006; UN Energy 2007):

- residues from agriculture (i.e. primary residues such as cereal straw and secondary residues such as rice husks),
- forest residues (i.e. primary residues such as branches and twigs and secondary residues such as sawdust and bark);
- conventional energy crops (e. g., sugar-beet, sugar-cane, different cereals, wheat, maize, rice, potato, rapeseed, sunflower, soybeans, oil palm, etc.);
- lignocellulosic dedicated energy crops (i.e. energy plantations of coppice crops such as willow, poplar or eucalyptus, and tall perennial grasses such as reed canary grass, switchgrass or miscanthus);
- animal dung;
- organic wastes (e. g., waste wood, municipal solid waste, etc.).

All of the mentioned feedstock types undergo conversion processes depending on the need for final products. Bioenergy route involves a number of steps which transform raw biomass feedstock into a final energy product (Bauen *et al.* 2009). There are three main groups of conversion routes including: 1) thermochemical conversion (i. e. combustion, gasification, pyrolysis and torrefaction); 2) physicochemical conversion (i. e. oil extraction possibly followed by transesterification); 3) biological conversion using micro-organisms (i. e. fermentation from sugar, starch and lignocellulosic feedstock; anaerobic digestion and bio-photochemical routes) (Bauen *et al.* 2009). Fig. 2-1 is an aggregated scheme of existing bioenergy conversion routes including a variety of biomass feedstocks and end products (Bauen *et al.* 2009).

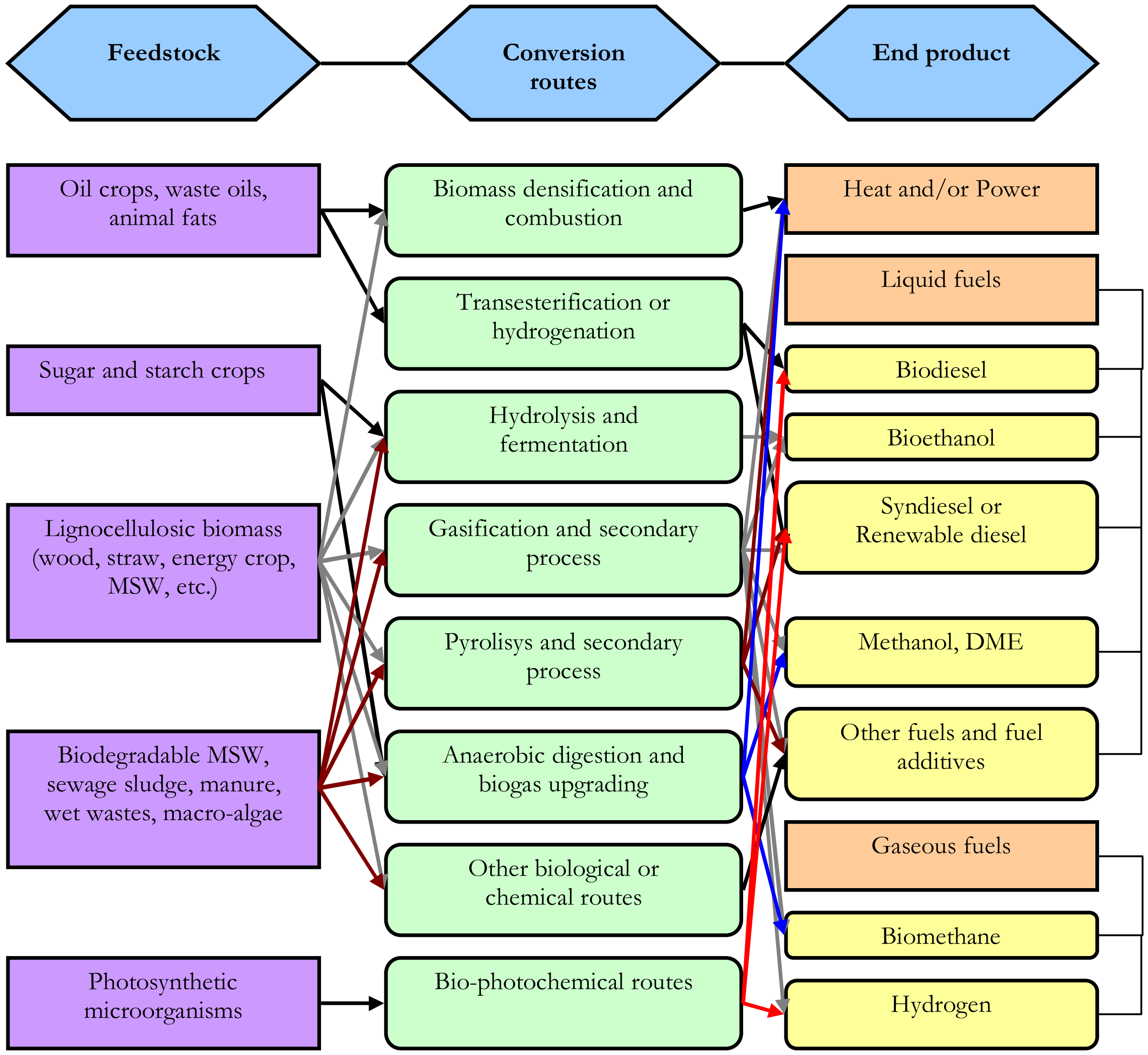

Figure 2-1. Bioenergy feedstocks, conversion routes and end products

Source: Bauen et al. 2009

Some of the key challenges of biofuels as compared to fossil fuels is their low energy density and great variability of physical nature and shapes, which complicates the processes of handling, storage and transportation (Bauen *et al.* 2009). That is why a number of biofuel pre-treatment and upgrading technologies aimed at biomass densification are frequently applied (Bauen *et al.* 2009). These among others include pelletisation and briquetting of solid biomass transforming it into densified and dried fuels (Dubrovin *et al.* 2004; UN Energy 2007), pyrolysis and hydrothermal upgrading with production of liquid bio-oil, syngas and biochar (Bauen *et al.* 2009), and torrefaction of biomass (mainly wood) into a dry product that resembles coal in its appearance (Bauen *et al.* 2009).

Solid biofuels are mainly used for the production of heat and/or electricity while liquid ones are applied in the transportation sector. Liquid and gaseous biofuels are classically divided into different 'generations' depending on the feedstock used for their production and level of the conversion technology development (Bauen *et al.* 2009; UN Energy 2007). Understanding the difference between biofuels of 1st, 2nd and 3rd generations and associated sustainability implications of those is crucial within contemporary biofuel debate and thus is addressed in Sub-section 2.2.2 in detail.

2.2.2 Biofuel generations

There is no universally agreed definition of each biofuel generation category, however, most of the studies commonly divide biofuels into three groups including first-, second- and third-generation biofuels (Bauen *et al.* 2009).

1st generation fuels refer to liquid biofuels made from sugar, starch, vegetable oil, or animal fats with the application of conventional mature technology (UN Energy 2007) (Table 2-1).

Table 2-1. Simplified comparison of 1st and 2nd generation biofuel technology

	Biofuels				***Synthetic Fuels***	
	First-generation		*Second-generation*			
Feedstock	Plant oils/fats	Sugar plants	Lignocellulose	Wood, energy plants, biowaste	Natural gas	Coal
	Soy oil, animal fats	Sugarcane, sugarbeet, corn	Straw	Wood, straw		
Process	Transesterification	Fermentation	Enzymatic hydrolysis, fermentation	Gasification, Fischer-Tropsch (FT) synthesis, product up-grading		
Product	Biodiesel, FAME	Bioethanol	Cellulose ethanol	BtL[1]	GtL[2]	CtL[3]

Source: Bauen et al. 2009; Peck 2007

Some studies (Bauen *et al.* 2009) also refer biomethane from anaerobic digestion of wet biomass to 1st generation biofuels. Sugar and starch containing plants are used to get bioalcohols, which are later utilised as transportation fuels or blends to petrol (Dubrovin *et al.*

[1] BtL – biomass to liquid

[2] GtL – gas to liquid

[3] CtL – coal to liquid

2004; Wordlwatch Institute 2006). Oil is extracted from the plants with significant oil content through pressing procedures. It is then refined to produce bio-diesel (Bauen *et al.* 2009; Dubrovin *et al.* 2004; Wordlwatch Institute 2006).

First-generation liquid biofuels have become the fastest growing segment of the global agricultural market (UN Energy 2007). This trend and observed increases in prices for agricultural commodities (i.e. food and animal feed) (UN Energy 2007; WBCSD 2007), as well as negative economic and social effects of first-generation biofuels accompanied with their controversial environmental benefits have led to wide debates on the issue of their sustainability and further acceptability. On the other hand, bioenergy constitutes a very small share of the agricultural and energy sector, and energy crops cover less than 1% of agricultural land in OECD countries on average (Bauen *et al.* 2009). Thus the major sustainability implications from the production and use of first-generation biofuels are not of the global scale at this stage (Bauen *et al.* 2009). However, local hotspots for environmental and social concern arising from 1st generation biofuel production and use need to be considered. These are further addressed in Section 2.3.

2nd generation biofuels are produced from lignocellulosic biomass feedstock using advanced processes of biochemical and thermochemical conversion (Dubrovin *et al.* 2004; IEA 2004; Geletukha & Zheleznaya 1998; Wordlwatch Institute 2006; UN Energy 2007). There are two basic pathways to convert lignocellulosic material into liquid fuels for transportation (UN Energy 2007): 1) enzyme-enhanced fermentation, which entails conversion of crop residues, perennial grasses and other cellulose types into ethanol; 2) gasification and Fischer-Tropsh synthesis (also called FT diesel, or biomass-to-liquids (BtL) - the conversion of woody biomass into synthetic biodiesel. Some studies (Bauen *et al.* 2009) also include among 2nd generation biofuels bioethanol and biodiesel produced from conventional technologies but based on novel starch, oil and sugar crops (e. g., jatropha, cassava, miscanthus, etc.).

The most important consideration about 2nd generation biofuels is that any type of plant material can be a potential source of cellulose, and therefore can be processed into fuel.

Feedstocks for 2nd generation biofuels include all types of agricultural residues (straw, corn stalks, stems, sunflower husk etc.), forestry residues, waste fat and oils, organic municipal waste, animal manure, dedicated energy crops such as coppice willow or poplar and perennial grasses such as reed canary grass, switchgrass or miscanthus (Olmstead 2006; UN Energy 2007; WBCSD 2007). Since 2nd generation biofuels require a feedstock of inedible plant material, the potential competition between food and fuel is significantly reduced as compared to 1st generation biofuels. Besides, 2nd generation technologies allow to address a number of other sustainability issues including the better performance of 2nd generation biofuels on net GHG balance, low demand for fertiliser and pesticide use during feedstock cultivation, suitability of wider range of lands for dedicated crop production, etc. (Bauen *et al.* 2009; Göransson pers.comm. 2009; Rosenqvist *et al.* 1997).

2nd generation technology also entails a number of practical advantages. Crop feedstocks for 2nd generation biofuels have generally higher energy density and yields per hectare; derived biofuels are suitable for long-distance transportation and storage and are possible to use in existing distribution infrastructure and automotive engines (although can also be developed for more sophisticated engines) (Bauen *et al.* 2009; UN Energy 2007). Overall 2nd generation biofuels are viewed to be more sustainable in a greater variety of conditions than 1st generation bifouels (UN Energy 2007; WBCSD 2007). However, at present they are still in between research and demonstration phase and the technology is rather immature (Bauen *et al.* 2009). Currently only 1st generation biofuels are produced on large scale (IEA 2004; IER 2007; Wordlwatch Institute 2006; UN Energy 2007) while the production of 2nd generation biofuels is forecasted to become commercially available by some studies by 2015 (UN Energy 2007) and by others (WBCSD 2007) – only by 2030. The most important challenges for the 2nd generation biofuel technology include a need for new logistics of existing feedstocks, land-use changes to realise potential feedstocks, consideration of environmental and quality requirements of all processes in a biofuel life cycle, efficiency requirements and continuous technological development, which is both time and resource intensive (Peck 2007; UN

Energy 2007). The major feedstocks, conversion pathways and final products of 1st and 2nd generation technologies are summarised in Table 2-1.

Other pathways to advanced biofuels that are investigated include (Hydro Thermal Upgrading (HTU) diesel, which uses moist biomass as a feedstock, and biomethane from biogas and gasified wood (UN Energy 2007). One more promising research field is the possibility to produce biofuels from algae grown in ponds or photoreactors (Groom *et al.* 2008; UN Energy 2007; WBCSD 2007). These pathways are sometimes referred to as 3rd generation biofuels (Bauen *et al.* 2009).

2.3 Bioenergy and sustainability

Growing interest in bioenergy can be explained by its potential to deliver a number of economic, environmental and social co-benefits (Sub-section 1.1.3), which are discussed in this Section and summarised in Fig. 2-2. Sustainability of biofuels remains a widely debated issue. Most of socio-economic and environmental implications of bioenergy are largely context specific and need to be addressed for a relevant region, country or household with the consideration of local circumstances.

Overall 2nd generation biofuels are found to be more sustainable than 1st generation biofuels on a broad scale of socio-economic and environmental parameters, which are addressed in this Section in detail. These include better performance of 2nd generation technologies for GHG emissions mitigation, and neutral or even positive impacts on biodiversity, soil, water quality and availability. In addition, feedstocks for 2nd generation biofuels are less likely to compete with food crops for land and other resources and therefore should not induce increases in prices for food and feed on global market. The use of crop residues for energy production appears to be more sustainable than that of liquid biofuels. However, the issue of residue removal should be taken with a precaution so that it does not bare detrimental environmental consequences for soil ecosystems and biodiversity.

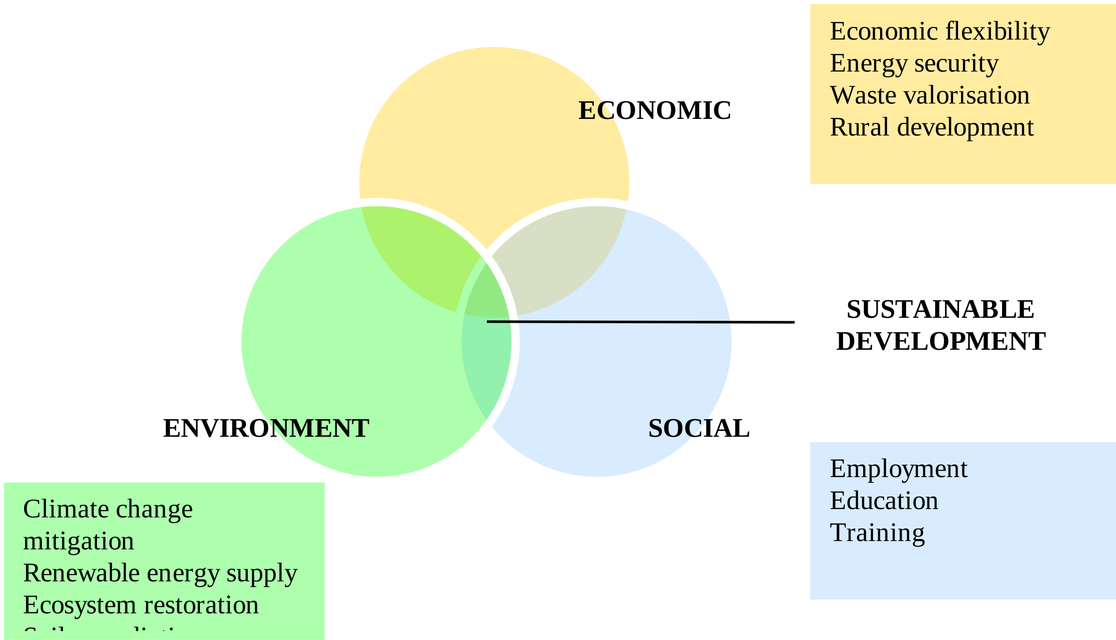

Figure 2-2. Bioenergy co-benefits contributing to sustainable development

Source: Voytenko 2007

2.3.1 Socio-economic implications

2.3.1.1 Energy security and economic flexibility

Fossil fuel dependence has become a major risk for many developing countries and countries dependent on the imports of energy sources (O. Cherp 2009; Dolinski & Geletukha 2006; Fernandez 2009; Gavrilita & Druta 2009; Geletukha & Dolinsky 2009; Voytenko *et al.* 2009). Of the world's 50 poorest countries, 38 are net importers of oil and 25 import all of their oil requirements (UN Energy 2007). Net energy imports of the EU account for at least 50% in its energy balance (Fagernäs *et al.* 2006).

Biomass being indigenous source of energy can potentially substitute fossil fuels both in local oil- and gas-based heating systems and in larger heat and/or power generation systems thus enhancing local or national energy security (Bauen *et al.* 2009). EU and its Member State targets on the increase of renewable energy and biomass use in TPES (EC 2005; EC 2009), and some steps in the policies of a number of European countries (e. g., Sweden, Finland, Austria, Denmark, Germany etc.) support the development of RES (Geletukha & Zheleznaya 2002a; Geletukha & Zheleznaya 2002b). The ideas behind are in many cases driven by the goal to ensure energy security and decrease dependency on imported fossil fuels. Since the international bioenergy market is expected to include a wide range of suppliers from different regions worldwide (Bauen *et al.* 2009), even if biofuels are imported, their imports should not be affected by the same concerns as oil and gas markets (Bauen *et al.* 2009).

2.3.1.2 Cost-competitiveness

One of the major economic implications of biofuels is their relative cost-competitiveness with conventional energy sources. Typically costs of USD 3-4 per GJ of energy contained in primary biomass are considered as a threshold for biofuel competitiveness with fossil fuels (Bauen *et al.* 2009). In many cases energy from biomass remains more expensive than that from conventional fuels, and requires additional policy incentives and economic support (B. Johansson 2000; Nikolaisen 2007; Nikolaisen *et al.* 1998; Sander & Skøtt 2007; Sterner 1994; Sterner & Löwgren 1994; WBCSD 2007; UN Energy 2007).

However, in some cases bioenergy proves to be competitive on its own. For example, liquid biofuels, where feedstock cost represents 75-90% of the fuel cost (e. g., bioethanol from corn) (Bauen *et al.* 2009), can be an option for rural areas. Energy from direct combustion of biomass residues can also be competitive with conventional energy sources without any additional economic support (Geletukha 2008; Geletukha *et al.* 2008). In addition, bioenergy can be the most economical option in remote rural areas or islands, where fossil fuel prices are high due to high transportation costs (UN Energy 2007). These examples support the argument to account for local conditions when establishing bioenergy systems.

2.3.1.3 Production scale

One more implication of modern bioenergy systems is that they favour large scale production and in this way may lead to the concentration of ownership in the hands of larger producers leaving small- and medium-scale farmers outcompeted (UN Energy 2007). At worst this could put the world's poorest farmers on the edge of survival (UN Energy 2007). This implication is not only referred to the growing of feedstocks for the 1st generation liquid biofuels but also to the expansion of 2nd generation technology. The latter is more complex and capital-intensive and thus is likely to require appropriate facilities, which have a bigger potential to be pursued by large companies (UN Energy 2007).

A balanced development of small and medium scale distributed bioenergy systems with extensive involvement of local actors is one of the solution pathways to the problem outlined above. This work focuses specifically on such systems and explores options for their expansion in various contexts.

2.3.1.4 Rural development and poverty

The development of local bioenergy sources can add value to national economies and support rural development (Bauen *et al.* 2009; IEA 2004; Wordlwatch Institute 2006; UN Energy 2007). Rural development is viewed differently in the context of developing and developed countries. While in industrialised countries bioenergy is rather seen as a pathway for the diversification of farm income, in developing countries it falls within a broader livelihood context embedding local employment and supporting the agricultural sector, which is in high need for additional aid (Bauen *et al.* 2009).

Organic waste, which is mainly comprised of biomass residues (e. g., wasted straw, stalks, husk, plant and tree residues, etc.), can be combusted in boilers for heat production. In this way an improved waste management system and higher resource efficiency is achieved. Since biomass residues are primarily found in rural areas, their local use for energy offers opportunities to supply heating to the closest districts almost for free. In some areas new roads are constructed to transport crop harvests to processing units (UN Energy 2007). Building up additional infrastructure also positively contributes to rural development.

In rural areas, however, modern bioenergy systems have a potential to compete with conventional biomass uses by indigenous populations. For example, residues used for energy can also be utilised as feed or bedding for animals, converted to fertilisers or construction materials (UN Energy 2007). In case when the latter pathways of biomass utilisation are of higher priority to local populations than the establishment of energy systems, there is a potential for concern.

2.3.1.5 Job creation and employment

Another co-benefit of successful bioenergy systems is the creation of new jobs (IEA 2004; Wordlwatch Institute 2006). Bioenergy is stated to empower new small- and large-scale agro-industrial development (UN Energy 2007). A lot of employees are needed to support the sector with an average of one new job created per 1 MW of installed bioenergy capacity (Geletukha 2000). As for developing countries, of all biofuel feedstocks oilseed crops are the most amendable to job creation particularly because they often require significant manual work inputs (UN Energy 2007).

Jobs range from unskilled agricultural labour to highly skilled science, engineering and business-related positions (UN Energy 2007). Employees include those employed to directly support the work of bioenergy installations (e. g., engineers, workers, farmers, foresters, etc.) as well as those who fulfil intellectual and organisational work in the field (e. g., scientists, researchers, managers etc.) (UN Energy 2007). What is important is that the majority of jobs are created locally, which positively contributes to the rural development of a particular region (UN Energy 2007). In addition, the education and training of different specialists in bioenergy field is needed and can be enhanced by the sector development.

However, in some cases a negative impact on employment can be induced by large-scale mechanised farming, which may displace workers (Smeets *et al.* 2005; UN Energy 2007). Also poor labour conditions are often linked to large-scale agricultural plantations (UN Energy 2007).

2.3.1.6 Food security

Since the majority of 1st generation biofuels require the same feedstock for their production as food industries (e. g., maize, cereals, sugar-beet, sunflower, rapeseed, etc.), crops that are grown for fuel production are likely to directly compete with those grown for the production of food and feed for animals. Outcompeting of food crops by fuel crops leads to the reduced supply of food crops on global market and increases prices for food. Such trends are likely to affect poor population groups, who spend a large share of their income on food (Bauen *et al.*

2009; UN Energy 2007). Price increases are reported to have already occurred in the major biofuel markets (UN Energy 2007).

However, the whole "food, feed, or fuel" debate is too simplistic as it "fails to reflect the full complexity of factors that determine food security at any given place and time" (UN Energy 2007). The first key consideration is that this debate is mainly relevant to the development of liquid 1st generation biofuels, which compete for land use and other resources with food crops, and divert land from crop production. The development of 2nd generation technologies and increased production of 2nd generation biofuels, which require lignocellulosic feedstocks, can help to tackle the problem of competition (Bauen *et al.* 2009).

Second factor determining the favourability of biofuel options for the country or household is the consideration whether this country/household is a net buyer or a net seller of energy services and food products (UN Energy 2007). This is important to account in the context of Ukraine since it is a net buyer of energy and is heavily dependent on energy imports while at the same time is a net exporter of grain (IEA 2006). Hence the whole issue of "food versus fuel" is of less relevance for Ukraine than it is for other countries and populations that are dependent on food imports and are therefore more vulnerable in terms of food availability. Overall, the analysis of food security implications should highlight differences between more and less developed societies (Bauen *et al.* 2009; UN Energy 2007).

2.3.1.7 Health and gender

Traditional use of biomass, which is only indirectly linked to modern bioenergy use, has health and gender implications. Biomass used for cooking and heating in households "locks people in the developing world, particularly women, into a cycle of poverty and ill health" (UN Energy 2007).

Other health risks associated with the production and use of biofuels involve exposure to the operation of hazardous machinery, pesticides and potentially high emissions of acetaldehyde from blended petrol, which is a suspected carcinogen (UN Energy 2007).

Positive health implications from biofuels is that locally created bioenergy systems and improved energy supply may contribute to better provision of services, access to food and water, etc. In case biomass substitutes coal in small scale boilers, better air quality can be achieved (Yerkhov pers.comm. 2010).

2.3.2 Environmental implications

2.3.2.1 Air emissions and net greenhouse balance

Biomass is referred to renewable energy source (Dolinski & Geletukha 2006; IEA 2004). It is also a part of the natural carbon cycle, and thus its utilisation is largely GHG free (Dolinski & Geletukha 2006; Wordlwatch Institute 2006). Bioenergy can contribute to GHG emission reductions in two principal ways: 1) via additional creation of natural carbon sinks with the establishment of energy crop plantations; 2) via substitution of fossil fuels in energy systems (Bauen *et al.* 2009). However, the issue of GHG neutrality is controversial as in many cases energy inputs and associated GHG emissions are not considered for the whole biofuel life cycle, which includes crop cultivation and harvesting, transportation of harvested biomass, its processing and fuel distribution (Groom *et al.* 2008; UN Energy 2007). Often it is only GHG emissions in the use phase (i.e. burning of biofuel) that are taken into account, and based on this biofuels are advocated to mitigate GHG emissions. Such strategy, however, does not adequately reveal the real impact of biofuels on global carbon balances (WBCSD 2007).

Typical production of Brazilian sugar-cane ethanol allows achieving 85% of GHG reduction, and the same figure is reported for cellulosic ethanol (Bauen *et al.* 2009). The relevant figure for wheat ethanol in Sweden is 80% while that for maize ethanol in the USA is from 25% (Groom *et al.* 2008) to 50-60% (Bauen *et al.* 2009). Overall maize corn is one of the planet's most energy intensive crops (Groom *et al.* 2008; Olmstead 2006), and requires significant amounts of synthetic nitrogen fertilizers, which are derived from petroleum based products (Olmstead 2006; UN Energy 2007). Some studies (Bauen *et al.* 2009; Groom *et al.* 2008) also provide examples when the production and use of starch ethanol has lead to slight GHG increase. In general, the amount of GHG emissions from a biofuel lifecycle depend on the fuel used for the conversion processes, the application of nitrogen fertilisers during crop cultivation and whether any land use change leading to deforestation or clearing of natural carbon sinks was involved or not (Bauen *et al.* 2009).

2nd generation biofuels are advocated to have significant advantages as compared to both conventional fossil fuels and 1st generation biofuels in terms of net energy balance and GHG emissions mitigation (Groom *et al.* 2008; UN Energy 2007; WBCSD 2007). Research shows (Soimakallio *et al.* 2007) that conversion of biomass feedstocks (i.e. forestry residues and reed canary grass) through Fischer-Tropsch process allows achieving 3-4 times less GHG emissions than from the production of first-generation biofuels. Moreover the overall auxiliary energy input per energy content of fuel in 1st generation technology was found to be 3 to 5 fold compared to that of fossil fuels (Soimakallio *et al.* 2007). However, a precaution should be taken when plantations for dedicated energy crops are developed to make sure that they do not replace primary forests (UN Energy 2007).

Except for their advantages in the net energy balance, 2nd generation biofuels also better perform on emissions of other substances. As such sulphur and aromatic hydrocarbons are not emitted at all, and there are significantly less exhaust gases emitted from the combustion of biofuels than from conventional fossil fuels (Soimakallio *et al.* 2007). Specific emissions associated with straw combustion are discussed in Sub-section 2.4.2.3.

Since the largest potential for GHG emission reductions comes from replacing coal rather than petroleum products, using biomass for combined heat and power (CHP) production is reported to be the best option for GHG emissions mitigation in the next decade (Bauen *et al.* 2009; UN Energy 2007). In case of liquid biofuels, however, the greatest potential for the reductions of GHG emissions lies in the development and application of 2nd and 3rd generation technologies (Bauen *et al.* 2009; UN Energy 2007).

2.3.2.2 Impacts on soil

Negative impacts on soil from bioenergy crop cultivation are also broadly discussed (Olmstead 2006; UN Energy 2007; WBCSD 2007). Application of fertilisers and pesticides contributes to soil contamination, and extensive ploughing causes top soil erosion. Mono-cropping leads to significant biodiversity loss, soil erosion, and nutrient leaching (UN Energy 2007). Increasing demand encourages farmers to grow corn every year without rotation, which leads to the deterioration of soil properties (Olmstead 2006). However, if nitrogen-fixing crops for biofuel production are rotated with cereals, the overall productivity of the system may be enhanced (UN Energy 2007).

The majority of concerns listed above refer to practices of growing feedstock for the 1st generation biofuels. 2nd generation biofuels are expected to minimise these negative impacts since the crops that are used for their production are much less demanding to soil conditions. For example, willow or poplar can be grown on abandoned, degraded, polluted or other deteriorated soils that are not suitable for agricultural production. Moreover, such dedicated energy crops offer a number of co-benefits for agricultural ecosystems as they serve as protective buffers or wildlife corridors, can be used for the removal of heavy metals and radio-nuclides from soils and waste water, improve soil structure and fertility and facilitate ecosystem restoration (Bauen *et al.* 2009; Rosenqvist *et al.* 1997; Rosenqvist & Dawson 2005; UN Energy 2007).

Concerns about 2nd generation biofuels are linked to the excessive and uncontrolled removal of crop and forestry residues from natural ecosystems to be used for energy production (UN Energy 2007; WBCSD 2007). Since this study is primarily focused on agro-biomass, the removal of crop residues is recognised within this discussion as the one having important implications for soil protection since it defines physical and chemical properties of the soil (Blanco-Canqui & Lal 2009; Buchholz *et al.* 2009; Lemke *et al.* 2009). However, a substantial consensus regarding the influence of crop residue removal on soil properties has not yet emerged (Blanco-Canqui & Lal 2009; Lemke *et al.* 2009). This said, complete residue removal is recognised to have greater adverse effects on soil properties than its partial removal (Blanco-Canqui & Lal 2009; Lemke *et al.* 2009). Various authors use different methodologies for the estimation of 'safe' amounts of residue removal for soil properties, which are suggested from 22% (Lemke *et al.* 2009) to 30-50% of residues to be taken away (Blanco-Canqui & Lal 2009). All studies recognise the effects of straw removal on soil properties to be 'highly site specific' (Blanco-Canqui & Lal 2009) and depend on soil type and texture, drainage, slope, duration of residue management, tillage and cropping systems, application of fertilisers and organic amendments, climate, etc (Blanco-Canqui & Lal 2009; Lemke *et al.* 2009). One of the challenges in this context may be the difficulty to persuade farmers to leave a certain amount of their harvest in the field (UN Energy 2007).

2.3.2.3 Impacts on water

Growing the feedstock for the production of 1st generation biofuels as well as water use for fuel conversion processes has a number of negative implications for water quality and availability (UN Energy 2007; WBCSD 2007). In dry areas, where heavy water is often used for extensive irrigation, a major threat is posed to biodiversity (Groom *et al.* 2008). The expansion of large-scale energy crop plantations leads to increased evapotranspiration, which in some countries could exacerbate an already stressed water situation (Bauen *et al.* 2009). Similarly to soil pollution from pesticide and fertiliser use, both surface and groundwater are under the risk of contamination (WBCSD 2007). In addition, different biofuel production processes bear adverse impacts on water quality (WBCSD 2007).

Since the crop feedstock for 2nd generation biofuels in the majority of cases neither requires additional irrigation nor pesticide and fertiliser use, such feedstocks are more advantageous from environmental perspective than the ones for the 1st generation biofuels (Bauen *et al.* 2009; Groom *et al.* 2008; UN Energy 2007). Also a bioenergy sector that pursues the utilisation of biomass residues is not likely to cause significant water use (Bauen *et al.* 2009).

In addition, as a number of studies outlined (Rosenqvist *et al.* 1997; Rosenqvist & Dawson 2005; Rosenqvist & Ness 2003), dedicated energy crops such as willow or perennial grasses can potentially be used for biological treatment of waste water. The latter activity not only contributes to the restoration of ecosystems but also creates potential business opportunities for farmers. A farmer can use waste water enriched with nutrients for irrigation and in this way increase crop yields, while waste water treatment plant (WWTP) reduces its spendings on chemicals and necessary equipment for other forms of waste water treatment.

2.3.2.4 Impacts on biodiversity

Another concern about biofuel expansion involves changes in land use patterns. The present share of world's arable land used to grow biomass for 1st generation biofuels is expected to increase from 1% to 3.8% by 2030 (WBCSD 2007). This might occur at the expense of conversion of natural ecosystems (mainly biodiversity rich grasslands and forests) into agricultural plantations.

The issue of deforestation is of specific concern for tropical countries such as Brazil, Colombia, Malaysia, Indonesia etc. (Groom *et al.* 2008; Olmstead 2006; UN Energy 2007). Large areas of tropical rainforest are cleared for the establishment of palm-oil plantations dedicated for biodiesel production. Such activities pose a major threat to habitats of species and biological diversity in the regions. For example, in Indonesia due to deforestation about 140 species of land animals are endangered while in Malaysia Sumatran tiger and Bornean orangutan have been pushed to the brink of extinction (Olmstead 2006). In Brazil a woodland savannah mix known as Cerrado region, which was promoted as "the last agricultural frontier", has been cleared for agricultural production by nearly 80% (Olmstead 2006; Groom *et al.* 2008).

The expansion of intensive farming may affect biodiversity via release of hazardous substances into the environment primarily from fertiliser and pesticide application (Bauen *et al.* 2009). Another major threat to biodiversity can result from large-scale mono-cropping (Sub-section 2.3.2.2) (UN Energy 2007).

However, the cultivation of dedicated crops for the production of 2nd generation biofuels can on the contrary enhance biological diversity. Plantations of short rotation coppice (SRC) crops such as willow or poplar have a more rich representation of wildlife than traditional agricultural plantations, and also serve as a shelter to butterflies, invertebrates, birds and small mammals (DEFRA 2002). In addition, some species provide natural pest control function as they consume organisms that damage plants (DEFRA 2002; UN Energy 2007). Still it is important to keep the "push to plough up "waste lands" (including rangelands and savannas)" for the growing of 2nd generation biofuel feedstocks at reasonable pace and scale so that it does not bear adverse impacts on natural ecosystems (UN Energy 2007). In the case of biomass use from natural forests, the quantity and quality of natural vegetation and availability of dead wood can be reduced, which would consequently reduce biodiversity (Bauen *et al.* 2009).

2.4 Energy from straw

Since straw is within the primary focus of this work, this Section addresses the specifics of straw conversion to energy via combustion. It provides the description of straw properties as a fuel, discusses the peculiarities and technical and environmental challenges of straw combustion process, integrates specific features of straw handling and logistics and concludes with the discussion of sustainability implications related to straw use as a fuel.

2.4.1 Straw uses and properties

Straw is a by-product of cereal crop production, and is primarily used in the agriculture for cattle bedding and fodder (Nikolaisen *et al.* 1998). Varied amounts of straw are also ploughed back into the soil by farmers to maintain its fertility by keeping its carbon content, which is removed from the soil with land cultivation practices (Nikolaisen *et al.* 1998). About 7-8 tonnes of straw can be produced from 1 ha of farmland covered with cereals (e.g. wheat, barley, oat, rye) (SCB 2007).

In addition to traditional practices of straw application in agriculture, straw as a source of carbohydrates can also be used as a fuel in the burners of various scales and purposes. The latter include small scale burners on the farms for heating, grain drying, etc.; medium scale neighbour and district heating (DH) plants for the supply of heat in villages and towns; and large scale installations for the generation of electricity or combined heat and power (CHP) (Nikolaisen *et al.* 1998; Sander & Skøtt 2007; Skøtt & Hansen 2000a).

One tonne of straw contains about 14.5-15 GJ[1] of energy, which is equivalent to 600 kg of coal or 355 m^3 of natural gas (Sander & Skøtt 2007; Zhovmir *et al.* 2007). Three kilograms of straw can also substitute one litre of oil in terms of energy content (Holst 2007). A comparison of straw with other solid fuels in terms of moisture content and calorific value is given in Table 2-2. Straw from grain is considered to have the best properties for energy use, however, straw from rapeseed and other seed-producing crops can also be burnt (Sander & Skøtt 2007). Straw from wheat, barley and rye is almost identical in its chemical composition except for that wheat straw has higher silicon content than that from barley and rye (Sander & Skøtt 2007).

Table 2-2. Average values of moisture and energy content in solid fuels

Fuel	*Moisture content, %*	*Calorific value, MJ/kg*
Straw	14	15
Coal	10	25
Wood pellets	8	17.5
Wood chips	45	9.5

Source: Sander & Skøtt 2007

Straw use for energy bears many peculiarities linked to combustion challenges, specific logistical arrangements and a number of sustainability implications. All of those are discussed in the following sub-sections.

2.4.2 Straw combustion

2.4.2.1 Combustion process

Straw that is used as a fuel usually contains 14-20% of water that evaporates during the burning (Nikolaisen *et al.* 1998). Dry matter consists of up to 50% carbon, 42% oxygen, 6% hydrogen and small amounts of nitrogen, sulphur, silicon and other minerals (e. g., sodium, potassium and chloride) (Nikolaisen *et al.* 1998).

Straw combustion includes four phases: 1) water evaporation; 2) pyrolysis (gasification) with production of combustible gases; 3) complete combustion (on the condition of sufficient oxygen supply); and 4) burning of charcoal (Nikolaisen *et al.* 1998). Straw can be co-fired with other fuels including wood chips or pellets, and coal (normally with up to 50% of straw on energy basis) (Nikolaisen *et al.* 1998; Sander & Skøtt 2007). Straw is co-fired with wood chips in a grate-fired boiler, and with wood pellets or coal in a suspension-fired or a fluidized bed boiler (Hinge 2009). Straw can also be pelletised and combusted in dust-fired burners, however, this is only recommended when economically feasible (Hinge 2009).

In water-based boilers the heat released from straw combustion is absorbed through the boiler walls and fire tubes by the water in the boiler (Nikolaisen *et al.* 1998). Emissions from straw combustion include carbon dioxide, water vapour, small amounts of carbon monoxide (CO) and other gases, e.g. tar and compounds of chlorine, particles of ash and alkaline salts (Nikolaisen *et al.* 1998). There are two types of ash left from straw combustion: fly ash and bottom ash (slag). Fly ash leaves the boiler with flue gases and is collected in filters while bottom ash is accumulated at the bottom of the boiler (Hinge 2009).

2.4.2.2 Technology

Straw is used for energy on various scales, which entail different combustion technologies. Boiler plants located on farms and agricultural enterprises are of two types, i.e. batch-fired boilers and automatically fed boilers (Nikolaisen *et al.* 1998). Batch-fired boilers are mainly designed to burn round, medium-sized rectangular or big rectangular bales (Table 2-3). They often have a hot water accumulator built together with a boiler-house located outdoors to prevent the risk of fire (Fig. 2-3).

Except for the small bales, firing and ash removal is usually carried out by a tractor with a front-end loader (Nikolaisen *et al.* 1998) (Fig. 2-4).

[1] 14.5 GJ = 4 MWh = 0.344 toe

Figure 2-3. Batch-fired straw boiler with hot water accumulator

Figure 2-4.A tractor with front-end loader used to feed in straw bales to the boiler and remove bottom ash (Photo: Courtesy of V. Belay)

Automatically fired boilers have a 10-20 m long conveyor (Fig. 2-5), which is loaded with straw at approximately 24 hour intervals and supplies bales into the boiler automatically depending on straw requirement (Nikolaisen *et al.* 1998). From the conveyor belt straw is disintegrated with a rotating straw shredder (Fig. 2-6), and then supplied into the burner with a worm conveyor (a screw stoker) or a blower system.

Figure 2-5. Conveyor supplying straw to automatically fed boiler

Figure 2-6. Rotating straw shredder

District heating plants normally have a boiler of 3.7 MW on average (Nikolaisen *et al.* 1998).

All DH plants consist of the following components (Nikolaisen *et al.* 1998):

- straw storage with scales;
- straw crane and conveyor belt;
- chaff cutter/shredder/slicer (if the bales are shredded before burning);
- firing system and boiler;
- combustion air fans;
- flue gas cleaning and ash/slag conveyor;
- chimney and flue gas fan;
- control and regulation equipment.

Boilers in DH plants vary as they can use chaffed, shredded or sliced straw, as well as whole bales (Nikolaisen *et al.* 1998). For chaffed and shredded straw the combustion is performed on a grate that moves forwards and backwards. In boiler plants that burn sliced bales the slice from a hydraulic knife is pushed into the boiler by a ram stoker (Nikolaisen *et al.* 1998).

Straw-fired power and CHP plants are designed similar to those working on traditional fuels, and have a steam turbine connected to electricity generator (Acciona Energía 2009; Nikolaisen *et al.* 1998; Sander & Skøtt 2007; Skøtt & Hansen 2000). An overall efficiency of power plants is considerably lower than that of CHP plants. Power plants can convert up to 40% of fuel energy into electrical energy with 60% losses in the form of waste heat (Nikolaisen *et al.* 1998). CHP plants in turn convert about 25% of fuel energy into electricity and up to 60% into heat production with only 15% of energy being lost (Skøtt & Hansen 2000).

Large straw-fired power and CHP plants apply different combustion technologies including (Hinge 2009; Nikolaisen *et al.* 1998; Sander & Skøtt 2007):

- a grate-fired boiler;
- a fluidized bed boiler (including bubbling and circulating fluidized beds) for co-firing of straw and coal;
- a suspension boiler.

Large power and CHP plants also differ in the ways they burn straw. They use either pure straw in the form of bales or pellets, or a mixture of straw with coal or wood (Hinge 2009; Sander & Skøtt 2007).

2.4.2.3 Challenges

- **Corrosive salts**

One of the main challenges associated with straw combustion is the formation of corrosive salts (mainly sodium and potassium chlorides) that can damage steel of the boiler and tubes, especially at high temperatures (Sander & Skøtt 2007). Chlorine content of straw is explained by the use of fertilizers while high potassium values are linked to potassium surplus in the farm soil, on which the crop is grown (Sander & Skøtt 2007).

To overcome the problem of corrosion straw can be left in the field and exposed to rain, which washes out the corroding agents and turns 'yellow' straw into 'grey' straw (Ericsson 2009; Hinge 2009; Nikolaisen *et al.* 1998; Sander & Skøtt 2007). Grey straw has also higher calorific value as compared to yellow straw (Nikolaisen *et al.* 1998). In addition, some plants apply washing/boiling of straw at 50-160^{o}C (Nikolaisen *et al.* 1998). In contemporary straw-fired power plants superheaters, which increase the steam temperature, are constructed of resistant materials to avoid corrosion problems (European Commission Energy 2008; Hinge 2009). Chromium content of 12-18% was proven to protect the superheater tubes (Sander & Skøtt 2007). If straw is co-fired with coal, the problem of corrosion is eliminated since the coal ash neutralizes potassium and chloride compounds from straw combustion (Hinge 2009).

- **Low ash melting point and ash management**

Another challenge of straw combustion is its low ash melting point. Ash from straw combustion may become viscid at already 450-600^{0}C and thus may cause slagging problems in the boiler especially via deposits on the superheater tubes (Sander & Skøtt 2007). This is particularly crucial for large power plants, which require high steam temperatures for achieving higher efficiency. However, after a few years of experience the use of new materials for straw-fired boilers eliminated the problem of operation at temperatures up to 540^{0}C (Hinge 2009; Sander & Skøtt 2007).

Significant amounts of ash are also formed from straw combustion as compared to other fuels (normally 3-5% of straw weight), which needs to be managed (Nikolaisen *et al.* 1998). If pure straw is burnt, bottom ash is normally returned to the field to maintain soil fertility and recycle soil carbon and nutrients (Blanco-Canqui & Lal 2009; Hinge 2009; Lemke *et al.* 2009; Nikolaisen *et al.* 1998). In case straw is co-fired with coal, fly ash is used for cement production and bottom ash – in the production of mineral wool (insulation material) (Hinge 2009; Sander & Skøtt 2007).

- **Incomplete combustion and emissions of CO and particles**

Straw combustion is accompanied with emissions of carbon monoxide (CO) and particulate matter (a mixture of unburnt hydrocarbons) from incomplete combustion process. These are the substances for regulation, however, in the majority of cases no legal restrictions are put on straw-fired boilers below 1 MW (Nikolaisen *et al.* 1998). The amount of these substances in flue gases can be reduced by supplying excess air to the combustion process. This practice is accomplished in different ways in various boilers as described below.

Batch-fired boilers represent the least efficient and most polluting straw-burning technology due to significant heat leaks and the absence of emission abatement equipment (Skøtt & Hansen 2000). However, their efficiency has been improving gradually from 35-40% in 1980 to 77-83% in 1997-2006 (Nikolaisen *et al.* 1998; SEC Biomass 2009; Skøtt & Hansen 2000). To prevent incomplete combustion and CO formation all batch-fired boilers are equipped with air fans, and the ideal target for the oxygen content in the flue gas is 6-7% (Nikolaisen *et al.* 1998).

More advanced automatic boilers are equipped with an oxygen-controlled screw stoker, which adjusts the amount of straw being burnt to the amount of oxygen in the flue gas. The latter is aimed at 6-7% (Nikolaisen *et al.* 1998). Such automatic oxygen control allows increasing the efficiency of a boiler by 5-10%, and reducing CO content of the flue gas and smoke nuisance from the boiler (Nikolaisen *et al.* 1998). The overall efficiency of automatic straw combustion systems has been also increasing steadily since 1980s (Skøtt & Hansen 2000).

To ensure complete combustion in larger boilers at DH plants secondary air is introduced via numerous nozzles in the boiler wall. This reduces CO and unburnt hydrocarbons (hence the smell) in flue gases, and also improves energy efficiency since less gases are emitted through the chimney (Nikolaisen *et al.* 1998).

The most common flue gas abatement equipment applied in straw-fired plants is a multicyclone followed by a bag filter (Nikolaisen *et al.* 1998; Sander & Skøtt 2007). Some plants have also installed flue gas scrubbers and condensers (Nikolaisen *et al.* 1998). In addition to the abatement equipment, the height of the chimney is another factor under regulation and should be established in accordance with local requirements (Nikolaisen *et al.* 1998).

- **Other air emissions**

Other emissions from straw combustion include nitrogen oxides (NO_x), sulphur dioxide (SO_2), hydrogen chloride (HCl), traces of polyaromatic hydrocarbons and dioxins (Hinge 2009; Nikolaisen *et al.* 1998; Sander & Skøtt 2007). Emissions of NO_x can be reduced with lower excess air, lower flame temperature and rapid cooling of flue gases (Nikolaisen *et al.* 1998). Both NO_x and SO_2 can be removed from flue gases but the processes are too expensive for small and medium installations including DH plants (Nikolaisen *et al.* 1998). As compared to coal, sulphur content of straw (and thus SO_2 emissions) is considerably lower (Sander & Skøtt 2007).

If straw is co-fired with coal at coal-fired plants, the latter are normally equipped with a desulphurization unit and a unit for catalytic NO_x reduction that uses ammonium (Sander & Skøtt 2007). The emissions of HCl, SO_2 and NO_x are thus lower than in straw-fired plants. Emissions of dioxins from straw-fired CHP plants are extremely low and well below the requirements for waste incineration plants (Sander & Skøtt 2007).

2.4.3 Straw handling and logistics

Straw handling for energy involves the following steps (Hinge 2009; Nikolaisen *et al.* 1998):

- combine harvesting of grain crops and straw production;
- turning/ranking of straw swarth in the field;
- baling;
- transportation to the storage;
- storage;
- transportation to the plant.

After combine harvesting of grain crops straw is left in the field in swarths (Hinge 2009). If straw is not dry enough (i.e. its average moisture content is about 15%), it should be left in the field for turning/ranking (Hinge 2009). Later it is handled in either of the two principal ways: chaff cutting or baling (Hinge 2009; Nikolaisen *et al.* 1998). The first technique has been tried at heating, CHP and power plants but requires specific construction of receptacle and feeding facilities at the plants (Nikolaisen *et al.* 1998). Besides, the main disadvantage of chaffed straw as compared to baled straw is its low density, which entails higher transportation costs (Hinge 2009; Nikolaisen *et al.* 1998). Hence baling is the most popular practice of straw handling for energy (Hinge 2009; Nikolaisen *et al.* 1998; Sander & Skøtt 2007). A comparison of different baling equipment is given in Table 2-3.

Danish experiences on straw handling show that production of big straw bales is the most cost-effective method of straw handling for energy (Hinge 2009). Straw can also be transformed into pellets. Converting of a coal-fired plant to biomass pellets is considered to be relatively simple (Sander & Skøtt 2007). Pelletising of straw on the one hand increases its density and optimises transportation and storage but on the other hand rises the cost of fuel since before being pelletised the straw has to be baled in any case (Hinge 2009).

Table 2-3. Typical straw transformation pathways

Straw handling equipment	*Bale dimension, cm*	*Bale weight, kg*	*Bale density, kg/cm^3*	*End use of straw*
Small bailer	46x36x80	12	90-100	Animal bedding, small farm boilers
Round bailer	Ø150x120	244	110	Animal feeding and bedding, small farm boilers
Medium-size bailer	80x80x240	235	140	Animal feeding and bedding, small farm boilers
Big bailer	120x130x240[6]	523[7]	139	DH, CHP and power plants

Source: Nikolaisen et al. 1998

[6] There has been a recent interest in the production of straw bales with 90-100 cm in height instead of 130 cm. This allows locating bales in three layers on the truck instead of two and thus increasing the average weight of a truck load by 40-50% (Hinge 2009).

[7] The weight of straw bales has slightly increased over the years, and modern bailers can produce straw bales with approx. weight of 600 kg (Sander & Skøtt 2007).

There are various techniques for loading and unloading of straw bales. Small bales are loaded in the field by hand, bale fork, bale loader, bale chute, or bale gun (Nikolaisen *et al.* 1998). They are then unloaded into storage places or conveyors manually (Nikolaisen *et al.* 1998). Round and medium-sized rectangular bales are both loaded and unloaded by a front-end loader (Fig. 2-7), a loader tractor or a trencher (Nikolaisen *et al.* 1998). Big bales (also known as Hesston bales) are loaded and unloaded with the same equipment as the previous category or by a telescope loader (Nikolaisen *et al.* 1998; Sander & Skøtt 2007). For round bales and medium-sized and big rectangular bales front-end loader is the most common (Nikolaisen *et al.* 1998) (Fig. 2-7).

Figure 2-7. Front-end loader for straw bales

For straw transportation tractor trailers or truck trailers are used (Hinge 2009; Nikolaisen *et al.* 1998). Tractor trailers are desired to be used only for short distances (a few kilometres) (Hinge 2009). When transporting by a truck there are almost always 12 bales loaded on the truck and 12 bales on the truck trailer distributed in two layers (Hinge 2009; Nikolaisen *et al.* 1998). Straw can be stored in barns or outside in the field, where it is often covered with waterproof folio or wrapped in plastic (Hinge 2009) (Fig. 2-8). The best way of straw storage is considered to be a barn with a roof, walls on all sides and a concrete floor (Hinge 2009).

Figure 2-8. Straw storage in the field

Straw delivery from producers to consumers is organised on mutual agreement or regulated in special straw trade contracts, which specify the terms and conditions of straw delivery and its quality requirements (Hinge 2009; Nikolaisen *et al.* 1998). These contracts can be set between individual straw producers, straw producing/farmer associations or contractors and the purchaser, and are valid for varied time spans (Hinge 2009; Nikolaisen *et al.* 1998). In Denmark, for example, in the past the contracts were made for several years but now there is a tendency towards one-year agreements (Sander & Skøtt 2007).

When straw is delivered to the plant storage, bales are weighed with a weighbridge or platform scales, and their moisture content is measured. Normally the limit for straw refusal is 20% of moisture content (Nikolaisen *et al.* 1998). At smaller neighbour and district heating plants straw bales are placed on a long conveyor (Fig. 2-5), which feeds them into a shredder (Fig. 2-6). At larger plants straw unloading is performed with automatic over-head travelling cranes, which are programmed to pick up the bales and place them in the storage and also on conveyor belts in a certain order (Sander & Skøtt 2007) (Fig. 2-9). These cranes also determine bale weight and moisture content (Sander & Skøtt 2007).

Figure 2-9. Overhead travelling cranes unloading straw to the plant storage

2.4.4 Sustainability implications

Being a bioenergy source, straw is expected to be GHG neutral. However, if one is to consider the whole life cycle of straw use, the transportation of straw by trucks from the field to storages and plants contributes to CO_2 emissions of approximately 1 kg per 1 km travelled for diesel trucks (Nikolaisen *et al.* 1998). In comparative terms this means that a truck needs to travel over 17 000 km with a load of straw to emit the same amount of CO_2, which is saved by burning this straw instead of coal (Nikolaisen *et al.* 1998). A truck with approximately 13 tonnes of straw uses the equivalent of 1% of energy stored in the straw for each 100 km it drives (Holst 2007). Transportation distances, however, in most cases are up to 50-100 km (Bauen *et al.* 2009) and rarely exceed 100-150 km for economic reasons (Hinge 2009). For local heating the straw delivery radius is normally below 30 km (Hinge 2009).

Straw combustion is associated with emissions of various substances (Sub-section 2.4.2.3). Small scale farm boilers are the most polluting ones as they lack emission abatement equipment and do not have afterburners to reduce dioxin concentration in flue gases (Hinge 2009). However, in most cases they are placed in remote locations, which partially reduces the impact of hazardous air emissions on human health and the environment. In addition, since 1995 the emissions of CO from manually fed boilers have dropped significantly mainly due to the introduction of electronic control systems that adjust the amount of excess air needed for complete combustion (Skøtt & Hansen 2000).

Ash from straw combustion contains nutrients (primarily potassium) and minerals such as magnesium, phosphorus, and calcium. Thus it can be applied as a natural fertiliser in agriculture, and is desired to be returned to the fields in order to recycle the nutrients and maintain soil carbon (Nikolaisen *et al.* 1998; Blanco-Canqui & Lal 2009; Buchholz *et al.* 2009; Lemke *et al.* 2009; Sander & Skøtt 2007). However, in some cases the return of straw ash to the soil can be limited due to high content of cadmium or phosphorus in the ash, which is, for example, regulated in Danish legislation (Hinge 2009; Sander & Skøtt 2007). Other ways of ash management (and especially these of fly ash) include its chemical treatment and landfilling (Hinge 2009). Ash landfilling is not considered a sustainable solution, especially if phosphorus is to become a limited resource in the nearest future (Hinge 2009). Ash from co-firing of straw and coal is now widely applied for cement and concrete production (Sander & Skøtt 2007).

Straw handling may also cause working environmental problems due to dust emissions and fungal spores, the exposure to which creates irritation of the mucous membranes in eyes, air pathways and skin (Sander & Skøtt 2007). Long-term exposure may cause respiratory diseases and become the reason of cancer (Sander & Skøtt 2007).

2.5 Theoretical considerations

This Section reviews theories that are of relevance for this work. Three major sets of theoretical considerations include neoinstitutional theory with its relation to the institutionalisation and legitimisation of new activities (Sub-section 2.5.1); studies addressing diffusion of new technologies (Sub-section 2.5.2); and theories explaining the behaviour of actors (Sub-section 2.5.3). Sub-section 2.5.4 suggests a synthesis of described theories in their application to this study.

2.5.1 Neoinstitutional theory and legitimisation of new activities

Key research focus of this work is upon the examination of concrete pathways towards the institutionalisation of bioenergy in Ukraine and associated difficulties. That is why theoretical framework is mainly built on inputs from neoinstitutional theory (DiMaggio & Powell 1991; Aldrich & Fiol 1994; Mizruchi & Fein 1999; Bergek *et al.* 2008), which highlights challenges and fostering factors for the establishment of new organisational forms and explains the patterns of their isomorphic changes.

An important prerequisite for the formation of new industries is their level of legitimacy (Bergek *et al.* 2008). Legitimacy is a "generalised perception or assumption that the actions of an entity are desirable, proper or appropriate within some socially constructed system of norms, values, beliefs and definitions" (Suchman 1995). Previous studies (Geletukha *et al.* 2008; Voytenko 2007) provided clear evidence that Ukraine did not have a significant established commercial bioenergy sector. Indeed, Ukraine's bioenergy sector has a set of characteristics that are typical for the formative phase of an industrial system (Bergek *et al.* 2008; Williamson 1975), which, by definition, has low level of legitimacy[8].

According to Aldrich and Fiol (1994), the concept of legitimacy has two components namely cognitive legitimacy and socio-political legitimacy. Cognitive legitimacy refers to the spread of knowledge about a new venture. New ventures are independent organisations initiating a new activity while new activities are specific product/process innovations (Aldrich & Fiol 1994). New activities can also be interpreted as new organisational forms, which are in the focus of this work. Socio-political legitimacy "refers to the process by which key stakeholders, the general public, key opinion leaders, or government officials accept a venture as appropriate and right, given existing norms and laws" (Aldrich & Fiol 1994). With regards to various bioenergy options in Ukraine both of legitimacy components were found to be missing

[8] Although the progress of bioenergy in Ukraine has been quite visible since 2006-2007, when this research started, the bioenergy sector remains in its formative phase of development. Its key actors (e.g., SEC Biomass, Alternative Fuel consultancy, etc.) are working towards the enhancement of the sector's legitimacy via the assessment of potentials for biomass and bioenergy technologies, and formulation of 'rational' arguments (Bergek и др. 2008) on why bioenergy options are desired to be pursued.

(Geletukha *et al.* 2008; Geletukha & Zhelezna 2010a; Geletukha & Zhelezna 2010b; Geletukha & Zheleznaya 2010; Voytenko 2007).

Legitimacy is recognised as one of crucial factors determining the establishment of a new activity since it helps mobilising resources, forming demand and makes stakeholders, who are involved in this activity, acquiring political strength (Bergek *et al.* 2008). According to Aldrich and Fiol (1994), "access to capital, markets, and governmental protection are partially dependent on the level of legitimacy achieved by an emerging industry". Low levels of legitimacy imply that systems lack the familiarity and credibility in the eyes of key stakeholders, which otherwise constitute "the fundamental basis of interaction" (Aldrich & Fiol 1994).

Based on the considerations above, it is anticipated that the institutionalisation of bioenergy in Ukraine will require legitimisation of its options in the first instance. Academic school of thought brought forth by Aldrich and Fiol (1994) is expected to help identify key factors that hinder and support the progression from the founding of a completely new activity – new agro-biomass based frameworks (ABFs) for organisation and action - through its development as a legitimate activity. Aldrich and Fiol (1994) also suggest a number of strategies to enhance legitimacy of new industry (Table 2-4), which streamed the formulation of topics for recommendations put forward at the closure of this study. A special focus is given to collective mechanisms to reshape industry and institutional environments and provides "one set of constraints facing entrepreneurial emerging industries".

Table 2-4. Entrepreneurial strategies to promote new industry development

Level of analysis	***Type of legitimacy***	
	Cognitive	***Sociopolitical***
Organisational	Develop knowledge base via *symbolic language* and *behaviors*	Develop *trust* in the new activity by maintaining *internally consistent stories*
Intra-industry	Develop knowledge base by encouraging *convergence* around *a dominant design*	Develop perceptions of *reliability* by mobilising to take *collective action*
Inter-industry	Develop knowledge base by promoting activity through *third-party actors*	Develop *reputation* of a new activity as a reality by *negotiating and compromising with other industries*[9]
Institutional	Develop knowledge base by creating	Develop *legitimacy* by organizing *collective marketing*

[9] This is lacking in UA at the moment and there is an evidence that the absence of compromise and negotiations within energy sector hinder the development of bioenergy industry

	linkages with established educational curricula	and *lobbying efforts*

Source: Aldrich & Fiol 1994

According to Aldrich and Fiol (1994), "an entirely new activity begins, by definition, with low cognitive legitimacy". Establishing cognitive legitimacy of new frameworks for organisation and action is viewed as a step towards gaining further support in the eyes of political leaders (achieving socio-political legitimacy) (Aldrich & Fiol 1994). A strategy to achieve legitimacy of new ABFs for organisation and action in Ukraine includes several steps. First, the cognitive essence of this concept is established with the help of a conceptual framework developed in Sub-section 3.4.1 (Table 3-4). Second, the types of such frameworks are identified and their forms are described (Section 7.1) with the help of empirical inputs from the functioning agro-biomass based systems in European countries with advancing and/or institutionalised bioenergy sectors (i.e. Sweden, Denmark, and Spain) (Chapter 5) and in Ukraine (Chapter 6). Third, a comparative analysis of Western European and Ukrainian practices on straw use for energy is performed (Section 7.2) and pathways for Ukraine to institutionalise its agro-biomass sector are put forward (Sections 7.3 and 7.4).

It is believed that gaining cognitive legitimacy of such frameworks in Ukraine is more likely to happen once uncertainty around them is reduced. This is partially achieved via presentation and analysis of successful examples from other countries (Chapter 5). This assumption rests on the definition of 'mimetic isomorphism' concept, which was suggested by the school of thought put forward by DiMaggio and Powell (1991). The authors claim that "organisations tend to model themselves after similar organisations in their field that they perceive to be more legitimate or successful". Since in Ukraine bioenergy field is not institutionalised yet, it is assumed that mimetic processes of bioenergy activities from other countries with advancing bioenergy sectors can help to reduce uncertainty about similar practices in Ukraine.

Neoinstitutional theory and theoretical considerations on the legitimisation of new activities contribute to the explanation of the nature of the problem, the roots of which are found in the lack of legitimacy of bioenergy options by various actors in Ukraine. These theories are required to build theoretical ground for the first research question, i. e. *Why is bioenergy not established as a commercial energy carrier in Ukraine?* Partially they also provide inputs to the second research question, i. e. *How can Ukraine leverage agro-biomass for energy use?* However, a better approach is required to enable structured presentation of bioenergy systems and their comparison in various contexts. Thus the theoretical framework is expanded to include other schools of thought.

2.5.2 Diffusion of new technologies

Neoinstitutional theory is complemented with diffusion models that describe the variables critical to the rate of adoption of new ventures. Such models include attributes of technology and innovation, types of innovation-decisions and communication channels (Bergek *et al.* 2008; Hillman *et al.* 2008; Jacobsson & Bergek 2004; Jacobsson & Johnson 2000). As it is stated by Jacobsson and Bergek (2004), "the real issue is no longer the technical potential of… renewable energy technologies, but how this potential can be realised and substantially contribute to a transformation of the energy sector." The emphasis is made on the type of transformation taking place and the manner in which it affects existing institutions, power bases, norms, and so forth. It is also recognised that the details of such transformations are likely to be significantly context specific.

Hence in order to analyse the transformation of agro-industrial and energy sectors towards bioenergy a conceptual framework is needed that would account for all the aspects of bioenergy system including its technical parameters (e. g., conversion technologies, biomass resources and potentials, etc.) and socio-political parameters (including the issues of legitimacy in the eyes of various actors). Such a framework should also enable structured comparisons of bioenergy systems in various contexts.

Many theorists who study the diffusion of new technology (including renewable energy and bioenergy technology) apply analytical framework called Technological Innovation System (TIS) approach (Bergek *et al.* 2008; Carlsson & Stankiewicz 1991; Jacobsson & Bergek 2004;

Jacobsson & Johnson 2000; Hillman *et al.* 2008). TIS framework is applied for the assessment of: 1) the phase of technology developmentl; 2) system comparisons; and 3) policy support (Coenen 2010). This framework "addresses not just the technical and economic dimensions of technological trajectories but also the broader process of societal embedment" (Hillman *et al.* 2008). TIS is defined by the actors (organisations), networks of actors and institutions (regulations, norms, cultures) involved in the generation, diffusion and utilisation of technology (Carlsson & Stankiewicz 1991). All these components are used in this work for the construction of a conceptual framework (Sub-section 3.4.1, Table 3-4).

A modern approach that applies TIS is considered to be dynamic as the analysis of a system is performed through the evaluation of its functions, which influence each other and create feedback loops (Bergek *et al.* 2008; M.P. Hekkert *et al.* 2007; Hillman *et al.* 2008). Different studies come with slightly varied lists of functions; however, the enhancement of any (or all) of those stimulates the development of a TIS. In this work we adopt the list of TIS functions suggested by Hillman *et al.* (2008). They are presented in Table 2-5 together with the types of events that indicate the level of development of each function. Identification of facilitating and constraining factors for bioenergy in Ukraine (Sub-section 7.2.1) as well as recommendations on the promotion of bioenergy pathways in the country (Section 7.4) are guided by these indicators.

Table 2-5. TIS functions and their indicators

System function	**Event types (indicators)**
F 1: Entrepreneurial activities	Projects with a commercial aim, demonstration, portfolio expansions
F 2: Knowledge development	Studies, lab trials, pilots, research programmes
F 3: Knowledge diffusion	Conferences, workshops, alliances between actors
F 4: Guidance of the search	Expectations, promises, policy targets, standards, research outcomes
F 5: Market formation	Market regulations, tax exemptions, events constituting niche markets
F 6: Resource mobilization	Subsidy programmes
F 7: Support from advocacy coalitions	Lobbies, advice

Source: Hillman et al. 2008

Thus the major strength of diffusion theories is in their potential to provide ground for the practical solution pathways of a bioenergy sector establishment in the country and thus contribute answering the second research question, i.e. *How can Ukraine leverage agro-biomass for energy use?*

2.5.3 Theory to explain the behaviour of actors

Bioenergy stakeholders stay at the heart of new frameworks for organisation and action since they are the ones to push such frameworks and create preconditions for the legitimisation of a bioenergy sector in Ukraine. Interdisciplinarity of bioenergy systems is revealed to be of high importance for their success (UN Energy 2007). Bioenergy stakeholders are represented with actors from various sectors and fields including energy, agriculture, forestry, environment, rural development, industry and trade (UN Energy 2007). Many of those are among target audience of this study (Sub-section 1.2.4).

Farm-based entrepreneurs form a special category of stakeholders whose behaviour and motivation is found to be important for the functioning and success of agro-biomass based frameworks suggested in this work. That is why an analytical approach from Alsos *et al.* (2003) that groups all farm-based entrepreneurs in three categories namely *a pluriactive farmer*, *a resource exploiting farmer* and *a portfolio farmer* is adopted to analyse field data. More details on this are provided in Sub-section 3.4.3. The work by Roos *et al.*(1999) also streamed the formulation of key research questions for the interviews with farm-based entrepreneurs (Annex II).

2.5.4 Integration of theories

In a nutshell, theoretical framework of this research is based on the inputs from neoinstitutional theory, which for the purpose of this work is mainly represented with areas covering the legitimisation of emerging ventures and new technologies (Aldrich & Fiol 1994; Bergek *et al.* 2008; Hillman *et al.* 2008; Jacobsson & Johnson 2000), and underlining the role of collective action in the institutionalisation of new activities (Aldrich & Fiol 1994; Bergek *et al.* 2008; Hillman *et al.* 2008; Jacobsson & Bergek 2004). Also further inputs are obtained from business management and strategies including three perspectives that determine the behaviour of farm-based entrepreneurs (i.e. rural sociology, resource based and opportunity perspectives) (Alsos *et al.* 2003).

Such theoretical framework is adopted for several reasons. Since the research focuses on the institutionalisation of bioenergy in Ukrainian context, neoinstitutional theory enriches the study with a number of constraining factors that are recognised by many (neo-) institutional theorists as those appearing on the way towards the establishment of new ventures (Sub-section 7.2.1) and delineates strategies to enhance the legitimacy of new systems (Table 2-4). Diffusion models guide the formulation of pathways for moving the systems forward (Section 7.3) through the amplification of their functions (Table 2-5). The behaviour of actors in such systems and their motivations is supported with theoretical underpins from Alsos *et al.* (2003).

Based on theoretical considerations (Aldrich & Fiol 1994; Bergek *et al.* 2008) it is also concluded that both cognitive and socio-political legitimacy are important for the establishment of a new industry. Moreover the establishment of the cognitive essence and legitimacy of an activity are preconditions for gaining its socio-political acceptance. The later consideration streams this work into the development of a conceptual framework (Step II in Table 3-1) that aims to operationalise the concept of *"an agro-biomass based framework for organisation and action"* and in this manner establish its cognitive essence. After the cognitive essence is established, the work proceeds to its empirical phase (Steps III-IV in Table 3-1).

Cognitive legitimacy is also directly linked to actors, their perceptions and trust (Aldrich & Fiol 1994). So bioenergy actors are put at the heart of research analysis (Alsos *et al.* 2003) (Section 0, Table 5-15 and Section 6.3, Table 6-12) and are also the key movers in the pathways for the development of Ukraine's agro-biomass potential (Section 7.4). Particular attention is given to collective actions by organisations, which are perceived by theorists as more efficient ways to achieve common goals than actions by separate individuals, and thus facilitate the institutionalisation of a new practice in the field (Aldrich & Fiol 1994; Bergek *et al.* 2008; Hillman *et al.* 2008; Jacobsson & Bergek 2004).

2.6 Forms of organisation for bioenergy

A number of theoretical and empirical studies addressed different forms of organisation arising around new technologies including renewable energy and bioenergy in particular. The terms used by researchers are varied. Some of the former include "technological innovation systems" (Bergek *et al.* 2008; Carlsson & Stankiewicz 1991; Hillman *et al.* 2008; Jacobsson & Bergek 2004; Jacobsson & Johnson 2000) or even "biofuel innovation systems" (Hillman *et al.* 2008), "strategy models for transformation towards bioenergy" (Mårtensson and Westerberg 2007) "planning models" (Hektor 2000), etc. - all suggesting important components, factors and characteristics of what is understood under "a framework for organisation and action" in this work.

Technological Innovation System (TIS) approach is quite popular among institutional theorists who study innovative technologies and emerging industries (Bergek *et al.* 2008; Carlsson & Stankiewicz 1991; Hillman *et al.* 2008; Jacobsson & Bergek 2004; Jacobsson & Johnson 2000). Key components of a TIS include (Bergek *et al.* 2008):

- *Technology:*
  - Artefacts (hardware: e.g. products, design tools and machinery; or software: e.g. procedures/processes and digital protocols);
  - Knowledge (competence within actors, recipes, e.g. texts, drawings, etc., embedded in artefacts).
- *Actors:*
  - Firms and other organisations along the supply chain;
  - Universities;
  - Industrial associations;
  - Bridging organisations (e.g. Greenpeace);
  - Interest organisations;
  - Government bodies;

  - Agency.

- *Institutions:*
  - Hard regulations (juridical systems);
  - Norms and cognitive rules (social systems).

- *Networks:*
  - Learning networks;
  - Political networks;
  - Links between artefacts.

Alternatively, in his description of a value based planning model for bioenergy, which is relevant for the resource/development planning and thus has direct implications for this work, Hektor (2000) identifies the following factors:

- Natural resources (land, water, trees, minerals, etc.);
- Technical factors (machines and equipment, conversion mills, factories and other infrastructural aspects);
- Labour input;
- "Soft" factors (knowledge, experience, organisation, etc.).

To describe the forms of organisation of bioenergy systems the term *"agro-biomass framework for organisation and action"* is used in this work. A detailed operationalisation of this concept is presented in Table 3-4 and its structural elements are given in Section 3.4.1 (see also Fig. 3-3).

3 Methodology

Chapter 1 identified research problem and questions of this inquiry while Chapter 2 provided a review of theoretical underpins behind this study. Chapter 3 first describes the ideology and value system of the author (Section 3.1), which influenced the construction of research questions, streamed this research and helped formulate its findings. It then proceeds into the summary of key research steps followed in the work, and explains how the validity of the study is ensured (Section 3.2). Sections 3.3 and 3.4 describe methods for data collection and analysis (Fig. 3-1) that were applied to find out the answers to research questions of this inquiry. Section 3.5 discusses the major constraints encountered in this research.

3.1 Research ideology and values

While identifying the general research area and choosing specific research problem, researchers should be able to justify why they care about the issue under the study as well as why others may care about it. In other words, it is crucial to understand which values and ideologies form a background for and stream the phases of research (Brown & Tandon 1983). The ideology behind this work is based on consensus social theory when values and benefits are shared between the actors within the system (Brown & Tandon 1983). The purpose of this research is rather to cooperate with different bioenergy stakeholders to achieve overall system improvements by bringing betterment to all its members, and not to work against the system explicitly joining one set of actors (Brown & Tandon 1983). Problem solutions are sought in a manner that they can be supported by consensus among relevant actors (Brown & Tandon 1983).

This study is conducted by the researcher, who provides expertise on the issue, and a client system, which is essentially formed by the target audience specified in Sub-section 1.2.4 and provides sanction, insights and information (Brown & Tandon 1983). Data collection and analysis is undertaken in the way that is collaborative with the whole system under study, and research results aim to suggest solutions to the problem with systemic benefits (Brown & Tandon 1983).

3.2 Research steps and validity

Specific steps undertaken in this research are presented in Table 3-1.

Table 3-1. Research steps and sources for data input

Research step	*Research step in this study*
I Setting up research	I Theoretical framework (FM)
	II Conceptual FM
II Working with data: • gathering; • organising; • analysing	III Empirical FMs for organisation and action in Western Europe (WE)
	IV Empirical FMs for organisation and action in Ukraine (UA)
III Producing results and findings	V FM contrast/comparison; discussion of pathways for UA

Extensive archival research was carried out to formulate theoretical (Step I) and build up conceptual (Step II) frameworks for this study (Table 3-1, Fig. 3-2). The development of empirically derived agro-biomass frameworks (ABFs) for organisation and action that exist in European context (Step III) also involved a reasonable amount of archival research, however, was more targeted at data collection in the field. Danish experience of straw use for energy is sufficiently described in literature so archival research was important to reflect upon Danish initiatives in this work. The development of empirical ABFs in the conditions of Ukrainian agro-industrial sector (Step IV) was essentially carried in the field with some inputs from the literature. Important areas for literature review and interviews within this step include knowledge on bioenergy co-benefits and technologies for biomass conversion, mapping of Ukrainian bioenergy actors and highlighting their forms of organisation, description of existing and emerging markets in Ukraine, analysis of state policies supporting biofuel development in the country, etc. Step V involved analysis and discussion, and thus very few literature sources were consulted.

A number of techniques were used to ensure empirical validity of the query. First of all, the study was developed with its adherence to a traditional scientific protocol, which presupposes framing of a research problem and questions, development of hypotheses, and construction of theoretical and conceptual frameworks at early stages in the study (Blumer 1969).

Besides, to ensure roughly symmetrical outcomes the work also highlights areas where the pursuit of bioenergy in Ukraine may not be a valid strategy. Triangulation (employing multiple methods to obtain answers to research questions) (Fig. 3-1) and multiple information sources were used to overcome single method deficiencies and ensure the validity of findings (Fig. 3-2).

3.3 Data collection

This study involved a multiple level data collection procedure done via archival and case study research (Fig. 3-1). First, in order to understand global and national contexts of energy use from biomass and straw archival research was carried out. It involved documentary analysis of various literature sources on the subject and relevant theories in the field, analysis of proceedings from bioenergy conferences and workshops, and review of bioenergy related policies (Fig. 3-1). Participation in bioenergy events has not only provided the author with materials for documentary analysis but also created platforms for interviews with experts and networking opportunities.

Archival research streamed the selection of case studies on straw use for energy both in Western European (WE) and in Ukrainian (UA) contexts, which was accomplished in the second stage of data collection. 23 case studies were analysed including 14 cases from WE and 9 cases from UA. These involved 33 in-depth interviews (i.e. 19 in WE and 14 in UA) and 13 site visits (i.e. 11 in WE and two in UA).

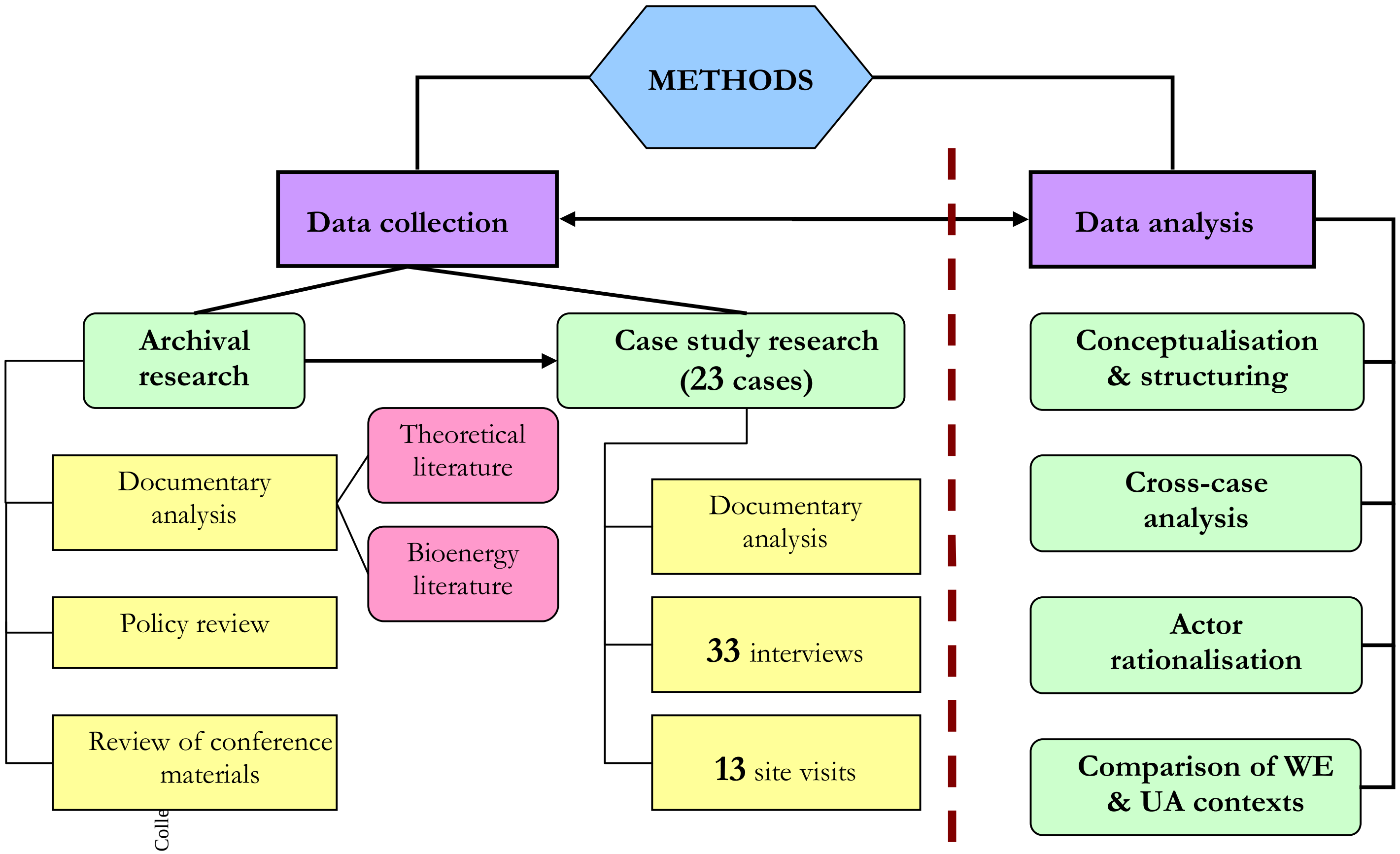

Figure 3-1. Methods for data collection and analysis

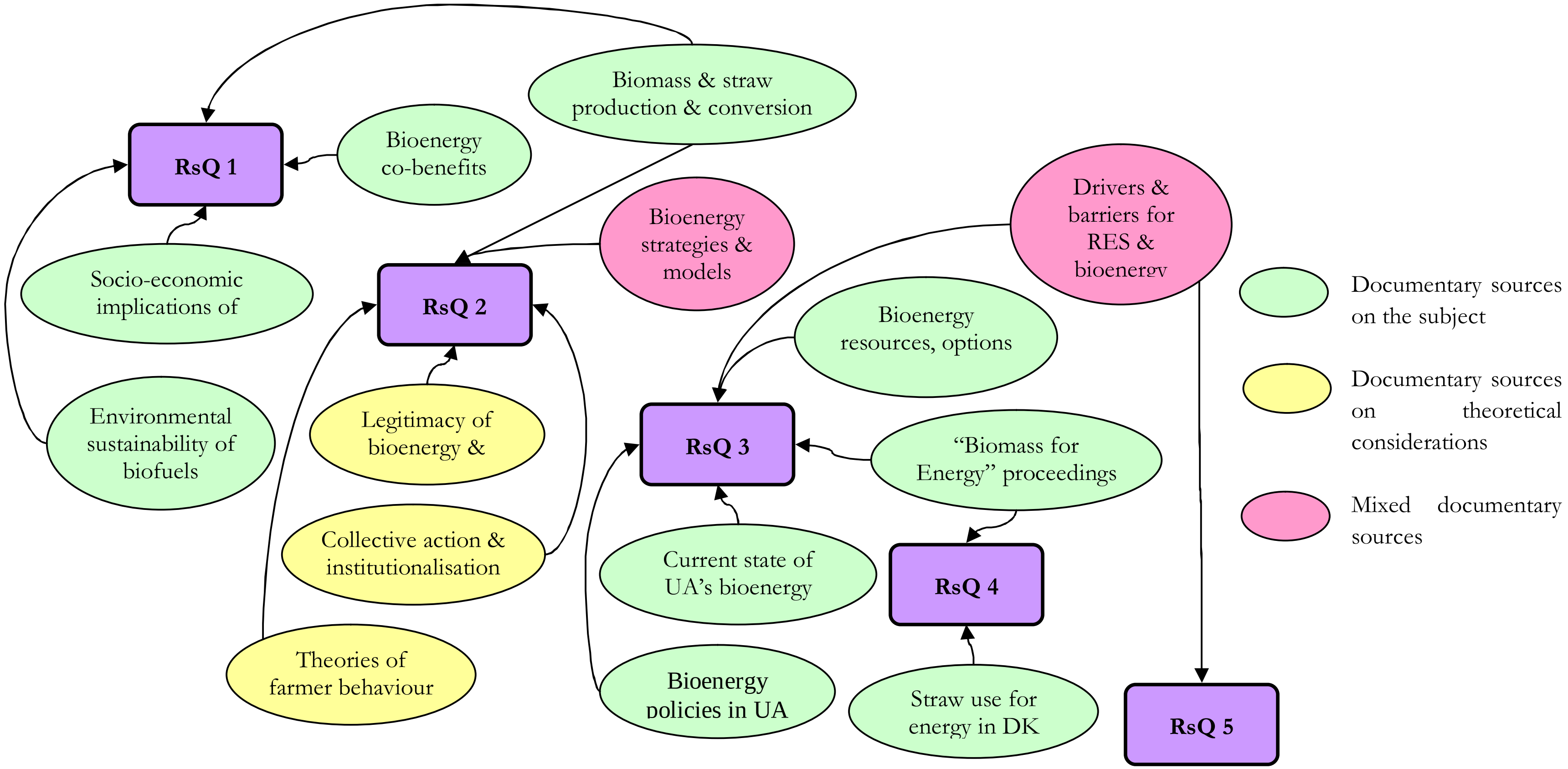

Figure 3-2. Interrelation between research sub-questions (RsQs) and topics from documentary sources

RsQ 1: How can biomass from agriculture deliver energy service in a manner that avoids problems and leverages gains?
RsQ 2: What will be the main characteristics and desirable parameters of key potential agro-biomass based frameworks for organisation of energy service delivery? **RsQ 3:** What are the facilitating and constraining factors for agro-bioenergy development in Ukraine?
RsQ 4: How are the key parameters of an agro-biomass system business set up organised in Western Europe and Ukraine?
RsQ 5: How can existing, emerging and potential constraints to agro-bioenergy in Ukraine be circumvented to facilitate the rise of a sustainable supply and utilisation of agro-biomass for energy in the country?

3.3.1 Archival research

Archival research included the review of background literature within the areas of sustainable development, environmental science and policy, sociology, business strategy and political economy. The answers to research sub-questions (RsQs) were obtained via documentary analysis of specific topics and themes (Fig. 3-2). First three RsQs required significant amount and variety of documentary sources to be consulted. The main input to RsQ 2 was obtained from literature on theoretical considerations. RsQ 4 is rather based on data inputs from case study research, and RsQ 5 is answered via detailed analysis of data collected.

Participation in bioenergy related events within the context of this work refers to taking part in various conferences, seminars, exhibitions, research meetings, summer courses, etc., and in the activities conducted by the Bioenergy Network of Excellence (NoE). Dates of participation and the role of the author in these events are provided in Annex I. It is worth to highlight three dedicated conferences, which both supplied updated information on the issues under study and provided with a range of network opportunities including those with some of the key informants to the study. These conferences include:

- Annual International Conference on Biomass for Energy, Kyiv, Ukraine;
- Annual European Biomass Conference and Exhibition: From Research to Industry and Markets;
- Biannual Conference and Exhibition on Biomass for Energy: World Bioenergy, Jönköping, Sweden.

Archival research enabled the grasping of a broader research field picture, and facilitated the identification of knowledge gaps for this study. Another advantage of this data collection method is in its relatively low resource consumption, e.g. the majority of literature sources were available electronically, which was quite economical and could be also accomplished time efficiently. The major limitations of the archival research technique, which placed a need for other data collection methods, include the lack of documented case specific data both for

Western Europe and Ukraine, and very little knowledge documented on bioenergy developments in Ukraine. In addition, limited information appeared to be available on specific forms of bioenergy systems organisation in a broader context. These deficiencies were sought to be overcome with other data collection techniques described in the following sub-sections.

3.3.2 Case study research

Case study research is comprised of two principal stages that correspond to field data collection for Steps III and IV in Table 3-1. The first stage was carried out in October 2008 – January 2010 in Sweden and Denmark, and provided inputs to Step III, while the second stage was undertaken in June 2009 – February 2010 in Ukraine and Sweden, and supplied information for Step IV. The organisation behind these two stages is described below.

3.3.2.1 Western Europe

This work presents results on straw use for energy at various scales in three EU countries, i.e. Sweden (SE), Denmark (DK) and Spain (ES). A detailed analysis of 14 initiatives (Annex III) that utilise straw for energy is used to underpin the proposal of four types of frameworks for organisation and action. Information was gathered via interviews, site visits and from literature. ABFs for organisation and action are developed for each case, and then are contrasted and compared in a cross-case analysis.

The cases documented here are drawn from Sweden, Denmark and Spain, however, the major motivation for case selection from the three countries and their role within this discussion differs.

The eight cases from the region of Scania, Southern SE, are chosen for the purpose of this work as it is the region with the highest straw potential in SE (Ottosson pers.comm. 2009; Simmons 2008) and it has recently commenced a number of initiatives on straw use for energy. As such, it is believed that it constitutes a good 'learning environment' for other regions in Western (Edwards *et al.* 2005) and Eastern Europe (Gavrilita & Druta 2009; Kolská

& Sobolíková 2009; Voytenko 2009; Voytenko *et al.* 2009; Voytenko & Peck 2009), where straw-based systems are anticipated to emerge in the near future.

DK has more than 30 years experience in energy policy formation targeting straw based systems (Skøtt & Hansen 2000a) and is the most advanced country in the world in the area of utilisation of straw in the national energy mix at all scales (Nikolaisen *et al.* 1998; Hinge 2009). As such, it is an important bench-mark country with experience of energy sector transition towards straw. A detailed analysis of five Danish experiences enriches this work with specific success factors defining the context for such transition. In addition, data from four reports on the history and organisation of Danish straw-based energy systems (Hinge 2009; Nikolaisen *et al.* 1998; Sander & Skøtt 2007; Skøtt & Hansen 2000b) informs the discussion and analysis.

The case of Sangüesa, Navarre region, Spain, is analysed in the study as it is one of the biggest and most advanced straw-fired power plants in Europe (Acciona Energía 2009b; Lerga pers.comm. 2009; Ottosson pers.comm. 2009; Steineck pers.comm. 2009), and demonstrates a successful large scale straw use for electricity generation in a different context from that of Northern Europe. In addition, the background situation describing the development of a Spanish biomass-to-energy sector is also presented in the work. While Sweden can be considered as the country having an emerging/incipient straw-to-energy market, and Denmark – a rather mature and established one, Spain can be placed in the intermediate position in this area (Bergek *et al.* 2008).

Topics that have driven the selection of case studies are provided in Table 3-2.

Table 3-2. Topics for case study selection in Western Europe

#	*Coverage topic*	*Comment*
1	*Installation capacity*	Examples of different boiler capacities including small (<1 MW), medium (1-6 MW) and large (>6 MW) installations are examined
2	*Stage of industry/market development*	Examples from SE illustrate an incipient (formative) straw market; the one from ES – an intermediate market; and those from DK address an established (intermediate to mature) market
3	*Purpose of the installation*	Cases examined represent different energy end-uses (e. g. grain drying, local heating of agricultural premises, DH of municipal and industrial buildings, and dwelling houses, supply of electricity to the National grid)
4	*Boiler ownership*	Straw-fired boilers owned by actors such as private users, agricultural enterprises, cooperatives and companies are discussed

Field studies were carried out during October 2008 – January 2010, and included 19 in-depth interviews with key actors within an agro-biomass production chain (Annex III). Analytical framework suggested by Roos *et al.* (1999) (Annex II), in which the authors listed critical factors to bioenergy implementation, guided questionnaire construction for a structured field work. Sample questionnaires for the interviews are given in Annex IV.

All sites were visited with the exception of three initiatives (i.e. Falkenberg, Svalöv and Sangüesa). Interviews were conducted face-to-face, over telephone and via e-mail. The questions sought to reveal the main components of a conceptual framework to this study (Sub-section 3.4.1, Table 3-4), and points expressed by Alsos *et al.* (2003). Key overarching areas of query for the interviews were framed as follows:

- *How did actors collect and combine resources for a new straw based business?*
- *Why did farm based entrepreneurs engage in straw-to-energy activities?*

Insights into the first area of query are provided with the description of four framework types for straw organisation and with the ensuing analysis, discussion and comparison of these frameworks. The second area of query is partially addressed through the description of framework types, and by the content of case study narratives (Voytenko & Peck 2009). It is answered in more detail via identification of entrepreneur types along the framework by Alsos *et al.* (2003) (Sub-section 3.4.3).

This study also involved 11 site visits. The site visits examined various facilities along the agro-biomass production chain: straw-fired installations at different scales (i.e. boiler-houses and plants), agro-biomass technical processes (e. g. straw storages, baling installations, etc.), heating installations (e.g. grain dryers), perennial grass fields, and fuel storages.

3.3.2.2 Ukraine

A detailed analysis of nine initiatives (Annex V) on straw for energy is applied to underpin the proposal of three types of ABFs for organisation and action in Ukrainian setting. ABFs are developed for each case, and then contrasted and compared in a cross-case analysis and a broader cross-country context. Coverage topics that have driven case study selection are given in Table 3-3.

Field studies were carried out in June 2009 – February 2010, and involved 14 in-depth interviews with key actors within an agro-biomass production chain (Annex V). Six interviews were conducted face-to-face and eight - over the telephone. The study also involved site visits to two grain producing farms with straw-fired installations, straw storages, baling equipment, premises with heating needs, etc.

Table 3-3. Topics for case study selection in Ukraine

#	Coverage topic	Comment
1	*Installation capacity*	One or two examples are examined in-depth for each straw-fired boiler capacity that is available in UA at present
2	*Purpose of the installation*	Cases examined represent different ways of energy end-use (e.g. grain drying, local heating of industrial premises, DH of municipal buildings and dwelling houses)
3	*Boiler ownership*	Straw-fired boilers examined are owned by various actors i.e. agricultural enterprises, companies and municipalities
4	*Boiler manufacturer*	Initiatives described involve installations developed and manufactured by various producers
5	*Degree of the installation success*	Not only successful examples are included but also those facing constraints in their establishment or operation

Like in Western European field studies, the interviews sought to reveal the main components of a conceptual framework (Sub-section 3.4.1) and answer the key overarching area of query framed as follows:

- *How did actors collect and combine resources for a new straw based business?*
- *Why did farm based entrepreneurs engage in straw-to-energy activities?*

Insights into the first area of query are provided with the description of three framework types for straw organisation in Ukraine and with the ensuing analysis, discussion and comparison of these frameworks. The second area of query is partially addressed through the description of framework types, and by the content of case study narratives. It is answered in more detail via identification of entrepreneur types along the framework by Alsos *et al.* (2003) (Sub-section 3.4.3).

3.4 Data analysis

Data was analysed in several steps (Fig. 3-1). First, data from each case study in the EU was structured along the categories of a conceptual FM developed in this work and presented in Sub-section 3.4.1. Then cross-case comparison was applied to identify types of agro-biomass frameworks for organisation and action (ABFs) and classify them in line with the stages of industry development (levels of analysis) by Aldrich and Fiol (1994) (Step III in Table 3-1). Also the rationalisation of actor behaviour was achieved via grouping of farm-based entrepreneurs according to entrepreneur types suggested by Alsos *et al.* (2003).

In the next research step (Step IV in Table 3-1) a similar procedure was followed for straw-to-energy initiatives in Ukraine. Cross-case analysis of Ukrainian cases also informed the identification of constraining and facilitating factors to the development of agro-bioenergy sector in the country (Table 7-3, Sub-section 7.2.1). Within Step V contrast and comparison of findings from WE and UA was performed, and the discussion on the advancement of those ABF types that are currently missing in Ukrainian context was put forward.

3.4.1 Conceptualising and structuring

According to Blumer (1969), concepts are categories for which data are sought and in which the data are grouped. They are also chief means to establish relations between data and the anchor points in the interpretation of findings. In this study a conceptual framework is needed to build a link between the theories and practical elements and terms, the understanding and applicability of which are indispensable for the sense of this work.

First of all, it is important to define what *"an agro-biomass based framework for organisation and action" (ABF)* is or, in other words, establish its cognitive essence. This should help reduce the level of uncertainty about a new activity, which is one of the first steps towards achieving legitimisation (Aldrich & Fiol 1994). As Aldrich and Fiol (1994) put it "where entrepreneurs can establish clarity, comfort, understanding and non-ambiguity of novel technical systems, cognitive legitimacy can be achieved much faster, which becomes vital to their success". This step was pursued through the development of a conceptual framework for this research and operationalisation of the concept *"agro-biomass based framework for organisation and action*".

In the context of this work *"an agro-biomass based framework for organisation and action"* is understood as a form of organisation that creates favourable conditions for the utilisation of energy from agricultural biomass as a commercial energy carrier (Sub-section 1.2.3, Assumption 4). Operationalisation of this concept seeks to answer research sub-question 2, which looks for the list of concrete characteristics and parameters of such a framework independently of its practical context. This Sub-section establishes the cognitive essence of *"an agro-biomass based framework for organisation and action"* (portrayed in Table 3-4), which is then used as an overarching framework and in which field data is fed in.

Key structural elements of the conceptual framework (i.e. ABF) constructed here enrich the concept of Technological Innovation System (TIS) (Bergek *et al.* 2008; Carlsson & Stankiewicz 1991; Hillman *et al.* 2008; Jacobsson & Bergek 2004; Jacobsson & Johnson 2000) with a 'natural resources' component suggested by Hektor (2000). Four main categories within the conceptual FM developed in this work include: actors and their networks, natural resources, technical components, and "soft" (non-technical) components (Fig. 3-3).

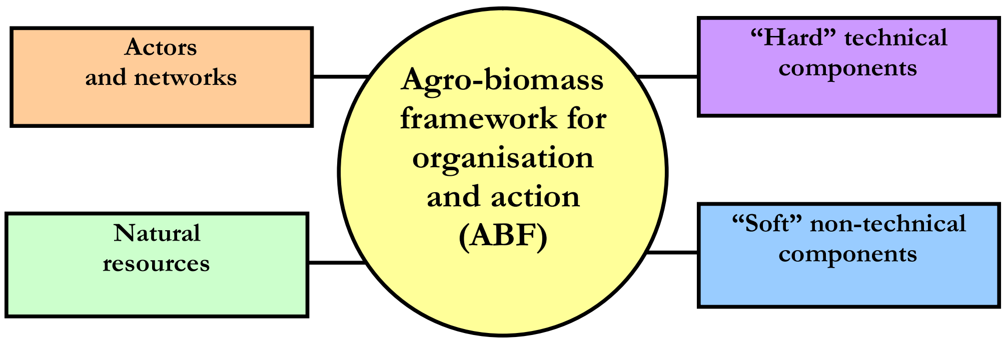

Figure 3-3. Components of an agro-biomass framework for organisation and action

In order to provide a degree of consistency with earlier work by others, the break-down of four main components into (sub-)categories was performed in a manner reflecting the approaches applied in the field (Costello & Finnel 1998; Bo Hektor 2000; Lindh *et al.* 2001; Lindh *et al.* 2007; Mårtensson & Westerberg 2007; Mirata *et al.* 2004; Roos *et al.* 1999; Rösch &

Kaltschmitt 1999). The classifications developed in this work are then grouped according to the empirical examples of straw use for energy identified in Sweden, Denmark and Spain (Chapter 5), and in Ukraine (Chapter 6).

The natural resources component is of crucial importance because an agro-biomass based system is not a purely technological one, and the natural matter (i.e. biomass) is at its heart. "Soft" (non-technical) components are complemented with "co-benefits" category since the existence and sharing of the latter to a large extent defines the level of sustainability each specific framework for organisation and action will have. Also "soft" components are expanded to include institutions (i.e. laws, policies and other norms), which are important elements of a technological system (Jacobsson & Bergek 2004; Jacobsson & Johnson 2000) "Institutions" category is complemented with economic parameters including economic incentives and support, funding schemes, feedstock prices and costs, and investment returns (Table 3-4). Labour input is not specified as a separate item in the framework, and is considered within its other components (mainly "actors" and "technical components").

"Actors and their networks" are argued to be the most important component within the ABF. It will largely depend on them and their ability for collective action whether such frameworks will move forward (Aldrich & Fiol 1994). Moreover, bioenergy actors determine the legitimacy of the overall bioenergy sector as underlined in the theoretical framework to this study (Aldrich & Fiol 1994; Bergek *et al.* 2008).

3.4.2 Cross-case analysis and ABF comparison

After the elements of each specific case study had been conceptualised and structured with the help of Table 3-4, cross-case analysis was performed. It yielded a number of agro-biomass framework types both in Western European (Step III in Table 3-1) and in Ukrainian (Step IV) contexts.

Table 3-4. Components of an agro-biomass based framework for organisation and action

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*		Farmers
				Business entrepreneurs
		Feedstock handlers		Sub-contractors
				Resellers
		First-hand users of biomass for energy		Boiler houses of various scale
				District heating plants
				Power plants
				Combined heat and power plants
		Second-hand users of energy from biomass		Residents
				Municipal buildings
				Companies
				Industries
		Competitors for biomass use		Food industry
				Pulp and paper industry
	Indirectly involved in biomass chain			Governmental authorities
				Municipalities
				Associations of agricultural producers
				Other associations (e.g. of fuel suppliers, bioenergy, etc.)
				Companies including equipment manufacturers
				Non-governmental organisations
				Academia and research institutions
				Media
				General public
				Advisors and consultants
				Financial institutions and funding bodies
				Insurance companies
				Waste water treatment plants
Natural resources	*Biomass feedstock*	*Types of feedstock*		Agricultural residues
				Other biomass types (e.g. wood, perennial grasses)
		Feedstock origin		Domestic
				Imported
		Markets for feedstock		No market
				Domestic
				Export
		Feedstock transformation pathways	*Primary*	Bulk
				Bales
				Briquettes
				Pellets
			Secondary	Fuel mixtures
				Liquid biofuels
				Biogas
	Other	*Land*		Agricultural land in use
				Set aside land
				Low opportunity cost land (e.g. abandoned, degraded, polluted)
		Soil		Physical properties
				Chemical properties
		Water		Irrigation (i.e. waste water treatment with energy crops)
		Air		GHG balances
		Biodiversity		Habitats, species diversity, composition, ecosystem services, etc.

			Machinery and equipment	Planting/establishment

			Fertilisation
			Harvesting
			Baling
			Transportation
			Irrigation
		Conversion facilities	Existing
			Newly constructed
			Combined
			Small-scale boilers (below 1 MW)
			Medium-scale boiler-houses (1-6 MW)
			Large plants (more than 6 MW: DHPs, PPs, CHPs)
			Near/medium area (within 50 km from the fuel source)
			More distant area (generally above 50 km from the fuel source)
	Technology	*Conversion pathways*	Combustion of primary fuel
			Co-firing with other fuels
		End-use of energy from biomass	Heating
			Electricity
			Transportation
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	Programmes and policy documents
			'Hard' laws
		Economy	Economic incentives and support
			Funding schemes
			Feedstock prices and costs
			Investment returns (e.g. IRR or 'payback')
		Social systems	Norms and cognitive rules
			Credibility of systems
	Co-benefits	*Energy security/insecurity*	Reduction of energy imports
			Energy source diversification
			Energy efficiency improvements
		Rural development/impoverishment	Job creation
			Amelioration of depopulation trends
			Waste valorisation
		Ecological benefits/costs	GHG emissions
			Ecosystem condition
			Soil quality
			Surface and groundwater quality
			Waste water purification
			Reduction of fertilisation requirements
			Biodiversity
	Knowledge	*Actor capacity*	Level of education
			Years of professional experience
			Other qualifications
		Recipes	Texts, drawings, schemes, maps, etc.

Aldrich and Fiol (1994) identify four stages in the industry development (levels of analysis) - organisational, intraindustrial, interindustrial, and institutional (Table 2-4, Sub-section 2.5.1). All analysed case studies represent different stages in the development of industrial bioenergy sector, in which straw is being institutionalised as a commercial energy carrier. Hence the frameworks embedded in each case study can be classified along these four levels of analysis (1994).

After the types of ABFs had been identified, they were compared within the following categories:

- Levels of analysis (i.e. organisational, intraindustrial, interindustrial);
- Number and diversity of actors;
- Role of collective action;
- Degree of system complexity;
- Degree of formalisation (e. g., existence of written contracts);
- Reasons for transformation towards bioenergy.

No ABF type is suggested for the institutional level of analysis since it rather defines how a new organisation fits into the community or a broader institutional environment, which is already shown with three previous levels of analysis. Organisations in case studies within this research include farms, subcontractor companies for straw handling, DH, CHP and power plants, funding bodies, competing businesses, consultancies, etc.

Results from cross-case analysis of Ukrainian initiatives (Section 7.1) and examination of the broader country context (Chapter 4) are then used to identify facilitating and constraining factors for the development of Ukraine's straw-to-energy sector (Sub-section 7.2.1). These factors are structured along the categories of the conceptual framework (Table 7-3), and their contribution to each of the eight TIS functions (Table 2-5, Sub-section 2.5.2) is discussed.

3.4.3 Actor rationalisation

This work uses the terminology and seeks to maintain consistency with the classification of farm-based entrepreneurs suggested by Alsos *et al.* (2003). This has been applied to a broad suite of rural diversification strategies and studies on socio-economic and cultural factors stimulating and hindering the development of farmers' entrepreneurial capability (e.g., Barbieri & Mahoney 2009; De Wolf *et al.* 2007; Oughton *et al.* 2003). In this work, this classification helps to group and rationalise the spectrum of entrepreneurial behaviour within the new ABFs. While the actors are identified as one of the key components of any ABF

(Sub-section 3.4.1), farmers form an important stakeholder category being the suppliers of the primary biomass feedstock. As such, a straw supply chain would not exist without them while a straw-to-energy initiative can still be built without significant involvement of other actors (e.g., see ABF 1 and 2, Section 4.2). Hence the understanding of the farmers' behaviour and the reasons for them to engage in new ABFs is among important preconditions for the success of such ABFs.

Relevant to this analysis is the work of Alsos *et al.* (2003) who investigated factors that motivate farmers to commence new business activities that add to, or diversify the portfolio of activities on the farm. They describe three underlying theoretical approaches: the rural sociology perspective, resource based perspective, and opportunity perspective. Pursuant to this, they identify three categories of farm-based entrepreneurs: *pluriactive*, *resource exploiting*, and *portfolio* farmers.

The authors describe a ***pluriactive farmer*** as the one characterised by a strong commitment to the established farming lifestyle and norms. New business is considered as a way to increase income on the farm, and it should be possible to combine it with traditional farming and fit it into the existing workload. New business is prioritised according to those activities requiring the least change.

A ***resource exploiting farmer*** is motivated by a wish to utilise unique material and/or immaterial resource(s). These actors view new business as equally, or even more important than traditional farming (with regard to income, quality of life, job satisfaction, etc.). A key motivational factor for such entrepreneurs is to leverage all, or any, resources under their control.

A ***portfolio farmer*** is primarily motivated by a desire to exploit business opportunities and is least attached to the traditions of farming. For such entrepreneurs resources can be acquired, and do not need to be necessarily owned. New business ventures typically involve larger teams and higher dependence on other actors. Such ventures may grow larger than the farm (with regards to income). If a new business provides more return, portfolio farmers may completely shift to it.

Farm-based entrepreneurs within empirically derived ABFs are analysed in line with the categories described above. This type of analysis and its results are presented in Chapter 5 for Western Europe, and in Chapter 6 for Ukraine. Such analysis helps to establish the spectrum of entrepreneurial behaviour within the new frameworks. It is sought to enable the possibility to conclude which types of farmers are more likely to engage in agro-biomass activities as well as which lines of entrepreneurial behaviour would be more efficient for the functioning of new ABFs both in Western Europe and in Ukraine.

3.4.4 Comparison and contrast of Western European and Ukrainian contexts

Last but not least in the data analysis the comparison and contrast of experiences on straw use for energy in Western Europe and Ukraine is carried out (Sub-section 7.2.2). This leads the delineation of pathways for agro-bioenergy development in Ukraine (Section 7.3) and formulation of recommended actions to key bioenergy stakeholders to move forward (Section 7.4).

3.5 Research constraints

One of the main limitations for case studies in Western Europe is linked to language constraints, which had a certain influence on case study selection and data collection. Although the majority of respondents were able to speak English, sometimes additional translation from native speakers was obtained.

In the case of Skurup, Sweden, it was not possible to communicate with municipality representatives due to the constraints with obtaining the contact information of those who were directly involved in the initiative. Only one sub-contractor to the plant was interviewed. Two other sub-contractors had been contacted, and a questionnaire had been faxed to one of them but resulted in no response. A likely reason for the interview failure was due to the lack of English language proficiency by respondents.

Only two study visits to straw-fired installations were carried out in Ukraine while interviews in seven other cases were mainly conducted over the telephone. This is linked to the large geographical scale of the country and associated time and financial constraints. However, distant data collection methods are not expected to significantly affect the results.

4 Bioenergy in Ukraine: current status

Chapter 4 constructs an overall picture of bioenergy options in Ukraine (UA) and seeks to identify those that have better prospects for the development in the first instance. Section 4.1 presents country setting and gives an overview of current bioenergy practices in UA. In Section 4.2 existing and prospective bioenergy related national support programmes and policies are analysed. Factors that are crucial for the rate of bioenergy adoption including current market environment (Section 4.3), investment needs, level of technology and knowledge development, and logistics requirements (Section 4.4) are considered. Section 4.5 delineates the trends surrounding emerging bioenergy sector in Ukraine and driving forces that stream its development, and concludes Chapter 4.

4.1 National agro-bioenergy production

Ukraine is the largest country in Europe with a total area of 60.36 million ha (SCLRU 2005). The share of forest resources in UA's total land area is 17.4% while that of agricultural land is 71.2% with arable land constituting 53.8% of the total. In other words, the country has a very high share of agricultural lands in its national land structure. However, the contribution of agricultural sector to the national economy has been declining in the last years articulating the need for the revitalisation of UA's agriculture (MEU 2009). In addition, the country is characterised with a broad need for the enhancement of energy security and reducing its dependence on fuel imports through the diversification of the national energy mix and improvement of its energy efficiency (Sub-section 1.1.3) (IEA 2006). Environmental improvement is among other issues of concern in Ukraine (IEA 2006).

As it was shown in Sub-section 1.1.4, the country has significant potentials for all bioenergy options (Dolinski & Geletukha 2006; K. Ericsson & L. J. Nilsson 2006; Faaij *et al.* 2004; Geletukha & Dolinsky 2009; Smeets *et al.* 2005). Earlier work (Voytenko 2007; Voytenko *et al.* 2009) identified a number of co-benefits (Sub-section 1.1.3) that the development of a bioenergy sector could deliver for the country. Ancillary benefits include improved energy security, reduction of GHG emissions, rural diversification and development, environmental improvement, job creation, strengthening of the agricultural sector, increased value of land, waste valorisation, reduced risk in agriculture, and amelioration of rural depopulation trends. Development of agro-biomass options can become a pathway for the revitalisation of Ukraine's agricultural sector in particular and country's economy in general.

Currently energy produced from biomass in UA is about 38 PJ (0.9 Mtoe) per year, which comes only in the form of heat and constitutes 0.65% in Ukraine's TPES (Geletukha *et al.* 2008). According to SEC Biomass (Dolinsky 2008), Ukraine utilises biomass mainly as firewood (about 0.7 Mtoe per year) for private heating and via burning wood residues in more than 1000 boilers at forestry and wood processing enterprises. Boilers for wood combustion include both converted coal-fired ones and dedicated wood-fired boilers of Ukrainian manufacture (Geletukha *et al.* 2008). Wood pellet production exists in Ukraine, however, is mainly export oriented as currently there are no internal markets for wood pellets in the country (Geletukha pers.comm. 2007; Fominykh pers.comm. 2009).

The "wood for energy" option is followed by the combustion of crop residues. Sunflower husk is burned in both converted and specifically designed boilers at large oil-extracting plants (Geletukha *et al.* 2008; Listopad 2009; Zhelezna & Morozova 2007), which helps to satisfy plant heating needs. A combined heat and power (CHP) installation was developed at the oil extraction plant Open Joint Stock Company (OJSC) Kirovogradoliya in the city of Kirovograd, which utilises sunflower husk for steam and power generation. It has three boilers (two operational and one reserve husk fired boiler) and a 2.5 MW steam turbine. The project was introduced under the framework of Austrian joint implementation (JI) programme (SEC Biomass 2006).

Straw combustion is performed in more than 25 straw-fired boilers located in different regions in rural areas in Ukraine (Svintsitskiy pers.comm. 2009; UTEM 2009b). Almost all of these were manufactured by OJSC UTEM, which is the only Ukrainian manufacturer of licensed straw-fired boilers (UTEM 2009a) (Sub-section 4.4.2). Information available on 23 UTEM boilers is aggregated in Table 6-1 (Sub-section 6.1). In most cases these boilers are used for heating of municipal buildings in the villages (i.e. schools, kindergartens, premises of village councils, cultural centres, multi-storeyed living houses, etc.) or for the local energy needs of agricultural enterprises. This is shown in more detail in Chapter 6 and Annex VII .

Agricultural producers in UA install heat generators on their farms to run grain dryers and satisfy other farm energy needs (Melnychuk & Dubrovin 2007; Toropets pers.comm. 2009). There exist Ukrainian producers of such heat generators, which burn any type of crop residues (Lytvyn pers.comm. 2009; Kuzmin pers.comm. 2010; OJSC "Bryg" 2010; RETRA 2009; TM "Ukrsetka" 2008; Toropets pers.comm. 2009) (Sub-section 4.4.2). However, these installed systems do not always reach maximum efficiency due to their connection to other outdated equipment on the farm (Butenko pers.comm. 2009).

A few farms operate small-scale individual biogas units (Geletukha *et al.* 2008). Among larger biogas installations a pilot plant was put in operation in December 2004 within a demonstration project in Yelenovka village, Dnipropetrovsk province, at a pig breeding farm Agro Oven (Kucheruk *et al.* 2007). The project was funded by Dutch government and carried out by SEC Biomass, Dutch company BTG and research coalition UkrNDIagroproject (Kucheruk *et al.* 2007). The plant has dewatering system and all modern equipment (Geletukha & Matveev 2004). It had been the only functioning biogas installation of larger scale for a few years. Currently a few other installations exist in UA including a CHP plant of 250 kW electricity and 310 kW heat in the village of Terezyne, Kyiv province, which digests cattle and pig manure, and a CHP plant of 330 kW electricity and 686 kW heat in the village of Velykyi Krupil, Kyiv province (Matveev 2009).

Today only a few large-scale plantations of dedicated energy crops exist in UA. All of them have been introduced quite recently, and no reports were found about on the crop harvesting. One of such examples is growing of energy willow *Salix viminalis* on 160 ha of land in Ivano-Frankivsk province near the town of Kolomyya in the Western part of Ukraine. This trial plantation was established by LLC "Agrospivdruzhnist" in 2006 and should be harvested in 2010 (Fominykh pers.comm. 2009). Another project, which was also initiated by LLC "Agrospivdruzhnist", is in the stage of a business plan development. It envisions the establishment of willow plantations on 2000 ha of currently underutilised land, and a construction of a wood pellet production plant in Chernivtsi province, Western Ukraine (Fominykh pers.comm. 2009).

One more initiative on willow cultivation is being developed in Lugansk province, Eastern Ukraine. It is carried out within the project on the Development and Commercialisation of Bioenergy Technologies in UA. *Salix viminalis* will be planted on 96 ha of lands flooded with groundwater from closed coal mines (Severyn pers.comm. 2009). Currently the project is in its initial phase.

As for densified solid biofuels, currently there are about 40 biomass pellet producers and about 90 biomass briquette producers (mainly those from sunflower husk and saw dust) in Ukraine (Geletukha & Zhelezna 2010a). These are small companies with low production capacities (i.e. 1000-2000 tonnes of pellets and 500-1000 tonnes of briquettes per month) (Geletukha & Zhelezna 2010a). More than 90% of densified solid biofuels produced in UA are exported to European markets (Geletukha & Zhelezna 2010a).

First generation liquid biofuels (i.e. bioethanol from grain and biodiesel from rapeseed) are also produced in UA. There are six ethanol production plants in the country with a total capacity of 135 000 million tones per year (Korol 2009). Ukraine is also among five largest producers and second important exporter of rapeseed in the world (Listopad 2009). Now there are eight big oil-extracting plants in the country that produce rapeseed oil (Listopad 2009).

4.2 *Support schemes for bioenergy production*

4.2.1 State Programme on Biofuel Development

The *State Development Programme on Biofuel Production and Consumption* was put suggested by the National Agency on Effective Energy Use in Ukraine (NAER) and approved by the Cabinet of Ministers on 12 February 2009. Its execution was envisioned for 2010-2014, however, it has not been implemented yet (Dolinski & Geletukha 2010). The Programme aims to increase the share of biofuels in the national energy balance to 5-7% and increase the level of energy security in the country by two times (CMU 2009a). Among other goals on bioenergy development and emission reduction it envisions the installation of more than 70 000 of modern energy efficient biomass boilers with a total capacity of 9180 MW in order to substitute 5 billion m^3 of natural gas. The funding of the Programme is envisioned from state and local budgets, business investments and other sources. The total projected cost for the execution of this Programme is about EUR 700 million.

The Programme, however, is rather focused on the development of first generation liquid biofuels with some attention given to biogas. Although it puts the state of the environment as one of its primary objectives, the Programme does not specify any sustainability criteria for biofuel production (e. g., specifications of lands that can be used for biofuel feedstock cultivation, qualitative and quantitative criteria of fertiliser and pesticide use, etc.). The document does not account for or build any framework for the development of energy crops that do not have "food cousins" (i.e. coppice crops and perennial grasses).

4.2.2 Law on Support of Biofuel Use

The Law of Ukraine *On Amendments to Some Laws of Ukraine on Support of Biofuel Production and Consumption* (#1391-VI) was accepted on 21 May 2009 (VRU 2009b). A number of changes to formulations and term definitions were made in the Law of Ukraine *On Alternative Fuels* (#1391-XIV from 14 January 2000) (VRU 2000). Among other provisions, the Law sets a target to increase the share of biofuel use to 20% in total fuel consumption in Ukraine by 2020 (VRU 2009b).

However, according to SEC Biomass (Geletukha 2009; Geletukha & Zheleznaya 2010), this Law requires further amendments for its efficient enforcement. Currently it excludes unprocessed biomass (e. g., straw, wood logs and residues, sunflower husk, etc.) from the definition of a biofuel (Geletukha & Zheleznaya 2010). Agricultural, forestry and other enterprises that are not biofuel producers per se but generate biomass from their activities are also falling out from the category 'a biofuel producer', which is defined in the Law (Geletukha & Zheleznaya 2010). In addition, it is desired (Geletukha & Zheleznaya 2010) that the list of equipment with import allowances is expanded to include internal combustion engines modified for biogas and their parts. The Law is also criticised for the establishment of certification and licensing requirements for liquid biofuels and biogas, which could create perverse incentives for the development of these options (Geletukha & Zheleznaya 2010). Not least the Law is rather focused on the development of first generation liquid biofuels and bioethanol in particular. Less attention is given to biogas, crop and wood residues. Energy crop plantations are not considered.

4.2.3 Law on Green Electricity Tariff

In Ukraine there exist no taxes on fossil fuel use that could create cost preferences for bioenergy production and consumption. However, on 1 April 2009 the Parliament accepted so called Law *On Green Electricity Tariff* (or the *Law of Ukraine #1229-VI On Amendments to the Law of Ukraine On Electrical Energy in Regards to Stimulation of Alternative Energy Use* from 1 April 2009 (VRU 2009a). It obliges energy companies to purchase electricity produced from alternative sources with higher tariffs than those from conventional sources. Each alternative energy source is assigned with a relevant coefficient, which is then multiplied by the existing tariff for the electricity consumers of second category. The coefficient is set at 2.3 for bioenergy, 1.2-2.1 for wind installations, 4.4-4.8 for solar energy depending on the installed capacity, and 0.8 for small hydro (Geletukha 2009; VRU 2009a). The minimal green electricity tariff in UA is 12.39 Euro cents per kWh (Geletukha & Zheleznaya 2010). This figure is even higher than that for many biomass sources in Germany, which varies from 6.65 to 17.5 Euro cents (Geletukha & Zheleznaya 2010).

Green tariff is operational till 2030 and will reduce gradually after 2014, 2019 and 2024 by 10, 20 and 30% respectively. Currently it is applied at two biomass-fired CHP plants in UA: OJSC "Kirovogradoliya" (from 1 January 2010 till 1 January 2030) (NERCU 2009) and LLC "Smilaenergopromtrans" (from 1 June 2010 till 1 January 2030) (NERCU 2010a). The tariff is established at UAH 1.3446[10] per kW for both enterprises (NERCU 2010c).

Potentially this Law can create favourable conditions for power generating bioenergy enterprises. In the first instance this relates to biogas installations rather than small and medium scale boilers on solid biofuels. Considering the practice of European countries with advanced bioenergy sectors (e.g., Sweden, Denmark) in most cases small and medium scale biomass-fired boilers (up to 6 MW) are used only for heating purposes (Voytenko & Peck 2009). At the same time, the majority of biogas installations are those of co-generation type (Kucheruk *et al.* 2007; Matveev 2009).

However, like the previous Law, this Law has also a number of imperfections identified by Geletukha and Zheleznaya (2010). Firstly, due to incomplete definition of 'biomass' in the Law#1229-VI such important bioenergy feedstocks as animal residues and manure, waste water sediments, organic share of municipal solid waste are excluded from the regulation. This creates potential challenges for biogas installation applying for 'green' electricity certification. As one example, National Electricity Regulatory Commission of Ukraine (NERCU) declined such an application from "Ukrainian Milk Company" (Geletukha & Zheleznaya 2010). Secondly, co-firing of biomass with conventional fuels is not regulated by the Law. Thirdly, bioenergy sources are not differentiated, and the same coefficient is applied

[10] UAH 1.3446 = 13.33 Euro cents (EUR 1 = UAH 10.09 as of 13 August 2010), which is 2.3 times higher than conventional electricity tariff for II class users (i.e. UAH 0.5846 = 5.79 Euro cents)

to all biomass options. Lastly, the procedure to obtain a 'green' tariff is quite sophisticated (Geletukha & Zhelezna 2010a). Initially one has to obtain a license for electricity generation, then get a 'green' tariff for it and later in order to be able to operate in real conditions one has to become a member of the whole sale electricity market (Geletukha & Zhelezna 2010a).

4.2.4 Laws on Minimisation of Financial Crisis Impact

The Law of Ukraine *On Amendments to Some Laws of Ukraine in regards to the Minimisation of Financial Crisis Impact on Domestic Industry Development #694-VI* was accepted on 18 December 2008 (Geletukha & Zhelezna 2010a). It introduced a number of amendments to the existing laws, which create mechanisms of economic support for the development of bioenergy sector in Ukraine. In particular, the Law #273-VI (VRU 2008) envisions customs tax exemptions for imported equipment and structural components that are applied in new production lines for energy efficient technologies. The same rules are outlined in the Cabinet of Ministers Decree #284 from 18 March 2009. These goods include boilers, machines and mechanical equipment, turbines, combustion chambers, etc (CMU 2009b). They are also exempted from value added tax (VAT) till 1 January 2011 according to the changes made in the Law of Ukraine *On Value Added Tax* (VRU 2009).

In addition, according to the changes in the Law of Ukraine *On the Taxation of Enterprise Revenues* (VRU 2004) the enterprises are allowed to apply annual fastened depreciation rate at 25% for all assets including bioenergy equipment and technologies. For equipment on alternative fuel and for alternative fuel production technologies the rate of depreciation is allowed at 50% till 1 January 2019. This Law also identifies tax exemptions till 1 January 2011 for the following income streams:

- revenues of biofuel producers from biofuel sales;
- enterprise income from co-generation of heat and power or heat from bioenergy;
- revenues of equipment manufacturers specified in the Law of Ukraine *On Alternative Fuels* (art. 7) from the sales of this equipment.

4.2.5 Biofuel standardisation

Ukraine has experienced active development of biofuel standardisation procedure in the last few years. A few State Committees, the Ministry of Agriculture and some other institutions have been involved in this process (Geletukha & Zhelezna 2010a). In 2009 eight dedicated state standards were developed to describe parameters of solid biofuels (e. g., mechanical stability of fuel pellets and briquettes, their grain size composition, etc.) (Geletukha & Zhelezna 2010a). Two of those were implemented from 1 September 2009, five are trial standards valid from 1 July 2010 till 1 July 2013, and one will be implemented on 1 January 2011 (Geletukha & Zhelezna 2010a).

4.2.6 Joint Implementation Opportunities

Ukraine is a party to Kyoto Protocol, which enables its participation in Joint Implementation (JI) projects (Geletukha & Zhelezna 2010a) and Green Investment Scheme (GIS) (Epik *et al.* 2010). In cases of a JI and GIS project revenues are gained by Ukrainian partner while the foreign investor receives GHG emission reduction quotas in return (Geletukha and Konshyn 2007).

Currently bioenergy projects fall within three JI categories, which were identified as those having good prospects in Ukraine (Geletukha and Konshyn 2007). These include collection and utilisation of biogas from municipal solid waste (MSW) landfills, CHP generation from alternative energy sources and use of unconventional and renewable energy sources. Within the last five years a few such projects have been carried out in UA with information and technical support from SEC Biomass (SEC Biomass 2009). GIS is a relatively new practice in Ukraine (Epik *et al.* 2010), for which the potential of bioenergy projects needs to be clarified.

According to the United Nations Framework Convention on Climate Change (UN FCCC) agricultural projects, fuel switching, industrial processes and waste management are referred to small-scale projects, which result in emission reductions of less or equal to 60 000 tonnes of CO_2 equivalent annually (UNFCCC 2009). However, in practical terms such projects very often are not considered to be profitable by developers (Tsvetkova pers.comm. 2009). For instance, biogas projects should lead to the reduction of at least 30 000 tonnes of CO_2 (i.e. a farm with 3000 cows or 50 000 pigs) to be considered feasible under JI scheme (Matveev 2009). In this case bundling (or forming so called 'pools') can be an option when small and medium enterprises unite their efforts and apply together for a JI project. This in turn allows them to cut down project transaction costs (UNFCCC 2008). In UA a potential barrier for bundling can be the lack of information exchange between actors and lack of awareness about such possibilities. In this case consultancy companies can serve as intermediaries and facilitators to link smaller partners under the umbrella of a JI project.

4.3 Market environment and potentials

4.3.1 Energy imports and transit

Ukraine's net energy imports account for about 46% in its TPES, which places the country among those with the highest total energy dependency in Central and Eastern Europe (Sub-section 1.1.3) (IEA 2006). It is forecasted that UA's total import dependency for natural gas and oil could rise to 65-70% in 2020 (Bossong 2006). The situation is complicated with a high to very high energy intensity of Ukraine's economy, which is about three times higher than the average in the EU (IEA 2006).

Natural gas consumption plays a very important role for Ukraine's economy. This is not only because the relative share of natural gas in the country's total final consumption (TFC) is the highest (about 40%) (Geletukha & Zhelezna 2010a) but also because it has increased significantly as compared to 1993 (31.0%) (IEA 2006). The country, however, satisfies only 35% of its gas needs with domestic sources (Geletukha & Zhelezna 2010a). The rest of it is imported through Russian pipelines from Russia and Turkmenistan (Bossong 2006; IEA 2006).

In addition to the above–mentioned challenges, natural gas prices have been increasing steadily since 2004 (Fig. 4-1). The latest dispute over the gas price occurred at the beginning of 2009 when Russia stopped gas transit through Ukrainian territory for almost two weeks (Ukrayinska pravda 2009). An average price in 2009 was USD 228.8 per 1000 m^3 while in the first quarter of 2010 it was increased to USD 305 (Geletukha & Zhelezna 2010a; Finance.ua 2010). Only in the second quarter of 2010 a drop can be seen when due to a political agreement between Russian and Ukrainian governments a new price was negotiated at USD 236 per 1000 m^3 and a special discount of up to USD 100 per 1000 m^3 was set for UA (Finance.ua 2010). In return Russia received a permission to locate its navy forces in the city of Sevastopol, Ukraine, for at least 25 years (Ukrayinska pravda 2010b). As yet, there is no evidence for the latter incident of price decrease to bear any systematic pattern in the future. Moreover, in the third quarter of 2010 the price was increased again to USD 246 per 1000 m^3 (Dolinski & Geletukha 2010).

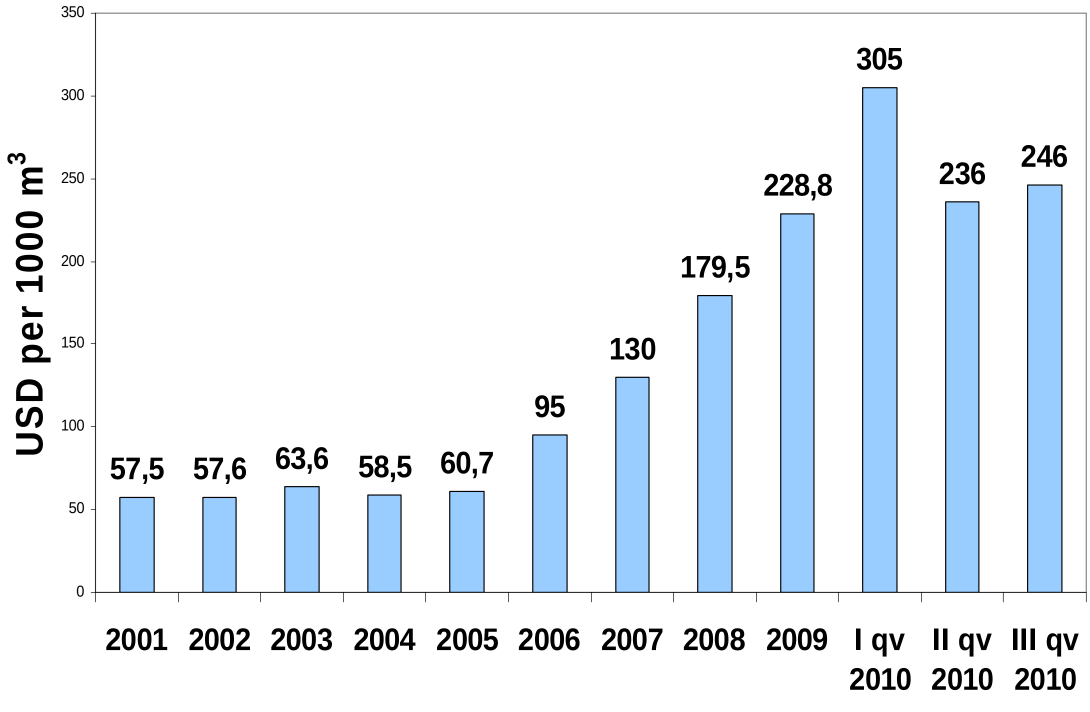

Figure 4-1. Natural gas prices in Ukraine in 2001-2010

Source: Dolinski & Geletukha 2010; Geletukha & Zhelezna 2010a

Another important implication for Ukraine's energy security is the intention of Russia to diversify its gas transit routes to Europe (IEA 2006). As such at the end of 2011 a market gas supply of 55 billion m^3 per year is planned to start through Nord Stream pipeline connecting

Vyborg, Russia, and Greifswald, Germany (Ukrayinska pravda 2010). This may help reduce the dependence of Russia on Ukraine, reach new markets that are able to pay more and thus further increase its ability to demand higher prices from UA.

As for oil, Ukraine imports 80-90% of this commodity. About 80% of this comes from Russia and smaller amounts - from Kazakhstan (Bossong 2006). The control over infrastructure is also being dominated by foreign investors with Russian companies controlling four out of six refineries in UA (IEA 2006).

Unlike oil and natural gas, most of Ukraine's coal is produced domestically. However in 2006 to supply its metallurgical enterprises with coke UA needed to import about 7 000 000 tonnes of coking coal from Russia, which was about 1 000 000 tonnes more than in 2005 (Bossong 2006). Besides, Ukraine's coal sector is characterized with high social cost (Bossong 2006). Since the country's independence in 1991 there occurred more than 3 500 deaths and 700 underground fires in the Ukrainian mines (Bossong 2006). In addition, big industrial cities are suffering from high levels of air pollution with hazardous substances (Bossong 2006).

In the nuclear sector Ukraine relies on its four nuclear power plants with a total of 15 reactors, which contribute to the production of 40-50% of electricity in the country (Bossong 2006). Ukraine is 100% dependent on Russian nuclear fuel needed for these plants (Bossong 2006; IEA 2006).

Together with its heavy dependency on imported energy sources Ukraine occupies a strategic geopolitical location between Europe and Asia. Ukraine is an important energy transit country on the route between East and West. About 80% of natural gas from Russia to Europe goes through Ukrainian territory, which makes UA the largest gas transit country by volume in the world (Bossong 2006; IEA 2006). The share of transit oil is 14-17%, which is also quite significant (IEA 2006).

All of the mentioned factors can be expected to significantly affect Ukraine's transit business and have ongoing and perhaps serious implications for the Nation's energy security (Bossong 2006; IEA 2006; Geletukha & Zhelezna 2010a). Therefore a need for energy source diversification is one of the leading drivers for the development of RES in the country and bioenergy in particular.

4.3.2 Bioenergy market and value chain

Currently bioenergy market in Ukraine is not established, and biofuel certification and standardisation systems are under development (Geletukha & Zhelezna 2010a). Long-term contracts between biofuel producers and consumers are not common yet and, if they exist, are of quite random nature (Geletukha & Zhelezna 2010a; Oliynyk pers.comm. 2010). It is recognised (Geletukha & Zhelezna 2010a) that in many cases the issue of security of biomass supply and associated risk perceptions are crucial factors for potential clients to get involved in biomass-to-energy business. The most important factors for bioenergy market expansion in Ukraine are identified in (IER 2007) and include resource availability and costs, production costs, future price trends, environmental considerations, knowledge and technology development, and other locally determined variants. Most of these are discussed here and in the following Sub-sections.

In Ukraine there is an established wholesale market for electricity, to which it is sold by the state enterprise "Energy Company of Ukraine" at the tariffs set by National Electricity Regulatory Commission (NERC). However, heat and electricity produced by small and medium entrepreneurs including farms, industrial companies and households are not sold on the market, which also creates uncertainties in statistics available (IER 2007).

In the past high investment costs were considered to be the key constraint for the development of renewable energy in Ukraine (IEA 2006; IER 2007). The latter has been disadvantaged for a long time with a targeted state subsidisation of coal industry, powerful lobbying of oil and nuclear sectors, and cross-subsidising of natural gas tariffs where tariffs for industrial consumers have been higher than these for the population (IER 2007; Geletukha & Dolinsky 2009; Geletukha & Zhelezna 2010a). From 1 August 2010 gas tariffs for private users were increased by 50%, and range from UAH 725.4 to 2954.1 per 1000 m^3

depending on the amount consumed (NERCU 2010b). Those who use more than 12 000 m^3 of gas per year are obliged to pay almost the same price (i. e. UAH 2685.6 -2954.1 per 1000 m^3) (NERCU 2010b) as industrial consumers and budget organisations (i. e. UAH 2631[11] per 1000 m^3) (Geletukha & Zhelezna 2010a). From 1 April 2011 it is forecasted that natural gas tariffs for private users will be increased by 50% more (Ukrayinska pravda 2010a).

In UA there are no fossil fuel taxes that could create cost preferences for bioenergy production and consumption. Also environmental external costs are very often not accounted, which does not help RES reach competitive advantage along with conventional energy sources (Geletukha & Matveev 2004). However, with a continuous increase in prices for natural gas from Russia (Fig. 4-1), a removal of tariff cross-subsidisation between industrial and private users, and with the introduction of the Law *On Green Electricity Tariff* (VRU 2009a) energy from biomass is more and more likely to become competitive with conventional energy sources.

Price breakdown for solid biofuels in Ukraine as compared to natural gas prices for different user categories is presented in Table 4-1 (Geletukha & Zhelezna 2010a). While for industries there is a clear incentive to substitute natural gas with any biomass source (i.e. the ratio of natural gas price to biofuel price is larger than one), in housing and public utility sector the use of wood pellets and briquettes remains economically unattractive as compared to natural gas. This can be overcome in future with a complete removal of cross-subsidised tariffs.

Overall the less steps the biomass chain contains, the less value is added to the end-product and the cheaper is the energy produced (Hinge 2009). Thus any pelletising or briquetting procedure increases biofuel cost. This can also be seen from Table 4-1, where the fuel energy cost per GJ is the highest for wood pellets and briquettes.

Additional storage of harvested biomass increases total production costs, however, is inevitable in the conditions of undeveloped bioenergy markets. Plants often need to store

[11] UAH 725.4 = USD 86.36 = EUR 74.17; UAH 2954.1 = USD 351.68 = EUR 302.06; UAH 2685.6 = USD 319.71 = EUR 274.60; UAH 2631 = USD 313.21 = EUR = 269.02 (USD 1 = UAH 8.4; EUR 1 = UAH 9.78 as of 1 August 2010)

biomass feedstock within their premises, which adds value at the level of EUR 1 to 3 per GJ (Oliynyk *et al.* 2007). For straw open storage is the cheapest option while storing in barns is the most expensive one contributing to 34% of the total cost, which is linked to the need for additional construction of buildings (Simmons 2008; Steineck pers.comm. 2009).

Table 4-1. Price comparison for solid biofuels and natural gas in Ukraine

Fuel type	***Average price***		***Low heating value, MJ per kg***	***Fuel price***		*Ratio: gas energy price/ biofuel price*	
	UAH per tonne	*EUR per tonne*		*UAH per GJ*	*EUR per GJ*	*Industries & budget organisations*	*Housing and public utility*
Wood processing residues	0...10	0…1.0	11	0...0.9	0.09	>85	>28
Firewood (delivered price)	200	20.4	11	18.2	1.9	4.3	1.4
Wood pellets	800	81.8	17	47.1	7.4	1.6	0.5
Wood briquettes	700	71.6	17	41.2	6.5	1.9	0.6
Baled straw (delivered price)	300	30.7	14	21.4	2.8	3.6	1.2
Natural gas:	*UAH per 1000 m^3*	*EUR per 1000 m^3*	*MJ per m^3*	*UAH per GJ*	*EUR per GJ*		
Industries and budget organisations	2631	269.0	34	77.4	7.9		
Housing and public utility sector	873	89.3		25.7	2.6		
Population	725.4 …954.1	74.2 …302.1		21.3 …86.9	2.2 …8.9		

Source: Geletukha & Zhelezna 2010a

Transportation is another cost category. Usually transportation distances for biomass should not exceed 50 km to make energy production from biomass economically profitable (Oliynyk *et al.* 2007).

4.3.3 Domestic market potential for commercialisation

Experts from SEC Biomass consider that expansion of bioenergy should start with the introduction of biomass fired boilers (Dolinsky 2008; Geletukha & Zhelezna 2010b). Technical and commercial potential for such technologies was estimated. It is suggested that by 2015 a total of 57 100 boilers fired with wood-, crop residues and peat with overall capacity of 8180 MW are feasible to be installed in Ukraine (Geletukha & Zhelezna 2010b). These include:

- 1000 DH wood-fired boiler-houses of 0.5-10 MW;
- 400 industrial wood-fired boilers of 0.1-5 MW;
- 35 000 domestic wood-fired boilers of 10-50 kW;
- 10 000 farm straw-fired boilers of 0.1-1 MW;
- 1000 DH straw-fired plants of 1-10 MW;
- 9000 farm boilers fired with sunflower and maize stalks of 0.1-1 MW;
- 800 DH peat-fired boilers of 0.5-1 MW.

The introduction of biomass-fired boilers would allow reducing GHG emissions by 8.2 million tonnes per year and substituting 4.8 billion m^3 of natural gas (or 5.5 million tonnes of coal) annually (Geletukha & Zhelezna 2010b). The total estimated investment cost is about UAH 5.64 billion[12]. The cost of substituted natural gas in one year would be:

4.8 billion m^3*(UAH 2631/1000 m^3)[13] = UAH 12.6 billion[14]

Considering average solid biomass price of UAH 200 per tonne, the total fuel cost for new boilers will be UAH 2.6 million (Geletukha & Zhelezna 2010b). Then net savings from natural gas substitution will be:

UAH 12.6 billion – UAH 2.6 billion = UAH 10 billion[15]

As compared to required investments in the installation of biomass-fired boilers (i. e. UAH 5.64), this figure is 1.77 times higher. What is important is that such savings can be achieved every year (Geletukha & Zheleznaya 2010).

Another agro-biomass option that has recently started its development in the country covers biogas production from pig and cow manure and agricultural residues. As it was mentioned, there are a few biogas installations in UA today including two new co-generation units that were put in operation in 2009 (Matveev 2009). Currently about 10 biogas projects are searching for funding and about 10 projects are under development in the country (Matveev

[12] UAH 5.64 billion = EUR 577 million = USD 671 million (EUR 1 = UAH 9.78; USD 1 = UAH 8.4 as of 1 June 2010)
[13] Current natural gas price for industrial users
[14] UAH 12.6 billion = EUR 1.3 billion = USD 1.5 billion (EUR 1 = UAH 9.78; USD 1 = UAH 8.4 as of 1 June 2010)
[15] UAH 10 billion = EUR 1 billion = USD 1.2 billion (EUR 1 = UAH 9.78; USD 1 = UAH 8.4 as of 1 June 2010)

2009). An average payback of such installations is about 6 years (Matveev 2009). It can be reduced to 3 years on the condition that electricity is sold at 'green' tariffs, digested manure is sold as a fertiliser and emission reduction units are traded (Geletukha & Zhelezna 2010b).

SEC Biomass also suggested the implementation strategy for electricity production from biomass in UA with a total installed capacity of 719 MW thermal and 433 MW electricity, which can be produced in 3164 units (Geletukha & Zhelezna 2010b). In particular, the installation of the following equipment is suggested (Geletukha & Zhelezna 2010b):

- 2253 small biogas plants of 200-600 m^3 reactor volume;
- 827 farm biogas plants of 600-3000 m^3 reactor volume;
- 4 large scale biogas plants of more than 3000 m^3 reactor volume;
- 60 mini power plants on landfill gas;
- 10 mini wood-fired co-generation units;
- 10 mini straw-fired co-generation units.

The total investment costs are estimated at UAH 12.75 billion[16]. The strategy will allow to replace 1.2 billion m^3 of natural gas and reduce GHG emissions by 4.86 million tones of CO_2 per year (Geletukha & Zhelezna 2010b). The cost of substituted natural gas in one year would be:

1.2 billion m^3*(UAH 2631/1000 m^3) = UAH 3.16 billion[17]

This figure is about four times lower than total required investment costs (i. e. UAH 12.75). High investment cost of biogas installations is one of the main barriers for their commercialisation in UA as the agricultural sector has a very low level of individual paying capacity (Matveev 2009; Oliynyk pers.comm. 2009). Also biogas installations are occasionally represented with bigger co-generation units, which require quite high demand for heat and electricity. The latter is not always feasible to achieve in rural areas in the country (Oliynyk pers.comm. 2009). Another problem is that natural gas tariffs in Ukraine for private

[16] UAH 12.75 billion = EUR 1.3 billion = USD 1.5 billion (EUR 1 = UAH 9.78; USD 1 = UAH 8.4 as of 1 June 2010)
[17] UAH 3.16 billion = EUR 323 million = USD 376 million (EUR 1 = UAH 9.78; USD 1 = UAH 8.4 as of 1 June 2010)

users and communal services are still lower than those for industrial users (Geletukha & Zhelezna 2010a; NERCU 2010b). Hence there is no economic incentive for the population and communal services to switch from natural gas to biogas.

Internal market for solid densified biofuels (i.e. pellets and briquettes from wood and straw) is not established in Ukraine, and about 90% of those are exported to Europe (Geletukha & Zhelezna 2010a). This is linked to high costs of dedicated boilers for these fuels, and also relatively high costs of the fuel per se (Table 4-1). Until the natural gas tariffs for the population and public utility sector remain at the current level, these fuels cannot compete with natural gas inside the country.

Considering all agro-biomass options baled straw is among the cheapest for energy production and use (at least on small scale) (Table 4-1) (Geletukha & Zhelezna 2010a; Geletukha & Zhelezna 2010b; Grynyuk 2009; Oliynyk pers.comm. 2009). For the farms that have their own straw resources a straw-fired boiler payback is about 1-2 years while for those farms that purchase it the price of USD 26-33 per tonne it is about 3 years (Geletukha & Zhelezna 2010b; Grynyuk 2009).

4.3.4 External market potential for bioenergy commercialisation

Solid agricultural and wood biomass is a bulky material, and thus its transportation is economically feasible within a radius of 50 km (Geletukha & Zhelezna 2010b; A. Gray pers.comm. 2009; Holst pers.comm. 2009; Oliynyk *et al.* 2007). However, pelletised or briquetted biomass could be transported for larger distances.

Currently the main share of pellets produced in the country is exported (Geletukha & Dolinsky 2009; Geletukha & Zhelezna 2010b). 200 000 tones of pellets were produced in Ukraine in 2008, out of which wood pellets constituted 65 000 tonnes (Geletukha and Dolinsky 2009). For 2009 and 2010 the total annual production of biomass pellets was forecasted at 240 000 and 300 000 tonnes respectively (Geletukha and Dolinsky 2009).

No studies were found on the forecasts regarding potential external markets for Ukrainian biomass pellet commercialisation. However, it is known that the main interest in purchasing wood pellets from UA was demonstrated by Sweden, Denmark and Italy while for straw pellets and briquettes the main potential external market can be found in Poland (Geletukha 2008). Also Ukraine is viewed by Danish experts as one of the promising leaders in straw pellet supply to European markets (Hinge 2009; Sander & Skøtt 2007). Potential problems with the export of densified biofuels are linked to the interest of international buyers in large amounts of product (i.e. 100-500 000 tonnes per year), which can hardly be supplied by current small producers (Geletukha & Zhelezna 2010b).

As for the first generation liquid biofuels, Ukraine is the second important exporter of rapeseed in the world (Listopad 2009). Among all countries Germany has demonstrated the biggest interest in purchasing rape seeds from Ukraine (Geletukha 2008). However, this option is out of the scope for this study and thus will not be discussed here.

If electricity production from biomass starts to take place on large scale and will be supplied to the national electricity grid, there will be a potential for its exports. However, currently the share of electricity production from biomass is so low (includes only the power from newly installed biogas CHP units and two co-generation plants on agro-biomass) that the discussion of its external market potential remains highly uncertain.

4.4 General requirements to start bioenergy production

4.4.1 Investments

Some bioenergy options like the installation of biomass-fired boilers for heat production in the areas with available biomass resources have already proven to be competitive even in the case of foreign equipment application (Geletukha *et al.* 2008; IER 2007). Capital investment costs for wood and peat-fired boilers in UA were estimated at USD 80-100 per kW, and at USD 130-150 per kW for straw-fired boilers (Geletukha *et al.* 2008). As it was mentioned, in order to realise the introduction of 8180 MW biomass and peat-fired boilers in UA by 2015 a total investment of about EUR 580 million will be required (Sub-section 4.3.3) (Geletukha & Zhelezna 2010b).

The total investment cost to implement a strategy for biogas plants in Ukraine is estimated at EUR 1.3 billion (Sub-section 4.3.3) (Geletukha & Zhelezna 2010b). The investment cost of the first in Ukraine biogas installation in the village of Yelenivka, Dnipropetrovsk province, was USD 400 000. This installation collects manure from 15 000 pigs and produces 3300 m^3 of biogas per day (Kucheruk *et al.* 2007). Overall one of the main barriers to biogas technology implementation is its high investment cost, which can be cut down to 30% by developing the project as a JI activity (Matveev 2009). Also the economic attractiveness of biogas installations is likely to increase with the Law *On Green Electricity Tariff*.

Georgiy Geletukha, the Director of SEC Biomass, assesses the current level of investment base development for bioenergy projects in UA at 10% from the needed level (Geletukha & Dolinsky 2009). He also assigns 50% to the level of legislation development in the area of bioenergy, 60% to information provision and 20% to the management of bioenergy issues (Geletukha & Dolinsky 2009).

4.4.2 Technology

There are about ten Ukrainian wood- and peat-fired boiler manufacturers, the most well-known of which include Closed Joint Stock Company (CJSC) "Zhytomyremharchomash", LLC "Royek-Lviv", LLC "Volyn-Kalvis", and LLC "Ekoenergokharkiv" (Geletukha & Zhelezna 2010b).

Straw combustion technology in Ukraine is represented with a few companies that produce straw-fired boilers and their parts, heat generators and grain-drying units that use straw and/or other crop residues as a fuel. The biggest straw-fired boiler manufacturer and the only one that produces water-based straw-fired boilers with the capacity of up to 1 MW that can be used for the heating of premises and hot water supply is OJSC UTEM (Svintsitskiy pers.comm. 2009; UTEM 2009a). The company produces boilers under the license of Danish company Passat Energi A/S; it also provides design works, arranges heat works and service maintenance (UTEM 2009a). Detailed information about 23 installed UTEM boilers in Ukraine is provided in Table 6-1. UTEM has also sold more than 75 of its boilers to the EU countries (UTEM 2009b).

SEC “Biomass” is also involved in research and development of straw-fired heat generators (SEC Biomass 2009). The company has developed three straw-fired installations so far. A 350 kW boiler was produced by OJSC AK “SATER”, which is Ustinovsk branch of “Sahenergoservis” company, and was installed in the village of Stavy, Kagarlyk region, Kyiv province (see Annex VII, case study 6 for details) (SEC Biomass 2009). Also a 250 kW straw-fired heat generator was developed by SEC “Biomass”, produced by OJSC “Umanfermmash” and will be installed at LLC “Dan-Farm Ukraine” in the village of Khalcha, Kagarlyk region, Kyiv province (SEC Biomass 2009). A 100 kW straw-fired heat generator was developed by SEC “Biomass” and produced by GP “703 Metal Processing Plant of Boiler Equipment” to be installed at the agricultural enterprise “Nina” in the village of Zhukovsti, Obukhiv region, Kyiv province (SEC Biomass 2009).

OJSC “Bryg” is one of the few companies that produces biomass-fired heat generators and grain-drying units working on biomass. Their products include grain dryers with the grain drying capacities of 2.5, 8 and 16 tonnes of grain per hour (OJSC "Bryg" 2010). Each of the grain drying units includes a biomass-fired heat generator from 200 to 500 kW, which can be fired with baled straw or wood logs (Kuzmin pers.comm. 2010; OJSC "Bryg" 2010). Currently about 20 of OJSC “Bryg” products are installed in UA (Kuzmin pers.comm. 2010).

There are also a few manufacturers of heat generators and boilers fired with a mixture of solid fuels. For example, a private enterprise “Retra” produces Retra-3M boilers in the capacity range of 22-1000 kW, which can use mixed fuels including coal, peat briquettes, pellets, sawdust, wood in pieces, brushwood, straw, waste paper, etc (RETRA 2009). Also TM “Ukrsetka” produces 20-40 kW biomass boilers that can use straw with moisture content up to 20%, wood logs and chips, briquettes, sunflower husk, etc (TM "Ukrsetka" 2008).

Another company that produces water- and air-based heat generators in the capacity range between 100 kW and 2 MW is NVT "Technology", which is located in the city of Chernihiv, Ukraine (Toropets pers.comm. 2009). Up to 30 heat generators fired with fuel mixtures, i.e. sawdust, sunflower husk, weed, ambrosia residues, straw, etc., were installed in UA (Toropets pers.comm. 2009). The company manufactures three main products, i.e. a burner (heat generator) ТПГ-100, a water-based heat exchanger ВДТ-100 and an air-based heat exchanger ВОТ-20000 (NVT "Technology" 2009).

Technological barriers are in the first instance linked to the lack of know-how and infrastructure access by Ukrainian producers and biomass consumers. Some bioenergy installations (e. g. biogas digesters, landfill gas collection systems) are functioning only as demonstration projects that were done with substantial international assistance. Ukrainian boiler market is currently missing cheap domestic biomass-fired boilers (Geletukha & Zhelezna 2010b). The cost of boilers offered in the market is about UAH 3000[18] per kW, which makes them almost unaffordable to the majority of consumers (Geletukha & Zhelezna 2010b).

The following bioenergy equipment is missing in Ukrainian market today (Dolinski & Geletukha 2006; Geletukha & Zhelezna 2010a):

- locally produced biomass boilers of more than 2 MW capacity;
- locally produced steam biomass boilers;
- commercially proved local technologies for biogas production from manure;
- "cheap" domestic biomass-fired boilers of 10-50 kW (including those for pellets).

Another problem identified by Geletukha *et al.* (2000) lies in crop handling techniques used by Ukrainian farmers. For example, the traditional system in UA is not used to apply straw baling. Instead collected straw is chaffed and stored in the field in stacks. This complicates transportation and further combustion in dedicated straw-fired boilers. In the demonstration

[18] UAH 3000 = EUR 306.7 (EUR 1 = UAH 9.78 as of 1 June 2010)

project in Drozdy, Bila Tserkva region, Kyiv province (Annex VII, case study 9), Danish experts along with the installation of a straw-fired boiler also introduced a straw baling technology, which was one of the success factors for the project (Hinge & Geletukha 2002). Nowadays more and more Ukrainian agricultural enterprises apply straw baling (see the description of Ukrainian straw-to-energy practices in Chapter 6 and Annex VII).

4.4.3 Knowledge

Sound knowledge base is needed for the development of all agro-biomass options in Ukraine. Lack of knowledge, expertise and awareness were recognised by experts and entrepreneurs dealing with bioenergy among key barriers constraining biomass business start up (Butenko pers.comm. 2009; Geletukha 2000; Geletukha & Dolinsky 2009; Severyn pers.comm. 2009). Previous work (Voytenko *et al.* 2009; Voytenko *et al.* 2010) revealed that foreign support was important in terms of knowledge and technology transfer as it could help building up experience and creating opportunities for external funding of bioenergy projects. With the help of different research institutions, NGOs and companies more information on bioenergy issues becomes available in Ukraine. SEC Biomass conducts international conferences on Energy from Biomass regularly and is involved in a number of other events (i.e. educational workshops, seminars, forums, etc.) that are aimed at bioenergy promotion and knowledge built up (SEC Biomass 2009). The consulting edition Fuel Alternative also organises regular events in the area including annual international conferences on Alternative Fuel, investment seminars, forums, etc. However, there are still a lot of actions that need to be taken in order to increase the awareness of bioenergy options in UA.

4.4.4 Logistics

The key components of an agro-biomass supply chain include crop growing and harvesting, biomass feedstock collection, transportation to the plant or central storage, moving from central storage to a boiler and combustion or digestion (in case of biogas installations) with the production of heat and/or electricity.

Depending on biomass feedstock some parts of the supply chain can differ. For example, a straw supply chain may also include straw drying (turning straw in wet seasons), baling, moving from the field (to the edge of the field or to storage houses), additional storing in the field as open storage or covered with plastic wrap or storing in specially designated barns (Sub-section 2.4.3) (Hinge 2009; Skøtt & Hansen 2000a; Steineck pers.comm. 2009).

For perennial grasses (e. g., miscanthus, hemp, switchgrass, etc.) the supply chain is very similar to that of straw with the only difference that additional care should be taken of the energy crop plantation itself (e. g., choosing a land plot, planting the crop, supplying it with water and nutrients, etc.) (A. Gray pers.comm. 2009; Göransson pers.comm. 2009). The harvesting takes place every spring with the use of conventional agricultural equipment. Typical crop rotation is 10-15 years (Oliynyk *et al.* 2007).

For short rotation coppice crop (SRC) plantations such as willow or poplar the supply chain is very close to the one of wood chips, which includes wood cutting, primary transportation, clearing of branches and bark, wood chopping, and secondary transportation of wood chips (Oliynyk *et al.* 2007). Modern equipment allows producing wood chips in the field when a chopper is linked to a harvester, and a tractor carries already chopped material from the field to the storage or plant (Larsson pers.comm. 2008). Coppice crops are harvested every 3-6 years during 25-30 years (Oliynyk *et al.* 2007). When the material is combusted, the boilers are adjusted so that the optimal moisture content in the wood is 50% (normal forest wood has a moisture content of 45-50%) (Larsson pers.comm. 2008; Oliynyk *et al.* 2007).

In many cases in order to ensure the efficient organisation of biomass supply chain and security of fuel supply the contracts between feedstock producers and buyers are put forward (Sub-section 2.4.3) (Geletukha & Zhelezna 2010a; Hinge 2009). Contractual forms vary depending on the contract durability, types of parties undersigned (i.e. individuals or organisations), variety of conditions regulated, etc. Discussion about desirable contractual forms of straw supply for energy in Ukraine will be discussed in Chapter 6.

4.5 Trends and drivers related to bioenergy production

A number of trends that created conditions for bioenergy production in Ukraine in the last few years were identified by Geletukha (2008). The first and the most important trend, which was discussed in Section 4.1, is the continuous increase in prices for natural gas that is imported from Russia. In addition, the competition for Russian and Middle Eastern natural gas from China, the EU and Russian consumers could increase the risks for Ukraine's energy security of supply (Geletukha 2008).

On the other hand, the interest towards bioenergy options in UA from the side of the government, industry, business, agricultural sector and foreign investors is growing (Geletukha 2008). As it can be seen from Section 4.2, a number of laws and policies to support bioenergy production and use were accepted in Ukraine during the last year. These documents not only declare bioenergy development to be one of the country's priorities for energy source diversification but also establish concrete economic incentives for such development.

As for businesses and agricultural sector, more and more examples of transition towards bioenergy systems appear in Ukrainian setting. For example, within the last year (2009) two new biogas co-generation units were installed in the country (Matveev 2009). The number of functioning straw-fired boilers in rural areas of UA has grown from 9 in 2008 to 23 in 2009 (Geletukha 2008; UTEM 2009b). In addition, the factor of growing foreign interest in biofuel imports from Ukraine is defined as another incentive for biomass development (Geletukha 2007).

A separate area of international opportunities for the development of Ukrainian bioenergy projects is offered by JI mechanism of Kyoto Protocol. JI projects are beneficial both in economic and environmental sense. Their number is growing in Ukraine (Kramar 2009; Voytenko *et al.* 2010). The attraction of foreign investors within the JI projects is not only financially profitable but also provides access to new knowledge, modern technologies and contributes to the creation of an improved country image.

Ukraine has also favourable natural conditions for bioenergy development. As it was already mentioned, vast areas of arable land - almost 5000 ha - remain unutilised in the country today (Geletukha & Dolinsky 2009). High harvests in the last years have led to relatively low prices for agricultural crops and the abundance of cheap crop residues (e. g., straw, husk, stems, etc.) (Geletukha 2008).

Ukraine is also characterised by growing unemployment rate and high level of immigration with about five million of Ukrainians working abroad (Geletukha 2008). The development of biomass options could contribute positively to local employment. In rural areas such development can also benefit from relatively inexpensive workforce (i. e., a monthly salary of an average worker is not higher than USD 500) (Geletukha 2008).

Having analysed the general trends related to bioenergy production in Ukraine, a number of drivers for bioenergy can be outlined. These include:

- energy security and economic flexibility;
- policy targets and established economic incentives;
- business opportunities within and outside the country;
- contribution to rural development and employment creation;
- large potentials for land and crop residues;
- reduced negative environmental impacts.

5 Agro-bioenergy experience in Western Europe

Chapter 5 looks into specific examples of straw use for energy in Western Europe (WE) including Sweden (SE), Denmark (DK) and Spain (ES). Section 5.1 describes the background of straw production for energy in each of the countries. Section 5.2 aggregates the description of existing practices from 14 case studies (a detailed presentation of narratives is given in Annex VI) and identifies the components of each case specific agro-biomass framework (ABF) via data structuring in line with the conceptual framework. Section 5.3 presents the analysis of the behaviour of farmer entrepreneurs involved in cases under the study.

5.1 Local context of straw use for energy

5.1.1 Sweden

Swedish straw market is incipient, and straw use for energy is rather limited in Sweden (Hinge 2009). While the potential is estimated at one million tonnes of straw per year only about 100 000 tonnes are used for energy in Sweden today (Hinge 2009).

The major initiatives in this field have emerged in the southern province of Scania (Skåne). A significant driver for this emergence, albeit with delay, has been the 1991 carbon tax introduced on fossil fuels (B. Johansson 2000; Sterner 1994; Sterner & Löwgren 1994). Non-industrial users are motivated to substitute the use of fossil fuels for heating as they are obliged to pay both a general energy tax (SEK 0.59/litre for heating oil and SEK 3.30/litre for petrol), and a full price of carbon tax (SEK 0.37/kg and SEK 0.86/litre for petrol[19]) (B. Johansson 2000; Brännlund & Kriström 1997). A continuous increase in the use of biomass in Swedish DH system is attributed to the introduction of the carbon tax (B. Johansson 2000). Although this increase was until recent years predominantly observed for forestry biomass, the main bioenergy source in Sweden (B. Johansson 2000), the reformed in 1991

[19] SEK 0.59 = EUR 0.06; SEK 3.30 = EUR 0.34; SEK 0.37 = EUR 0.04; SEK 0.86 = EUR 0.09 (EUR 1 = SEK 9.76 as of 7 May 2010)

energy taxation system has also had implications for the expansion of straw use for energy in Scania - the major grain producing area in Sweden and a particularly rich one in straw resources (Ottosson pers.comm. 2009; Skovsted pers.comm. 2009; Steineck pers.comm. 2009).

The total area under cereal crops in Scania is almost 236 000 ha, some 52 % of total arable land in the region (SCB 2007). Studies of the straw volumes and market potential in the region estimate the potential of straw for energy to be in the range of 200 000 (Mattsson 2006) to 400 000 (Ottosson pers.comm. 2009; Simmons 2008) tonnes per year. It is estimated that current annual straw use in individual boilers is 50-70 000 tonnes (Mattsson 2006; Simmons 2008). Generally the surplus is chopped and left on the surface or ploughed back to the soil (Simmons 2008). If the levels of straw extraction were kept in the range of 22-50% (Blanco-Canqui & Lal 2009; Lemke *et al.* 2009), the annual surplus of straw available in the region would be in the order of 65 000-273 000 tonnes.

At present it is considered that the straw market is not established in Scania. This said, it is considered that mainstream establishment will be achieved by the construction of a 45 MW straw-fired boiler in the Örtofta CHP plant near Lund. This is planned to be commissioned by the utility Lunds Energi (Lund's Energy) somewhere between 2011-2013 (Ottosson pers.comm. 2009; Simmons 2008; Steineck pers.comm. 2009). The annual straw requirement by the plant will be 80 000 tonnes (Simmons 2008). This demand exceeds the indicative lower bound margin of straw availability (i.e. 22%) in the region.

Currently there exist only two dedicated straw-fired boilers for district heat in Scania; a 5 MW DH plant in the town of Skurup and a 1 MW unit close to the city of Trelleborg (Ottosson pers.comm. 2009; Steineck pers.comm. 2009). A 6 MW straw-fired DH plant was functioning in Svalöv from 1985 till 2008 (Leire pers.comm. 2009) but this unit was closed when purchased by E-On, which substituted the straw-fired boiler with the wood-fired one. In addition to these, a 1.5 MW straw-fired boiler at the Svenstorp estate near Lund provides heating and hot water for the farm premises and manor house and also sells heat to Lunds

Energi for DH in Lund and Eslöv during the heating season (Skovsted pers.comm. 2009). There are also many single farmers in Scania who burn straw for the heating needs on their farms (Simmons 2008).

This work includes all mentioned cases and three smaller straw-fired installations on private farms (Annex III).

5.1.2 Denmark

In Denmark the straw market has nearly 30 years of experience and is mature. About 26% of straw production in the country is used for energy, 41% is ploughed back to the soil, 19% is used for animal feed and 14% - for bedding (Sander & Skøtt 2007). It is estimated (Sander & Skøtt 2007) that about 55 PJ of energy can be supplied from straw in Denmark while only 18 PJ (or 33% of this) is currently used.

Straw is combusted at a range of scales and for different end-uses. Currently up to 1.5 million tonnes of straw is used for energy per year including 0.65 million tonnes in local DH plants and boilers on the farms and 0.9 million tonnes at large CHP installations (Holst pers.comm. 2007). First farm scale straw-fired boilers in Denmark appeared in 1970s, DH plants - in the early 1980s and large CHP plants – in the beginning of 1990s (Holst pers.comm. 2007). Straw-based co-generation had been an unknown phenomenon before the construction of first plants in the country (Sander & Skøtt 2007).

The first subsidy schemes supporting biomass use in Denmark were introduced in 1980s (Nikolaisen *et al.* 998). A serious straw-for-energy expansion started in 1993 when a target to increase the use of straw for electricity production to 1.2 million tonnes by 2000 was set by Danish government and parliament (Hinge 2009). This agreement was revised several times. In 2002 the Danish Parliament accepted a total annual consumption of 930 000 tonnes of straw by large-scale energy installations (i.e. 700 000 tonnes by central power plants and 230 000 tonnes by CHP plants) as the final target in Danish Biomass Agreement (DBA)

(Hinge 2009). This was expected to be achieved in 2009 with the start up of Fynsværket and Amagerværket power plants (Hinge 2009; Sander & Skøtt 2007).

In addition, an exemption from fossil fuel taxes for heat from biomass, subsidy schemes for the construction of straw-fired boilers in the areas without DH supply and decentralised CHP plants, and "green tariffs" created incentives for the transition towards straw (Hinge 2009; Nikolaisen *et al.* 1998; Skøtt & Hansen 2000a). "Green tariffs" guaranteed a price for power generation companies of DKK 0.30/kWh for electricity from biomass for at least 10 years and additional DKK 100 per tonne of biomass combusted. Later the "green tariff" was changed to DKK 0.10/kWh[20] subsidy added to the baseline price for electricity (Hinge 2009).

In Denmark an important role in the promotion of straw use for energy and the establishment of straw market is attributed to agricultural organisations and Danish Straw Supply Association (DSSA – Danske Halmleverandører) (Hinge 2009; Hinge pers.comm. 2010). The history of farmers' organisation for straw supply dates back to 1980s when first DH plants were launched in the country (Hinge pers.comm. 2010). At that time farmers united their efforts in local straw supply associations to negotiate fuel prices with DH plants, establish platforms for securing the best straw quality and its timely delivery (Hinge pers.comm. 2010).

Later with the acceptance of Danish Biomass Agreement (DBA) local associations united in a national one – DSSA (Hinge pers.comm. 2010). DSSA put pressure on politicians to stimulate electricity companies, who demonstrated a certain degree of reluctance at the beginning of 1990s, implement DBA (Hinge pers.comm. 2010). DSSA also managed to push its "codes of conduct" on straw price establishment with electricity companies (Hinge 2009). These among other things resulted in farmers setting their straw price offers for power companies and demonstrating that sufficient amounts of straw were available for the completion of the agreement (Hinge 2009). DSSA was also responsible for the establishment of basic criteria for straw supply tenders with electricity companies (Hinge 2009).

Danish government also continuously promotes and supports research and development in the field of bioenergy, and information disclosure on straw opportunities among farmers and other parties (Hinge 2009).

In 1997 there were about 10 000 straw-fired boilers on farms, and in the period of 1980-1999 65 straw-fired DH plants were commissioned in Denmark (Nikolaisen *et al.* 1998). 12 CHP plants that use straw as the main or blended fuel are operated around the country (Sander & Skøtt 2007). All existing power and CHP plants are owned by two companies – DONG Energy and Vattenfall (Hinge 2009; Sander & Skøtt 2007).

This work analyses four initiatives of neighbour/district heating in DK and one case of a large scale straw use for energy (Annex III).

5.1.3 Spain

In Spain there are examples of medium and large scale straw-fired installations in operation, however, straw market is not as developed and mature as it is in Denmark (Acciona Energía 2009d; BioPlat 2009). The study on the diffusion challenges for electricity from biomass in Spain (Dinica 2009) concludes that the absence of markets for the supply of biomass resources is one of the major obstacles preventing the diffusion and expansion of power production from biomass in the country.

Currently about 177.6 PJ of energy in Spain is supplied from biomass (IDAE 2007). Total annual biomass potential is estimated at 809.4 PJ (i.e. 14.4% of the country's TPES) (Dinica 2009). Of this the major share (40.7%) is constituted by crop residues from agriculture (329.1 PJ) (Dinica 2009). A GIS-based assessment of potential energy production from cereal straw in the EU suggests that at least five 38 MW straw-fired power plants can be located in Spain (Edwards *et al.* 2005).

Spain has been one of the countries in the European Union (EU) with the highest dependency on imported energy sources (Fernandez 2009; IDAE 2007). Currently energy

[20] DKK 0.30 = EUR 0.04; DKK 100 = EUR 13.44; DKK 0.10 = EUR 0.013 (1 EUR = DKK 7.44 as of 10 May 2010)

imports account for about 78% of total primary energy supply (TPES) in the country (up to 80% are derived from fossil fuels) (Fernandez 2009). This figure is forecasted to grow to 85%, if the existing trends in energy production and consumption prevail (Fernandez 2009).

Already in 1970s energy policy of ES identified energy source diversification and energy saving among its priority areas, and energy from biomass first gained its support in the Energy Conservation Law in 1980 (Dinica 2009). 'Feed-in-tariff' laws were gradually modified from 1994 till 2007 creating favourable price differentiations for electricity from biomass (Dinica 2009). In 2005 a new Renewable Energy Plan (REP) (Artigas 2009; IDAE 2007) was introduced in ES, which put the goal on RES to constitute 12% in Spanish TPES in 2010 (or additional 419 PJ) with biomass accounting for 60% of this figure (BioPlat 2009). However, now the objectives of REP are far from being achieved (BioPlat 2009; Dinica 2009; IDAE 2007). The 661/2007 Royal Decree lowered the overoptimistic target on electricity production from biomass in Spain from 3100 MW to 1567 MW for 2011 (in 2007 it constituted 525 MW or only about 1.1% of total power generation in the country) (Dinica 2009).

The use of agricultural residues for energy is among more advanced and established bioenergy options in Spain (IDAE 2007). Acciona Energía has launched three power plants fired with straw including one of the biggest (25 MW) and most advanced straw-fired power plants in Europe located in Sangüesa, the region of Navarra (Acciona Energía 2009b; Acciona Energía 2009c; Acciona Energía 2009a; Acciona Energía 2009d; Lerga pers.comm. 2009). Acciona Energía plans to increase electricity production by constructing seven more straw-fired plants all over the country (Acciona Energía 2009d). The case of Sangüesa power plant is analysed in this work.

5.2 Agro-biomass frameworks for organisation and action

Section 5.2 describes existing practices of straw use for energy in Sweden, Denmark and Spain. It aggregates information from 14 case studies carried out in these countries.

Section 5.2 is divided into three sub-sections according to the scale of agro-biomass use by the actors (i. e. small, medium and large). Two categories of energy end-use are identified on medium scale, i. e. energy production from straw on the farm with the sale of excess heat (Sub-section 5.2.2.1) and straw use for district heating (Sub-section 5.2.2.2). Section 5.2 conceptualises and structures all case studies in ABFs for organisation and action in line with the conceptual framework developed in this study (Table 3-4, Sub-section 3.4.1). Detailed case study narratives are provided in Annex VI.

5.2.1 Agro-biomass use on small scale

Three Swedish case studies constitute this category, i. e. Pugerup, Falkenberg and Nöbbelöv. ABFs for each of those cases are provided in Tables 5-1, 5-2 and 5-3 respectively. Detailed case study descriptions can be found in Annex VI.

Straw-fired installations within this category are of small scale and are located on a private grain producing farm that also generates significant amounts of straw and has substantial heating needs. Although here only Swedish cases are presented, such initiatives are quite common both in Sweden and Denmark (Skøtt & Hansen 2000a; Hinge 2009; Nikolaisen *et al.* 1998; Treschow pers.comm. 2009; Weden pers.comm. 2009).

Figure 5-1. 600 kW straw-fired boiler in Pugerup estate, Eslöv, Sweden

Farmers obtain heat from their own straw-fired boilers (normally not bigger than 600 kW) (Fig. 5-1) installed on the farms at their own expense. All farms produce grain crops (e. g., wheat, barley, oat, rapeseed, etc.) and hence generate sufficient amounts of straw to satisfy their heating and other needs.

Table 5-1. Agro-biomass based framework of Pugerup case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Farmers
		Straw handlers	Hired sub-contractors who bale straw
		Second-hand users of straw for energy	Farm managers in a grain dryer
			Farm managers in a pig breeding facility on the farm
			People in residential houses on the farm
			People in administrative buildings on the farm
		Competitive users of straw	Farm managers for pig bedding
			Farm managers for soil fertilisation
	Indirectly involved in biomass chain		Lunds Energikoncernen as a potential buyer of straw
Natural resources	*Biomass feedstock*	*Types of feedstock*	Straw (mainly from winter wheat)
			Wood residues from trees damaged in storms
		Feedstock origin	Domestic
		Markets for feedstock	No
			Potential sale to Örtofta CHP
		Feedstock transformation pathways	Rectangular straw bales of 500 kg
			Fuel mixtures of wood residues, wood chips and straw
			Biogas production planned from pig manure
	Other	*Land*	Agricultural land of 1100 ha
		Forest	Native
Technical components	*Infrastructure*	*Machinery and equipment*	Own loaders, trucks and tractors
			Rented bailers
			A grain dryer
			A covered storage for wood and straw
		Conversion facilities	A 600kW straw-fired boiler constructed in 2003
			Located in the near area from the fuel source
	Technology	*Conversion pathways*	Combustion
			Co-firing of straw and wood residues
		End-use of energy from biomass	Heating and hot water supply
"Soft" (non-technical) components	*Institutions*	*Economy*	Savings from oil substitution
	Co-benefits	*Energy security/insecurity*	Reduction of dependence on oil
		Rural development/impoverishment	Straw residues valorisation

Excess straw is ploughed back into the soil (Göransson pers.comm. 2009; Treschow pers.comm. 2009; Weden pers.comm. 2009), sold for animal bedding (Treschow pers.comm. 2009) or planned to be sold for energy (Weden pers.comm. 2009). The heat distribution network is owned by the farmers. Often a mixture of fuels is used in a boiler, when straw is supplemented with wood chips or other biomass residues.

Table 5-2. Agro-biomass based framework of Falkenberg case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	A farmer who owns the farm
		Straw handlers	A farmer who lets a bailer during the harvesting season
		Second-hand users of energy from biomass	Operators of a grain dryer on the farm
			People in 8 residential houses on the farm
			Operators of particular equipment on the farm
		Competitive users of straw	Bull breeding stations
			Farm managers for soil fertilisation
	Indirectly involved in biomass chain		LIN-KA manufacturer
Natural resources	*Biomass feedstock*	*Types of feedstock*	5000 tones of straw from rapeseed, 3500-4000 tones of which is used for energy
		Feedstock origin	Domestic
		Markets for feedstock	No
		Feedstock transformation pathways	Rectangular straw bales of 500 kg
	Other	*Land*	1260 ha of cropland (rapeseed, wheat, barley, oat, triticale, and green beans)
			75 ha of grassland
		Forest	1000 ha of native pine tree forest
Technical components	*Infrastructure*	*Machinery and equipment*	A rented bailer
			A grain dryer
			A covered straw storage
		Conversion facilities	A 600 kW straw-fired boiler installed in 1998
			A distribution network owned by the farmer
			Located in the near area from the fuel source
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating and hot water supply
"Soft" (non-technical) components	*Institutions*	*Economy*	A 3-year payback period of the system due to fuel savings
	Co-benefits	*Energy security/insecurity*	A substitution of 92 m³ of oil every year
		Rural development/impoverishment	Straw residues valorisation
	Knowledge	*Actors' competence*	Experience exchange between the farm manager and farmers, who had similar heating installations before

In Swedish cases all boilers are of Danish manufacture (Göransson pers.comm. 2009; Treschow pers.comm. 2009; Weden pers.comm. 2009). All agricultural machinery and equipment is owned by the farmers while baling services are normally provided by sub-contractors, who own bailers. All farms analysed have their own roofed straw barns next to the boilers but straw can also be stored in the field. The ash from straw burning is recycled to farm fields.

Table 5-3. Agro-biomass based framework of Nöbbelöv case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	A farm owner
			The son of the farm owner
		Straw handlers	A farmer who lets a bailer during the harvesting season
		Hemp handlers	SLU representatives
		Second-hand users of energy from biomass	Operators of a grain dryer on the farm
			People in residential premises on 3 farms
			Farm managers in particular areas on the farm
		Competitive users of straw	Farm managers for soil fertilisation
	Indirectly involved in biomass chain		Danish boiler manufacturer Faust
			Austrian boiler manufacturer HDG Compact
			SLU researchers
Natural resources	*Biomass feedstock*	*Types of feedstock*	80 tonnes of straw (main part is used for energy)
			10 000 tonnes of hemp per year on 1 ha of land
			Wood chips from Lund municipality
		Feedstock origin	Domestic
		Markets for feedstock	No
		Feedstock transformation pathways	Rectangular 200 kg straw and hemp bales
			Wood chips (max size of 50 mm)
	Other	*Land*	80 ha of cropland (barley, sugar beet, wheat)
			1 ha of hemp (trial plantation)
		Water	Waste water use for hemp irrigation (400 m^3 of water per 1 ha of hemp)
Technical components	*Infrastructure*	*Machinery and equipment*	Rented bailers
			A grain dryer
			A combine harvester
			Ploughs
			Fertilising equipment
			Sprayers
			Tractors
			A covered storage for straw and hemp
		Conversion facilities	A 350 kW straw-fired boiler with 20 m^3 hot water accumulator in 1996
			An 80 kW wood-fired boiler with 5 m^3 hot water accumulator in 2008
			A distribution network owned by the farmer
			located within 50 km from feedstock source
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating
			Hot water supply

"Soft" (non-technical) components	*Institutions*	*Economy*	Savings on fuel
			Savings on fertilisers
	Co-benefits	*Energy security/insecurity*	A substitution of 20 m^3 of oil per year
		Rural development/impoverishment	Straw residue valorisation
		Ecological benefits/costs	Waste water treatment
	Knowledge	*Actors' competence*	No special qualifications for hemp cultivation are needed, if one knows how to grow barley and sugar beet

5.2.2 Agro-biomass use on medium scale

5.2.2.1 Sale of excess heat

An aggregated case study of Svenstorp and Björnstorp, Sweden, and the case of Horreby, Denmark constitute this sub-category. ABFs for each of those cases are provided in Tables 5-4 and 5-5 respectively. Detailed case study descriptions can be found in Annex VI.

This group of cases can be characterised by a larger scale of straw production and use as compared to the cases presented in Sub-section 5.2.1. From organisational perspective, however, this group is quite similar to the previous one with some unique parameters.

Figure 5-2. 1 MW straw-fired boiler on Horreby farm, Denmark

A grain production farm with significant heating needs is in the centre of the system (Palle pers.comm. 2010; Skovsted pers.comm. 2009). Since the heat demand is higher (either on the farm or by users in the region), more sophisticated and larger straw-fired boilers are installed (Fig. 5-2). They have a continuous system of fuel loading with embedded straw conveyor belt (Fig. 2-5, Fig. 5-3) and shredders (Fig. 2-6, Fig. 5-3). All hot water is circulating in a pipe system owned by the farmers. Boilers both in Swedish and in Danish case are of Danish manufacture (Palle pers.comm. 2010; Skovsted pers.comm. 2009).

Figure 5-3. A straw conveyor and shredder supplying fuel to the boiler at Svenstorp estate, Scania, Sweden

The specificity from organisational perspective is that the heat produced on the farm is not only used for the farm's own heating needs but its surplus is also sold to local energy users for neighbour or district heating. In Horreby baling of straw is carried out by the farmer who owns a bailer (Fig. 5-4) (Palle pers.comm. 2009) while in the cases of Svenstorp and Björnstorp baling service is purchased from sub-contractors (Skovsted pers.comm. 2009). The ash after straw combustion is returned back to the field on the farm.

Figure 5-4. Bailer, Horreby, Denmark

Table 5-4. Agro-biomass based framework of Svenstorp and Björnstorp cases

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Farm employees (26 people on 2 farms)
		Straw handlers	Sub-contractors who provide baling
		Second-hand users of energy from straw	Residents in both estates (18 buildings and a castle)
			Operators in a grain dryer on the farm
			Farm managers in the equipment that requires heat
			Residents in Lund municipality (DH from Svenstorp)
		Competitive users of straw	Farm managers for soil fertilisation
	Indirectly involved in biomass chain		Lund municipality
			Utility Lund's Energy
			Danish boiler manufacturer LIN-KA
Natural resources	*Biomass feedstock*	*Types of feedstock*	About 1300 tonnes of wheat straw is used for energy annually
		Feedstock origin	Domestic
		Markets for feedstock	No
		Feedstock transformation pathways	Rectangular 500 kg straw bales
	Other	*Land*	Wheat, barley, rapeseed, sugar beets, and grass grown at Svenstorp; 2400 ha in total with Björnstorp
		Forest	Björnstorp is a combined agricultural and forestry company
Technical components	*Infrastructure*	*Machinery and equipment*	Conventional farming equipment owned by the estates
			Two grain dryers
			A straw conveyor belt with a shredder
			Two covered straw storages of 1600 bales each in both estates
		Conversion facilities	A 1.5 MW straw-fired boiler in Svenstorp estate
			A 1.2 MW straw-fired boiler in Björnstorp estate
			A distribution network owned by the estates
			Located in the near area from the fuel source
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating and hot water supply on the farms
			Heating and hot water supply to Lund and Eslöv
"Soft" (non-technical) components	*Institutions*	*Economy*	6.2 years payback due to fuel savings
			Income from heat sales to Lund's Energy
	Co-benefits	*Energy security/insecurity*	A substitution of at least 120 m³ of oil on each farm annually
		Rural development/impoverishment	Straw residue valorisation

Table 5-5. Agro-biomass based framework of Horreby case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Farm manager and plant owner
			Other farmers in Stubbekøbing municipality
		Feedstock handlers	Farm manager
			3 employees
		First-hand users of straw for energy	Farm manager and 3 employees
		Second-hand users of energy from straw	Farm managers in farmhouses and pig breeding facility
			A local school
			2 kindergartens
			50 private houses
		Competitors for biomass use	DH plant in Horbelev
			Dong Energy plants
			Farmers for cattle and pig bedding and fodder
			Farmers for soil fertilisation
	Indirectly involved in biomass chain		Farmer's wife (co-owner)
			Stubbekøbing municipality
			Municipal Housing and Building Agency
			Danish Energy Agency (DEA)
			Danish boiler manufacturer LIN-KA
			A local construction company
			Funding institutions and banks
Natural resources	*Biomass feedstock*	*Types of feedstock*	600-700 tonnes of wheat and rapeseed straw used for energy annually
		Feedstock origin	Domestic
			Purchased from local farmers
		Markets for feedstock	Own use
			Horbelev DH plant
			Dong Energy plants
		Feedstock transformation pathways	500 kg rectangular bales with 11-12% moisture content
	Other	*Land*	340 ha of farmland (i.e. 140 ha wheat, 80 ha barley, 80 ha sugar beet, 20 ha rapeseed, 20 ha grass for seeds)
		Air	Emissions from straw combustion
Technical components	*Infrastructure*	*Machinery and equipment*	A barn next to the boiler-house (2 weeks reserve)
			A barn on the farm in a close proximity to the boiler-house
			Open straw storages in plastic wrap
			A big bailer
			A combine harvester
			Four tractors
			A double-blade straw shredder with a conveyor belt
		Conversion facilities	A 1 MW straw-fired boiler
			A 750 kW oil-fired boiler
			A heat distribution network owned by the farmer
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heat and hot water

"Soft" (non-technical) components	Institutions	*Juridical systems*	A permit from Municipal Housing and Building Agency
		Economy	Total investment cost (i.e. system and grid) - USD 396 000
			Annual operation cost - USD 62 700
			25% subsidy from DEA
			Consumer installations covered from municipal funds
			10 years payback for the boiler, 20 years - for the grid
			Straw sale at EUR 61-67 per tonne
		Social systems	Support from Stubbekøbing municipality
			Support from Horreby residents
	Co-benefits	*Energy security/insecurity*	Substitution of individual oil and electricity heaters
		Rural development/impoverishment	Straw residue valorisation
		Ecological benefits/costs	GHG emission reduction
			Straw specific air emissions (absence of abatement equipment)
	Knowledge	*Actor capacity*	Self learning of boiler operation
			80 hours of free advice from DAE

5.2.2.2 District heating

Swedish case studies of Trelleborg and Löderup, Skurup, and Svalöv and Danish cases of Horbelev, Hunseby, and Stokkemarke constitute this sub-category. ABFs for each of those cases are provided in Tables 5-6, 5-7, 5-8, 5-9, 5-10 and 5-11. Detailed case study descriptions can be found in Annex VI.

All cases within this sub-category have a medium-sized straw-fired boiler, which supplies heat for DH and hot water to the buildings in a village or town. In summer the plants run at 20% capacity and supply only hot water. In SE these are non-residential buildings (e. g., municipal, administrative, industrial premises; schools; fire stations; churches; greenhouses, etc.), which is explained by the fact that in rural areas in SE DH systems are not common, and residential houses are often heated with individual oil-fired stoves or gas heaters (Leire pers.comm. 2009; N. Ekholm pers.comm. 2009; M. Ericsson pers.comm. 2009). In DK a so called 'neighbour heating' (Nikolaisen *et al.*1998) is provided to both residential and non-residential buildings in the villages. In all Danish cases the heat distribution network for residential sector was constructed and is owned by the plant owners (Palle pers.comm. 2010; Sejdenfaden pers.comm. 2010; Rasmusen pers.comm. 2010). All straw-fired boilers in this sub-category are similar to those described in Sub-section 5.2.2.1 and are of Danish manufacture.

Figure 5-5. Straw moisture content measurement at Horbelev neighbour heating plant, Denmark

Straw in these examples is either purchased from the farmers or in two Swedish cases (Tables 5-5 and 5-7) (Ericsson pers.comm. 2009; Leire pers.comm. 2009) obtained for free. Straw is purchased according to written contracts with straw suppliers (Tables 5-6, 5-9 and 5-10) (Ericsson pers.comm. 2009; Palle pers.comm. 2010; Sejdenfaden pers.comm. 2010) or an agreement is made based on mutual trust between a straw buyer and a farmer (Tables 5-8 and 5-11) (Ekholm pers.comm. 2009; Leire pers.comm. 2009; Rasmusen pers.comm. 2010). In most cases straw is delivered to the plant by farmers or sub-contractors, who carry out the baling. Upon the delivery of straw bales their parameters are controlled including the measurements of moisture content (Fig. 5-5). Straw bales are stored in covered storages at DH plants (Fig. 5-6), and can also be left in open storages in the field, where they are often wrapped in plastic foil (Fig. 5-7). At DH plants straw bales are often transported to the conveyor belt (Fig. 5-8) and shredders with special crane lifters (Fig. 5-9). The ash from straw burning is returned back to the field on the farms. Installations that are larger than 1 MW would normally require flue gas abatement equipment (Fig. 5-10).

Figure 5-6. Plant straw storage at Hunseby neighbour heating plant, Denmark

Figure 5-7. Straw storage in the field close to Trelleborg, Scania

The forms of ownership can be different and include privately owned (Ericsson pers.comm. 2009; Rasmusen pers.comm. 2010; Sejdenfaden pers.comm. 2010), municipally owned (Leire pers.comm. 2009) installations or installations owned by farmers' (Ericsson pers.comm. 2009) or people's (Palle pers.comm. 2010) cooperatives. Distribution systems are either owned by the municipality (Ericsson pers.comm. 2009; Leire pers.comm. 2009) or boiler managers (Rasmusen pers.comm. 2010; Sejdenfaden pers.comm. 2010). In all cases municipalities are involved via provision of resources or initiative, and/or required permits for operation, via creation of a need for heat supply, etc.

Figure 5-8. Straw conveyor belts at Stokkemarke neighbour heating plant, Denmark

Figure 5-9. Crane lifting straw bales at Horbelev neighbour heating plant, Denmark

Figure 5-10. Flue gas cleaning and reserve oil boiler at Stokkemarke neighbour heating plant, Denmark

Table 5-6. Agro-biomass based framework of Trelleborg case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Farmers
		Straw handlers	A farm-based entrepreneur who harvests, bales, stores, transports and resells straw
		First-hand users of straw for energy	A manager at *Bal&Bob Cat* in the boiler
		Second-hand users of energy from straw	180 houses in Trelleborg
			A local school in Trelleborg
		Competitive users of straw	Farmers for animal bedding and fodder
			Farmers to cover crops
			Farmers for their heating needs
			Farmers for soil fertilisation
			Skurup DH plant
			Avedøre CHP plant
	Indirectly involved in biomass chain		Trelleborg municipality
			Danish boiler manufacturer LIN-KA
Natural resources	*Biomass feedstock*	*Types of feedstock*	Straw
		Straw origin	Delivered from nearby farms
		Markets for straw	12 farmers for their purposes
			Skurup DH plant
			Avedøre CHP plant (300 tonnes)
		Feedstock transformation pathways	Rectangular 500 kg straw bales (450 tonnes needed annually)
	Other	*Land*	Agricultural land
		Air	Emissions from straw burning
Technical components	*Infrastructure*	*Machinery and equipment*	3 regular bailers
			1 bailer for chopped straw production
			5 tractors
			BobCat bale loader
			Field storages with plastic wrap cover
		Conversion facilities	A 1 MW straw-fired boiler constructed in 2006
			A 3-4 MW straw-fired boiler planned in the same building
			A distribution system for heat and hot water supply
			Located in the near area from the fuel source
	Technology	*Conversion pathways*	Combustion
		End-use of energy from straw	Heating
			Hot water
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	Environmental standards on air emission from straw combustion
		Economy	Savings of SEK 400 per 1 MW of heat from straw as compared to oil
		Social systems	Relationships with straw suppliers based on mutual trust, no contracts
	Co-benefits	*Energy security/insecurity*	Reduction of oil use
		Rural development/impoverishment	Employment at the plant during winter
			Straw residue valorisation
		Ecological benefits/costs	GHG emission reduction
	Knowledge	*Actors' competence*	A farm-based entrepreneur involved in straw business since 1983

Table 5-7. Agro-biomass based framework of Skurup case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Farmers in the proximity to the plant
		Straw handlers	3 sub-contractors
		First-hand users of straw for energy	2 plant managers at Skurup DH plant
		Second-hand users of energy from straw	Municipal buildings in Skurup
		Competitive users of straw	Farmers for animal bedding
			Farmers for fodder
			Farmers for soil fertilisation
	Indirectly involved in biomass chain		Skurup municipality
			Farmer association Lantmännen AB
			Danish boiler manufacturer LIN-KA
Natural resources	*Biomass feedstock*	*Types of feedstock*	Straw
		Feedstock origin	Delivered by sub-contractors from nearby farms
		Feedstock transformation pathways	Rectangular 500 kg straw bales, 12 000 tonnes needed annually
	Other	*Land*	Agricultural lands
		Air	A ban on straw burning in the field resulted in Skurup DH plant construction
Technical components	*Infrastructure*	*Machinery and equipment*	Straw harvesting and baling by subcontractors and their machinery
			Heat exchangers in the buildings
		Conversion facilities	A 5 MW straw-fired DH plant constructed in 1998
			Located in the near area from the fuel source
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	DH and hot water supply
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	A ban on straw burning in the field
		Economy	Cost savings from oil substitution (some straw is obtained for free)
		Social systems	Contracts with 3 sub-contractors on straw handling and delivery
	Co-benefits	*Energy security/insecurity*	Oil substitution
		Rural development/impoverishment	Straw residue valorisation
		Ecological benefits/costs	Reduction of emissions from straw burning in the field
			GHG emission reduction

Table 5-8. Agro-biomass based framework of Svalöv case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	About 50 farmers around Svalöv
		Straw handlers	About 20 hired workers at Svalöv DHP
			Straw resellers
		First-hand users of straw for energy	3 permanent employees at Svalöv DHP
		Second-hand users of energy from biomass	About 1000 municipal buildings in the City of Svalöv
			Industrial buildings (e. g., Svalöv Weibull)
			Business offices
			Greenhouses
		Competitive users of straw	Farmers for animal bedding
			Farmers for soil fertilisation
			Farmers for their heating needs (about 1000-2000 tonnes of straw)
	Indirectly involved in biomass chain		Svalöv municipality
			Scandinavian Technological Engineering company
			Setab company
			Danish plant manufacturer Hollensen A/S
			E.On company
			Governmental authorities
Natural resources	*Biomass feedstock*	*Types of feedstock*	95% of wheat and 5% of rye and rapeseed straw
		Feedstock origin	Delivered from nearby farms
		Feedstock transformation pathways	Rectangular 500 kg straw bales, 7 000 tonnes needed annually
			Wood chips in a renovated plant by E.On
	Other	*Land*	Agricultural lands
Technical components	*Infrastructure*	*Machinery and equipment*	10 Hesston balers
			8 tractors
			A big wagon
			3 conventional loaders
			A big Telescope loader
			A distribution network owned by Svalöv municipality
		Conversion facilities	A 6 MW DH plant constructed in 1985 and put on straw in 1987
			Located within 20 km from the fuel source
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating and hot water
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	Swedish national objective to substitute oil in the country's consumption in 1982-1990
			A target by Svalöv municipality to substitute 2000 m³ of oil (i.e. to reduce oil consumption in municipal buildings by 50%)
		Social systems	No contracts on straw delivery, all based on mutual trust
	Co-benefits	*Energy security/insecurity*	Reduction of oil consumption
			Energy source diversification
		Rural development/impoverishment	Job creation: 20 additional work places during harvesting
			Straw residue valorisation
		Ecological benefits/costs	GHG emission reduction
	Knowledge	*Actors' competence*	Former plant manager has more than 30 years of experience in straw combustion

Table 5-9. Agro-biomass based framework of Horbelev case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Five farmers in the plant neighbourhood
		Feedstock handlers	Farmers
			Sub-contractors
		First-hand users of straw for energy	A boiler operator
		Second-hand users of energy from straw	205 private houses in Horbelev
		Competitors for biomass use	DH plant in Horreby
			Dong Energy plants
			Farmers for their needs
			Farmers for soil fertilisation
	Indirectly involved in biomass chain		Citizens in Horbelev
			Local municipality
			Chairman of the village council
			Danish boiler manufacturer Weiss A/S
			Local construction companies
			Bank (as a loan provider)
Natural resources	*Biomass feedstock*	*Types of feedstock*	1600 tonnes of wheat and barley straw burnt annually
			Wood pellets (burnt in the past)
		Feedstock origin	Purchased from local farmers
		Markets for feedstock	Domestic
		Feedstock transformation pathways	500-600 kg rectangular bales with optimal 11.5% of moisture
	Other	*Land*	Agricultural land managed by straw suppliers
		Air	Emissions reduced with abatement equipment
Technical components	*Infrastructure*	*Machinery and equipment*	Straw handling done by sub-contractors and their machinery
			Open straw storages and barns owned by suppliers
			A barn at the plant for 70 tonnes of straw
			A crane
			A straw shredder with a conveyor belt
			A bottom ash separator
			Air emissions abatement system (bag filters)
		Conversion facilities	A 1.6 MW straw-fired boiler
			A 550 m³ hot water accumulator
			A heat distribution network owned by local municipality
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heat and hot water
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	No certificates required for the boiler operation
		Economy	Total investment cost (1986) – USD 1 250 000
			Investment in a new boiler (2004) – EUR 603 000
			10 years payback for the boiler, 20 years - for the network
			Annual fee of EUR 67 per person for the boiler operation
			Annual savings of EUR 400-940 for the citizens from fuel switch
		Social systems	Support from local municipality
			Support from Horbelev residents
			Written contracts with straw suppliers
	Co-benefits	*Energy security/insecurity*	Substitution of individual oil and electricity heaters
		Rural development/impoverishment	Straw residue valorisation
		Ecological benefits/costs	GHG emission reduction

Table 5-10. Agro-biomass based framework of Hunseby case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	A plant owner
		Feedstock handlers	A plant owner
		First-hand users of straw for energy	Boiler operators
		Second-hand users of energy from straw	150 private houses in Hunseby
			A local school
			A kindergarten
		Competitors for biomass use	Plant manager for straw sale
			Dong Energy plants
	Indirectly involved in biomass chain		Citizens in Horbelev
			Local municipality
			Danish boiler manufacturer LIN-KA
			A neighbour who owns a straw bailer
Natural resources	*Biomass feedstock*	*Types of feedstock*	1400 tonnes of wheat straw burnt annually
		Feedstock origin	Own straw
		Markets for feedstock	100 tonnes of straw sold locally
		Feedstock transformation pathways	500-600 kg rectangular bales
	Other	*Land*	500 ha of farmland (wheat, barley, rapeseed, sugar beets) owned by the plant manager
		Soil	No straw is ploughed back
		Air	Emissions from straw combustion
Technical components	*Infrastructure*	*Machinery and equipment*	A bailer rented from a neighbour
			A barn on the farm
			A barn at the plant
			A three-blade straw shredder with a conveyor belt
			A bottom ash separator
		Conversion facilities	A 1 MW straw-fired boiler
			A 1 MW oil-fired boiler
			A heat distribution network owned by the farmer
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heat and hot water
"Soft" (non-technical) components	*Institutions*	*Economy*	Total investment cost (boiler and grid) – EUR 1 280 000
			13 years expected payback
		Social systems	Support from local municipality
			Support from Hunseby residents
	Co-benefits	*Energy security/insecurity*	Substitution of individual oil and electricity heaters
		Rural development/impoverishment	Straw residue valorisation
		Ecological benefits/costs	GHG emission reduction

Table 5-11. Agro-biomass based framework of Stokkemarke case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	A plant owner
			7-8 farmers in the plant neighbourhood
		Feedstock handlers	A plant owner
		First-hand users of straw for energy	A plant owner
			A boiler operator
		Second-hand users of energy from straw	145 private houses in Stokkemarke
			A local school
			A church
			An elderly people's home
		Competitors for biomass use	A local turkey farm
			Farmers for their needs
	Indirectly involved in biomass chain		Citizens in Stokkemarke
			Local municipality
			Danish boiler manufacturer LIN-KA
Natural resources	*Biomass feedstock*	*Types of feedstock*	1500 tonnes of mixed straw burnt annually
		Feedstock origin	400 tonnes of own straw
			Straw purchased from local farmers
		Markets for feedstock	Straw sale to a local turkey farm
		Feedstock transformation pathways	500 kg rectangular straw bales
	Other	*Land*	300 ha of farmland (sugar beet, barley, wheat, rapeseed, grasses) owned by the plant manager
			Agricultural land managed by straw suppliers
		Soil	No straw is ploughed back to the soil on the farm
		Air	Emissions reduced with abatement equipment
Technical components	*Infrastructure*	*Machinery and equipment*	A bailer
			One small and three big tractors
			CASE combine harvester
			A barn at the plant for 3000-4000 tonnes of straw
			Loaders
			Two conveyor belts
			A shredder that cuts straw bale in four parts
			A bottom ash separator
			Air emissions abatement system (bag filters)
		Conversion facilities	A 2.5 MW straw-fired boiler
			A 1 MW oil-fired boiler
			A heat distribution network owned by the farmer
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heat and hot water

"Soft" (non-technical) components	*Institutions*	*Economy*	Total investment cost – EUR 2 300 000
			Boiler cost – EUR 970 000; firewalls cost – EUR 1 000 000
			More than 10 years expected payback
		Social systems	Support from local municipality
			Support from Stokkemarke residents
			No written contracts with straw suppliers (mutual trust)
	Co-benefits	*Energy security/insecurity*	Substitution of individual oil and electricity heaters
		Rural development/impoverishment	Straw residue valorisation
		Ecological benefits/costs	GHG emission reduction
	Knowledge	*Actor capacity*	Plant owner learns to operate the boiler every day
			LIN-KA provides advice upon inquiry

5.2.3 Agro-biomass use on large scale

This group of cases presented here includes large-scale straw-fired CHP and power plants in Sweden, Denmark and Spain. ABFs for each of those cases are provided in Tables 5-12, 5-13 and 5-14. Detailed case study descriptions can be found in Annex VI.

In SE there are no functioning installations of large scale, and the first one, Örtofta CHP plant (Table 5-12), is still planned to be constructed although the plans are advanced (Ottosson pers.comm. 2009; Steineck pers.comm. 2009). It will be owned by Lunds Energikoncernen AB (Ottosson pers.comm. 2009; Steineck pers.comm. 2009).

Danish example presented here includes Avedøre CHP plant in Southern Copenhagen (Table 5-13) (Jansen pers.comm. 2009; M. Nielsen pers.comm. 2009; Sørensen pers.comm. 2009). Also aggregated data from reports on the development of Danish large scale power generation from straw (Hinge 2009; Nikolaisen 2007; Sander & Skøtt 2007; Skøtt & Hansen 2000b) informs the analysis and discussion in Chapter 7. In DK all CHP plants are owned by two energy companies - Dong Energy and Vattenfall (Hinge 2009; Sander & Skøtt 2007).

A Spanish case under analysis is a 25 MW straw-fired power plant in Sangüesa, Navarre region (Table 5-14), which is owned by Acciona Energía (Acciona Energía 2009b; Lerga pers.comm. 2009; BIOENER ApS 2009). Within this study it is the only example of the installation that produces pure electricity. The latter is due to the specificity of Spanish context, where the demand for heat is low and no DH systems exist (Lerga pers.comm. 2009).

All working installations analysed here are of Danish manufacture. In most cases straw is handled as big bales, which has been found to be the most cost-effective method (Hinge 2009). The major part of straw is stored in the field as an open storage (Hinge 2009; Acciona Energía 2009; Steineck pers.comm. 2009; Lerga pers.comm. 2009). All plants also have straw barns that ensure straw capacity enough for at least two days of the plant full-time operation (Lerga pers.comm. 2009; Sander & Skøtt 2007). The straw is delivered from distances in the range of 20-160 km from the plant (Hinge 2009; Lerga pers.comm. 2009; Steineck pers.comm. 2009). Straw delivery is organised in trucks with trailers, which unload bales at the plants (Fig. 5-11) as described in Sub-section 2.4.3 (Hinge 2009; Jansen pers.comm. 2009; Steineck pers.comm. 2009). After straw has been unloaded the trucks are cleaned with special vacuum cleaners (Fig. 5-12). The bottom ash from straw combustion is either delivered to the company that produces organic fertilisers (Lerga pers.comm. 2009), in which case the plant pays for it, landfilled, treated or returned back to farmers and spread on the fields (Hinge pers.comm. 2009; M. Nielsen pers.comm. 2009). In DK the contracts do not regulate the share of ash returned to the farmers, and thus the volume of ash return does not depend on the amount of straw delivered to the plant, which is considered to be imperfect (Hinge 2009).

Figure 5-11. Straw unloading at Avedøre plant, Copenhagen, Denmark

Table 5-12. Agro-biomass based framework of Örtofta case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Farmers
			Businessmen
		Feedstock handlers	Sub-contractors
		First-hand users of biomass for energy	Örtofta CHP plant located on the area of 17 ha
		Second-hand users of energy from biomass	Residents in Lund, Eslöv, Hörby and Lomma
			Municipal buildings in Lund, Eslöv, Hörby and Lomma
			Companies and industrial plants in Lund, Eslöv, Hörby and Lomma
		Competitors for biomass use	Farmers for animal bedding and fodder
			Farmers for their heating needs
			Farmers for soil fertilisation
			Pulp and paper industry
	Indirectly involved in biomass chain		Utility Lund's Energy
			Governmental authorities
			Lund municipality
			Eslöv municipality
			Hörby municipality
			Lomma municipality
			Örtofta population
			Companies and industrial plants
			Non-governmental organisations and opposing groups
			Academia and research institutions (e.g. Lund University, SLU)
			Media
			General public
			Advisors and consultants
			Funding institutions and banks
			Plant equipment manufacturers (e.g. Siemens)
Natural resources	*Biomass feedstock*	*Types of feedstock*	Mainly wheat straw, some rapeseed straw (moisture at 10-25%)
			Wood chips, waste wood and peat
		Feedstock origin	Locally sourced biomass
		Feedstock transformation pathways	Rectangular 500 kg straw bales, 80 000 tonnes needed annually
			Wood chips
	Other	*Land and soil*	Agricultural
		Forest	Dedicated plantations
		Air	GHG balances and emissions from biomass combustion
Technical components	*Infrastructure*	*Machinery and equipment*	Straw handling to be done by sub-contractors and their machinery
			A big wood fuel storage at the plant
			A straw barn of 100 m in length and 30 m in width
			Overhead travelling cranes
			A conveyor belt with a shredder
			A vacuum cleaner to clean trucks
		Conversion facilities	A 45 MW straw-fired roster boiler with low ash melting point
			A 110 MW wood chip-fired boiler
			A turbine with 53 MWe and 100 MW steam
			Ideally located within 20-30 km from straw source
	Technolog y	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating, hot water and electricity

"Soft" (non-technical) components	*Institutions*	*Juridical systems*	Environmental permits
			Building permits
			Swedish carbon tax in 1990s
		Economy	Savings from oil and gas substitution, and from heat pump replacement
		Social systems	Written contracts with sub-contractors
	Co-benefits	*Energy security/insecurity*	Reduction of energy imports
			Energy source diversification
			Energy efficiency improvements
		Rural development/impoverishment	Job creation (e.g. at least one person per straw storage for control)
			Straw and wood residue valorisation
		Ecological benefits/costs	GHG emission reduction

Contracts for straw purchase are set between the plant and farmers or farmer associations (Hinge 2009; Jansen pers.comm. 2009; Lerga pers.comm. 2009; Steineck pers.comm. 2009). Some straw experts (Lerga pers.comm. 2009; Steineck pers.comm. 2009) consider concluding contracts with farmer associations or intermediaries as a more efficient way of doing business while in DK this scheme does not exist any longer (Hinge pers.comm. 2010). Nowadays all contracts on straw purchase in DK are concluded between plants and individual straw producers. The plants prefer this scheme as it allows them getting straw at the best price via price tender system (Hinge pers.comm. 2010). Normally straw price is set in the contracts, and is a market price that is initially suggested by straw suppliers (Hinge 2009; M. Nielsen pers.comm. 2009; Steineck pers.comm. 2009).

Figure 5-12. Truck cleaning after straw unloading at Avedøre plant, Copenhagen, Denmark

Table 5-13. Agro-biomass based framework of Avedøre case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Individual farmers in the region
		Feedstock handlers	4 sub-contractor companies
			Farmers in the region
		First-hand users of straw for energy	Avedøre CHP plant consisting of two Units
		Second-hand users of energy from straw	1.3 million households in the northern electricity grid
			200 000 households on the DH grid of Greater Copenhagen area
		Competitors for biomass use	Farmers for animal bedding and fodder
			Farmers for soil fertilisation
			Farmers for their own heating needs
	Indirectly involved in biomass chain		Dong Energy
			Governmental authorities
			Media
			Local population in Copenhagen area
			Manufacturers (Babcock and Wilcox Vølund A/S, FLS Miljø)
			BWE
			Komunekemi fertiliser producing company in Nyborg
			Vattenfall
Natural resources	*Biomass feedstock*	*Types of feedstock*	170 000 of cereal straw per year (max moisture content - 24%)
			100 mil m^3 of natural gas, 160 000 tonnes of oil, 300 000 tonnes of wood pellets per year
			500 000 tonnes of coal per year
			135 million m^3 of gas per year by gas turbines
		Feedstock origin	Locally sourced straw from the farms
			Wood and coal supplied by sea
		Feedstock transformation pathways	Rectangular 500 kg straw bales
Technical components	*Infrastructure*	*Machinery and equipment*	Straw handling is performed by sub-contractors and their machinery
			On-site straw warehouse with reserves for 2 days fuel supply
			Covered conveyor belts for wood pellet supply from the harbour
			Fuel mills
			Overhead travelling cranes
			A straw conveyor belt with a shredder
			Screw stockers transporting straw to the boiler
			Brooms and vacuum cleaners
			Advanced flue gas cleaning units
		Conversion facilities	A coal-fired boiler of 250 MWe and 580 MWth (Avedøre-1)
			Avedøre-2: 570 MWe, 560 MWth; supercritical plant with steam pressure of 250-300 bars and temperature of 540-600^{o}C; electrical efficiency - 46%
			A mixed fuel boiler with 16 burners (Avedøre-2)
			A straw-fired Benson boiler (45 MWe, 50 MWth) with hanging super-heaters and vibrating grate (Avedøre-2)
			A steam turbine
			2 gas turbines
			A generator
			2 hot water accumulators (50 m in height)
			Located in up to 80-100 km from the fuel source

Technical components	*Technology*	*Conversion pathways*	Combustion and co-generation
		End-use of energy from biomass	Heat, hot water and electricity
"Soft" (non-technical) components			h green electricity tariff
		Juridical systems	Tax exemptions for heat from biomass
			A levy paid by Danish government to Dong Energy for straw handling
		Social systems	Contracts between Dong Energy and transportation companies
	Co-benefits	*Energy security/insecurity*	Fuel diversification and ultimate goal to switch to biomass completely
		Rural development/impoverishment	130 employees at the plant
		Ecological benefits/costs	CO_2 emission reduction

Plant managers seek to diversify their fuels by either exploring options to substitute straw with perennial grasses (Acciona Energía 2009; Lerga pers.comm. 2009; M. Nielsen pers.comm. 2009), co-firing straw with other biomass (e.g. crop residues or wood) (Hinge 2009) or constructing wood-fired boilers on the plant in addition to straw-fired ones (Ottosson pers.comm. 2009; Steineck pers.comm. 2009). It is clear that on large scale fuel security of supply is among crucial factors.

The investment costs for such plants are significant. For example, the investment cost of Sangüesa power plant was EUR 51 million (i.e. EUR 2.04 million per MWe) while that estimated for Örtofta CHP plant is nearly EUR 86 million (i.e. EUR 1.91 million per MWe[21]). Funds for plant construction are obtained from company (Hinge pers.comm. 2009; Lerga pers.comm. 2009) and through bank loans (Ottosson pers.comm. 2009; Steineck pers.comm. 2009). In Spanish case EUR 3 million were provided as a grant by European Commission (Acciona Energía 2009).

[21] The estimated investment costs for simple straw-fired boilers in Ukraine (Sub-section 4.4.1) is EUR 83 000-96 000 per MWth, which is about 22 times lower than investment costs for straw-fired CHP plants in Western Europe. The figure for Ukraine is revealed to be unreasonably low, and needs to be further scrutinised.

Table 5-14. Agro-biomass based framework of Sangüesa case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Farmers in Navarre region
			Farmer associations in Navarre region
			Businessmen
		Feedstock handlers	Sub-contractors to the plant
		First-hand users of straw for energy	Sangüesa power plant located on the area of 10 108 m^2
		Second-hand users of energy from straw	50 000 households in Spain who use electricity from National grid
		Competitors for biomass use	Farmers for animal bedding and fodder
			Farmers for soil fertilisation
			Pulp and paper industry (existed in the region till 1990s)
	Indirectly involved in biomass chain		Acciona Energía
			European Commission
			Governmental authorities
			Media
			Local population in Sangüesa
			Advisors and consultants
			General public
			Spanish Institute for Energy Diversification and Savings (IDAE)
			A company that produces organic fertilisers from straw ash
			Plant equipment manufacturers (e.g. FLS Miljø)
Natural resources	*Biomass feedstock*	*Types of feedstock*	Cereal straw
			Other biomass (i.e. wood chips and perennial grasses) – planned
		Feedstock origin	Locally sourced straw from farms within 120 km distance
		Feedstock transformation pathways	Rectangular 500 kg straw bales, 160 000 tonnes needed annually
	Other	*Water*	Water for heating and cooling form the irrigation channel of Irati river
		Air	GHG emission reduction from fuel substitution
Technical components	*Infrastructure*	*Machinery and equipment*	Straw handling is performed by sub-contractors and their machinery
			A straw warehouse (5120 m^2) with reserves for 3 days fuel supply
			3 overhead travelling cranes
			A straw conveyor belt with a shredder
			A superheater, which accepts the steam at 540^{o}C
			A steam condenser
			A smoke filtering system
		Conversion facilities	A 25 MWe straw-fired vibrating grate boiler with advanced steam conditions located in a boiler-house on 1900 m^2
			A turbine house, control and office areas (2635 m^2)
			A generator
			Electrical grid on the plant site
			Located in up to 120 km from the fuel source
	Technology	*Conversion pathways*	Combustion with "internal co-generation"
		End-use of energy from biomass	Electricity of 11 kV, which is transformed to 66 kV at the grid on the plant site

"Soft" (non-technical) components	*Institutions*	*Juridical systems*	Spanish Renewable Energy Plan (2005-2010)
			EU White Paper on Renewables
		Economy	EUR 51 million – total investment cost
			EUR 3 million as EC grant
			EUR 2.4 million by IDEA
			Total cost of straw supply – EUR 36 per tonne
			Payback from electricity sales of 15 years
	Co-benefits	*Energy security/insecurity*	Reduction of energy dependence is among Acciona Energía goals
			Security of straw supply ensured via long-term contracts signed with the farmers or farmer associations since 1998
		Rural development/impoverishment	100 direct and direct jobs created after the plant has been launched
			200 people employed for 18 months of construction works
		Ecological benefits/costs	CO_2 emission reduction of 200 000 per year

The reasons for transformation towards straw are economic, political and legal. In DK relevant policies were put forward, which set targets for the increase of straw use in the energy sector and established economic support mechanisms (Sub-section 5.1.2) (Hinge 2009; Nikolaisen et al. 1998; Sander & Skøtt 2007; Skøtt & Hansen 2000a). In SE high prices for natural gas, carbon and energy taxes have been driving the transition of conventional energy systems to bioenergy (Ottosson pers.comm. 2009; Steineck pers.comm. 2009). In ES the idea to start straw use for electricity is linked to the fact that significant amounts of straw in the region became available on the market due to the closure of local pulp and paper industry that used straw (Lerga pers.comm. 2009). In all countries legislation prohibits straw burning in the field (Hinge 2009; Steineck pers.comm. 2009; Lerga pers.comm. 2009).

5.3 Classification of farm-based entrepreneurs

The classification of entrepreneur types (Table 5-15) is based on Alsos *et al.* (2003) (Sub-section 3.4.3) and seeks to answer the following overarching area of query:

Why did farm based entrepreneurs engage in straw-to-energy activities?

It is applied to small and medium scale straw-fired installations since on these levels farm-based entrepreneurs are the main actors to diversify their activities on the farm by straw use for energy. On large scale the focus is shifted to plant operating managers, municipalities and energy companies, which are not the relevant stakeholder group to be classified within suggested categories.

Table 5-15. Summary of farm-based entrepreneur types observed in Western Europe

Case study	***Entrepreneur type***	***Comments***
Pugerup	Resource exploiting farmer	• Interested to utilise unique resources on his farm (planned biogas production for electricity)
Falkenberg	Pluriactive farmer	• Uses straw only for his own energy needs • Not interested to sell heat to other farmers
Nöbbelöv	Resource exploiting farmer	• Grows hemp to use during straw shortage
Svenstorp, Björnstorp	Resource exploiting farmer	• Interested to make the most of his own resources (sells excess heat to energy company) • New business on heat sale is equally important to other business activities
Trelleborg, Löderup, Skurup	Portfolio farmer	• Open to a range of new businesses and purchasing new equipment • In his business is dependent on other actors/organisations (i.e. municipalities, Skurup DHP managers, farmers) • New business (heat from straw) has grown as big as his old one on straw handling
Horreby, Horbelev	Portfolio farmer	• Open to a range of new businesses (i.e. straw baling for others, heat supply to villages, wind energy production, etc.) and to purchasing new equipment • In his business is dependent on other actors (i.e. heat consumers in the village, farmers, municipalities) • New business (heat from straw) has grown bigger than his farming business and is planned to be expanded
Hunseby	Portfolio farmer	• Open to new business and established it himself (heat sale from straw in the village) • Open to maximise the utilisation of resources on his farm (straw-to-energy) • Dependent on other actors in his business
Stokkemarke	Portfolio farmer	• Open to new business and established it himself (heat sale from straw in the village) • Open to purchasing new equipment (e.g. flu gas cleaning systems) • Dependent on other actors in his business • New business (heat from straw) has grown bigger than his farming business and is planned to be expanded
Svalöv	Portfolio farmer	• Open to new straw-based businesses and to purchasing new equipment • In his business is dependent on other actors (i.e. Svalöv municipality, farmers)

Sources: Ericsson pers.comm. 2009; Göransson pers.comm. 2009; Leire pers.comm. 2009; Palle pers.comm. 2009; Palle pers.comm. 2010; Rasmusen pers.comm. 2010; Sejdenfaden pers.comm. 2010; Skovsted pers.comm. 2009; Treschow pers.comm. 2009

Table 5-15 shows that all three farm-based entrepreneur types can be found within 11 studied cases (large scale installations are not included in the analysis as explained above). The degree of stakeholder engagement and commitment grows with the increased degree of the system complexity. It can be seen that while pluriactive farmers are encountered only at small scale level, portfolio farmers are more likely to be met in more complex and larger systems.

6 Agro-bioenergy experiences in Ukraine

Chapter 6 looks into specific examples of straw use for energy in Ukraine (UA). Section 6.1 describes the background of straw production for energy in the country. Section 6.2 aggregates the description of existing practices from 9 case studies (a detailed presentation of narratives is given in Annex VII) and identifies the components of each case specific agro-biomass framework (ABF) via data structuring in line with the conceptual framework. Section 6.3 presents the analysis of the behaviour of farmer entrepreneurs involved in the cases under the study.

6.1 Local context of straw use for energy

Straw market in Ukraine is not established (Geletukha & Zhelezna 2010a), and initiatives on straw use for energy are emerging. Potential of straw use for energy in the country was discussed in Sub-section 1.1.5. The technical straw potential is estimated at 175 PJ or 16.5% from total assessed biomass potential in the country (Table 1-1) (Geletukha & Dolinsky 2009). About 6-8 million tonnes of straw can be used for energy in UA per year (Dubrovin *et al.* 2004). The main regions with excessive straw production are located in Central and Eastern Ukraine and include Kharkiv, Dnipropetrovsk, Zaporizzhya, Crimea, Odessa, Donetsk, Kirovograd and other provinces, where also the major agricultural production takes place (EBRD 2008; Grynyuk 2009; Radchenko *et al.* 2009; Smeets *et al.* 2005).

Straw is also considered to be one of the easiest and the cheapest biomass options that can be developed in Ukrainian conditions (Sub-section 4.3.2) (Dubrovin *et al.* 2004; Grynyuk 2009; Oliynyk pers.comm. 2009). In addition, Ukraine is considered to be among largest potential suppliers of straw pellets on international markets (Sub-section 4.3.4) (Hinge 2009; Sander & Skøtt 2007).

In their strategy of biomass-fired boiler implementation (Sub-section 4.3.3) experts from SEC Biomass identified it feasible to install 11 000 straw-fired units with a total capacity of 4000 MW by 2015 in Ukraine (Geletukha & Zhelezna 2010b). These include 10 000 farm straw-fired boilers of 100 kW– 1 MW and 1 000 straw-fired DH plants of 1-10 MW. The implementation of the suggested strategy will require a total investment of UAH 2.8 billion[22], reduce GHG emissions by 2.7 million tonnes every year and substitute 2.36 billion m^3 of natural gas (Geletukha & Zhelezna 2010b).

Mechanisms that could foster energy production from straw are not fully developed in Ukraine (Section 4.2). The Law on Support of Biofuel Use (#1391-VI) (VRU 2000) does not clearly include straw into its definition of biofuels. The Law on Green Electricity Tariff can stimulate CHP generation from straw. However, taking into consideration Western European examples of straw use on large scale (Chapter 4), this would rather relate to larger straw-fired plants (perhaps above 10 MW), which do not exist in Ukraine yet.

According to statistical data, total fuel consumption in all boiler houses in rural areas of UA constitutes about 84 PJ per year, which can be fully supplied with straw resources available in the country (Zhovmir *et al.* 2007). Currently the main share of straw use for energy is performed in UTEM boilers, the available data on which (i.e. locations, capacities and purposes) is presented in Table 6-1. Their total installed capacity is about 8.9 MW and the annual use of straw in these boilers is nearly 16 400 tonnes[23] (or 237.8 TJ) (Avdeev pers.comm. 2008; Oliynyk pers.comm. 2010; UTEM 2009b; UTEM 2010).

6.2 Agro-biomass frameworks for organisation and action

Section 6.2 describes existing practices of straw use for energy in Ukraine. It aggregates information from 9 case studies carried out in the country. Section 6.2 is divided into two

[22] UAH 2.8 billion = EUR 286 million (EUR 1 = UAH 9.78 as of 1 June 2010)

[23] One tonne of straw delivers approximately 14.5 GJ of energy, which is equal to 4 MWh or 0.344 toe

sub-sections according to the scale of agro-biomass use for energy in UA (i.e. small and medium).

Two categories of energy end-use are identified on small scale, i.e. energy production from straw to be used on the farm (Sub-section 6.2.1.1), and the sale of straw fuel to other stakeholders (Sub-section 6.2.1.2). Section 6.2 conceptualises and structures all case studies in ABFs for organisation and action in line with the conceptual framework developed in this study (Table 3-4, Sub-section 3.4.1). Detailed case study narratives are provided in Annex VII.

Table 6-1. Functioning and planned straw-fired boilers in Ukraine

#	**Boiler brand**	**Straw use, t/yr**	**Province**	**Village/Town**	**Enterprise**
1	RAU-2-181	184	Kyiv	Drozdy	LLC Agricultural enterprise "DiM"
2	RAU-2-181	184	Donetsk	Volnovakha	Enterprise "Agroservis Donbasa"
3	RAU-2-181	184	Donetsk	Mariupol	OJSC "Ilyich Iron and Steel Works of Mariupol"
4	RAU-2-301	278	Vinnytsya	Strutynka	LLC "Rapsodiya"
5	RAU-2-301	278	Cherkasy	Lebedyn	OJSC "Lebedynskyi Seed Plant"
6	RAU-2-331	467	Vinnytsya	Vakhnivka	School
7	RAU-2-331	467	Vinnytsya	Olgopil	Vocational technical school
8	RAU-2-331	467	Kirovograd	Ulyanivka	Regional administration
9	RAU-2-331	467	Rivne	Uyizdtsi	School
10	RAU-2-331	467	Vinnytsya	Lukashova	School
11	RAU-2-331	467	Vinnytsya	Vilshanka	School
12	RAU-2-600	934	Kyiv	Berezan	LLC "Agroserviz"
13	RAU-2-600	934	Zaporizhya	Chkalovo	School
14	RAU-2-600	934	Zaporizhya	Kuybysheve	Regional administration
15	RAU-2-600	934	Donetsk	Zlatoustivka	LLC "Rosiya"
16	RAU-2-600	934	Kyiv	Polkovnyche	LLC "Polkovnychyi khutir", industrial facility
17	RAU-2-600	934	Vinnytsya	Rososha	School
18	RAU-2-600M	1122	Volyn	Viynytsya	LLC "Loteks", industrial facility
19	RAU-2-600M	1122	Volyn	Kholopychi	LLC "Loteks"
20	RAU-2-600M	1122	Volyn	Ozyutychi	LLC "Loteks"
21	*RAU-2-600M*	*1122*	*Sumy*	*Vysoke*	*Clinic (heating and hot water supply) [planned]*
22	*RAU-2-600M*	*1122*	*Kyiv*	*Pereyaslivske*	*Agricultural enterprise (poultry factory, pig farm) [planned]*
23	RAU-2-1210	1257	Kyiv	Drozdy	LLC Agricultural enterprise "DiM"
Total		**16381**			

Source: Oliynyk pers.comm. 2010*; Avdeev 2008; UTEM 2009b; UTEM 2010*

6.2.1 Agro-biomass use on small scale

6.2.1.1 Use on the farm

Four case studies constitute this sub-category, i. e. Strutynka, Lebedyn, Polkovnyche, and Dyagova. ABFs for each of those cases are provided in Tables 6-2, 6-3, 6-4 and 6-5 respectively. Detailed case study descriptions can be found in Annex VII.

All cases described here include privately owned small scale straw-fired installations (a water-based boiler or an air-based heat generator) located on a grain producing agricultural enterprise that also yields significant amounts of crop residues and has substantial heating needs (e.g., a grain dryer – Fig. 6-1).

Figure 6-1. Grain dryer in the village of Dyagova, Chernihiv province, Ukraine

In all cases (Antonik pers.comm. 2010; Demydov pers.comm. 2009; Orlovskyi pers.comm. 2010; Butenko pers.comm. 2009) the land is rented from private users (long-term leasing) since in UA the sale of land is prohibited by law. Most of the enterprises are not only involved in agricultural activities on the farm but also deal with industrial production and trading/service provision.

All farms generate sufficient amounts of straw to both satisfy their heating and other needs, and to sell excess straw for animal bedding and fodder, or to mushroom growing companies in the region. Sometimes other crop or wood residues are burnt with straw in a boiler. The ash from straw combustion is spread on the farm fields.

Table 6-2. Agro-biomass based framework of Strutynka case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Agricultural enterprise LLC "Rapsodiya"
		Feedstock handlers	Agricultural enterprise LLC "Rapsodiya" with its own bailers
		Second-hand users of energy from biomass	Workers on the farm
			Operators of a grain mill
			Farm managers for soil fertilisation
	Indirectly involved in biomass chain		Strutynka village council
			UTEM straw-fired boiler manufacturer
			A company V-Oil Agro
			Local authorities
			Elderly people in the village
Natural resources	*Biomass feedstock*	*Types of feedstock*	Straw from soy (mainly), rapeseed, wheat and barley
		Feedstock origin	Domestic
		Markets for feedstock	Domestic
		Feedstock transformation pathways	360-420 kg round bales
			Biodiesel from rapeseed (in the past)
	Other	*Land*	1500 ha of land rented from private owners (wheat, soy, barley, sunflower, rapeseed, kidney beans)
		Air	Air emissions from straw combustion in the boiler
"Hard" (technical) components	*Infrastructure*	*Machinery and equipment*	Grain dryers
			A bailer of Belarusian manufacture
			Heavy & light tractors of Ukrainian & Belarusian manufacture
			3 American combine harvesters Case IH
			Several seeding machines
		Conversion facilities	A 350 kW straw-fired boiler RAU-2-301, 85-89% efficiency (2005)
			A mill of Danish manufacture (2005)
			A small vegetable oil extraction line
			A distribution network owned LLC "Rapsodiya"
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating of the enterprise premises (e.g. administrative buildings, changing rooms, houses on the network rout, a mill, etc.)
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	No special permits required for the boiler installation and operation
		Economy	30% of boiler price prepaid, 70% paid within 10 days after its installation (all from the company's own funds)
			Energy production cost – EUR 7.58 /Gcal (January 2005)
		Social systems	Opposition from local elderly people against straw expansion
			Opposition from village council against straw expansion
	Co-benefits	*Energy security/insecurity*	Self-sufficiency and elimination of dependence on natural gas
		Rural development/impoverishment	No additional jobs created
			Straw residue valorisation
	Knowledge	*Actors' competence*	The boiler is very easy in operation

Table 6-3. Agro-biomass based framework of Lebedyn case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Agricultural enterprise OJSC "Lebedyn Seed Plant"
		Feedstock handlers	OJSC "Lebedyn Seed Plant" (with a rented bailer)
		Second-hand users of energy from biomass	Plant managers for administrative buildings heating
			Plant workers in a seed packaging unit
		Competitors for biomass use	Farmers for soil fertilisation
	Indirectly involved in biomass chain		UTEM boiler manufacturer
			Lebedyn village council
			Neighbour organisation that lets a bailer
Natural resources	*Biomass feedstock*	*Types of feedstock*	Mainly wheat and barley straw
		Feedstock origin	Domestic
		Markets for feedstock	No
		Feedstock transformation pathways	200 kg straw bales, 140-150 tonnes per season
	Other	*Land*	16 000 ha of land rented from private users (grain and technical crops)
		Soil	Some straw ploughed back
			Ash from straw combustion is spread on the fields
		Air	Emissions from straw burnt in the field and in the boiler
"Hard" (technical) components	*Infrastructure*	*Machinery and equipment*	Own tractors
			Own machines
			A rented bailer
			A 1.4 MW and a 1.6 MW grain dryers on natural gas
		Conversion facilities	A 250 kW straw-fired boiler RAU-2-301 (2008)
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating of administrative building (2400 m²) and premises for seed packaging
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	No permits required for the boiler installation and operation
		Economy	EUR 33 000 – boiler cost paid from the company's funds
			The boiler's payback – 2-2,5 years
			Straw handling cost - EUR 16.6 per tonne (baling is the most expensive)
			Cost savings from natural gas substitution
		Social systems	No opposition from local authorities
	Co-benefits	*Energy security/insecurity*	Substitution of natural gas, reduction of dependency on bureaucratic gas based heating system
		Rural development/impoverishment	No additional jobs created (less people are needed than for a gas-fired boiler operation)
			Straw residue valorisation
	Knowledge	*Actors' competence*	2 days required to train boiler operators
			No additional skills needed for the boiler operation

Table 6-4. Agro-biomass based framework of Polkovnyche case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	A daughter agricultural company of "ROPA Ukraine"
		Feedstock handlers	A daughter agricultural company of "ROPA Ukraine"
		First-hand users of biomass for energy	One boiler operator
		Second-hand users of energy from straw	Employees of "ROPA Ukraine"
	Indirectly involved in biomass chain		Trading company "ROPA Ukraine"
			UTEM straw-fired boiler manufacturer
			German plant "ROPA"
			Neighbour farms with straw baling needs
Natural resources	*Biomass feedstock*	*Types of feedstock*	Wheat straw harvested from 100 ha
		Feedstock origin	Domestic
		Markets for feedstock	No
		Feedstock transformation pathways	280-300 kg cylindrical bales, 800 bales required per season
	Other	*Land*	800 ha of land rented from private users by "ROPA Ukraine" (beetroot, wheat and rapeseed)
		Soil	Ash from straw combustion is spread on the fields
		Air	Air emissions from straw combustion in a boiler
"Hard" (technical) components	*Infrastructure*	*Machinery and equipment*	Own agricultural equipment
			Own bailer
			Construction equipment owned by "ROPA Ukraine"
		Conversion and storage facilities	A 600 kW straw-fired boiler RAU-2-600 (2007), operates at 60% load
			Straw storage in the field in separate bales
			A technical yard near the boiler used as a straw storage
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating of 3000 m^2
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	No permits required for boiler installation and operation
		Economy	Boiler cost - EUR 30 000 (from the company's own funds)
			Minimal costs associated with the boiler maintenance
			Boiler payback - 2-3 years
			Savings from the elimination of gas use
	Co-benefits	*Energy security/insecurity*	Energy self-sufficiency, elimination of dependence on bureaucratic natural gas heating system
		Rural development/impoverishment	No additional jobs created (the company's worker is employed part-time as a boiler operator)
			Provision of baling services to neighbour farms
			Straw residue valorisation
	Knowledge	*Actors' competence*	The boiler is very easy in its operation

Table 6-5. Agro-biomass based framework of Dyagova case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Farm manager at the farm enterprise "Butenko"
		Feedstock handlers	Farm manager at the farm enterprise "Butenko"
		First-hand users of straw for energy	Operator of a heat generator and a grain dryer
		Competitors for straw use	Farm manager for cattle bedding and fodder
			Mushroom growing enterprise "Ukrshampinyon"
			Farm manager for soil fertilisation (mainly rye straw)
	Indirectly involved in biomass chain		Biomass-fired heat generators manufacturer "NVT-Technology"
Natural resources	*Biomass feedstock*	*Types of feedstock*	Crop residues
			Straw (3000 tonnes produced per year)
			Husk
			Wood residues
			Saw dust
			Cow manure (5000 tonnes per year)
		Feedstock origin	Domestic
		Markets for feedstock	Domestic
		Feedstock transformation pathways	Baled straw, 300 tonnes per season
			Wood chips
	Other	*Land*	2000 ha of land rented from private farmers (grain crops - 1500 ha, corn - 150-200 ha, potatoes, buckwheat, millet, etc.; 200 milk cows)
		Soil	Some of straw is ploughed back to the soil
		Air	Air emission from straw burning in the field
			Air emissions from biomass burning in a heat generator
		Biodiversity	Detrimental impacts from straw burning in the field
"Hard" (technical) components	*Infrastructure*	*Machinery and equipment*	A grain dryer (6-10 tonnes of grain per hour)
			Four combine harvesters
			Three tractors
			A millet planter Grimmer
			A straw bailer (of Belarusian manufacture)
			A wood chopper
		Conversion and storage facilities	A 250 kW heat generator by "NVT-Technology" (max fuel moisture content - 60%)
			An old diesel oil fired boiler
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Grain drying
			2 tonnes of hot water for the farm's needs
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	Organic production on the farm certified by "BioLan Ukrayina"
		Economy	Biomass heat generator cost - EUR 5200 (the farmer's funds)
	Co-benefits	*Energy security/insecurity*	300-500 litres of diesel oil substituted per day (50 tonnes per season)
		Rural development/impoverishment	Son of the farm-manager is also working as a heat generator operator
			Biomass residue valorisation
	Knowledge	*Actors' competence*	Biomass heat generator is easy in operation

In all cases heat generators were purchased by farm managers at their own expense. The heat distribution networks are also owned by the entrepreneurs. In three cases of four these are water-based boilers produced by UTEM (Tables 6-2, 6-3 and 6-4) (Antonik pers.comm. 2010; Demydov pers.comm. 2009; Orlovskyi pers.comm. 2010). The biomass heat-generator in Dyagova (Table 6-5) was significantly cheaper than UTEM water-based straw-fired boilers (Butenko pers.comm. 2009). All boiler owners are satisfied with the work of their installations.

6.2.1.2 Fuel sale

Three case studies constitute this sub-category, i. e. Olgopil, Stavy, and Vyshnyuvate. ABFs for each of those cases are provided in Tables 6-6, 6-7 and 6-8 respectively. Detailed case study descriptions can be found in Annex VII.

In all cases described here the main consumer of heat from a straw-fired boiler is a village secondary school. In all cases a straw-fired boiler was (Tkachynskyi pers.comm. 2009; Oliynyk pers.comm. 2010) (or in the project case of Vyshnyuvate is planned to be (Belay pers.comm. 2009) installed in the substitution of an old coal-fired boiler-house. The owner of the boiler is/will be the local municipality, which purchases fuel from local agricultural enterprises that grow grain crops and have significant volumes of excess straw, which they bale for various purposes. Other biomass fuels including crop residues or wood can also be added in such a boiler but normally wheat or barley straw serves as the main fuel.

Only in the case of Olgopil the straw logistics system is already organised and functioning. The straw supplier is responsible for straw harvesting, baling, delivery and loading to the boiler (Tkachynskyi pers.comm. 2009). A similar scheme is planned in Stavy (Oliynyk pers.comm. 2010) while in the case of Vyshnyuvate the responsibility of straw handling will be either the feedstock grower or a third party (i.e. a local consultancy on renewable energies) (Belay pers.comm. 2009; G. Belay & Belay pers.comm. 2009; V. Belay 2009c; G. Belay & V. Belay 2009b).

Table 6-6. Agro-biomass based framework of Olgopil case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Agricultural enterprise LLC "Olgopil"
		Feedstock handlers	Agricultural enterprise LLC "Olgopil"
		First-hand users of biomass for energy	Operators of a school boiler
		Second-hand users of energy from biomass	Olgopil village secondary school
		Competitors for biomass use	Farmers for soil fertilisation
	Indirectly involved in biomass chain		UTEM boiler manufacturer
			Local construction company
			Chechelnyk regional administration
			Local administration of education
			Sanitary-epidemiological inspection
Natural resources	*Biomass feedstock*	*Types of feedstock*	Wheat and barley straw
			Possibly wood (i.e. forestry residues)
		Feedstock origin	Supplied from local company
		Markets for feedstock	No
		Feedstock transformation pathways	150 kg straw bales, 300-360 tonnes per year
	Other	*Land*	6000 ha of agricultural land managed by LLC "Olgopil"
		Soil	Ash from straw combustion is used by villagers for soil fertilisation
		Forest	20 000 ha of forest close to Olgopil
		Air	Air emissions from straw combustion in a boiler
"Hard" (technical) components	*Infrastructure*	*Machinery and equipment*	Modern equipment and bailers owned by LLC "Olgopil"
		Conversion facilities	A 300 kW straw-fired boiler RAU-2-331 (2008)
			Premises of a sanitary-epidemiological inspection for straw storage
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating
"Soft" (non-technical) components	*Institutions*	*Juridical systems*	State Programme on Energy Saving Technologies in Vinnytsya province
			Construction permit required
			No environmental or other permits required
		Economy	Boiler cost - EUR 39 000 (from state budget)
			EUR 57 000 supplied by Vinnytsya province for all procedures
			EUR 3800 provided by local administration of education for straw handling and storage
	Co-benefits	*Energy security/insecurity*	Substitution of coal use with locally sourced straw
		Rural development/impoverishment	No additional jobs created
			For straw storage in the field 3 more people need to be hired
			Funds circulate within local budget
	Knowledge	*Actors' competence*	Straw-fired boiler is very simple in operation
		Recipes	A written contract between village secondary school and LLC "Olgopil"

Table 6-7. Agro-biomass based framework of Stavy case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Agricultural enterprise "Plyuty"
		Feedstock handlers	Agricultural companies in the region
		First-hand users of biomass for energy	Director of Stavy secondary school
			Operators of a coal boiler (i.e. potential operators of the straw-fired one)
		Second-hand users of energy from biomass	Stavy secondary school
			Stavy kindergarten
		Competitors for biomass use	Farmers for soil fertilisation
	Indirectly involved in biomass chain		SEC "Biomass"
			Kagarlyk regional administration
			Stavy village council
			"Sahenergoservis" at OJSC AK "SATER"
			A local construction company
			U. S. Civilian Research and Development Foundation
			Environmental inspection
			Sanitary-epidemiological inspection
			Inspection on radioelectronic devices
Natural resources	*Biomass feedstock*	*Types of feedstock*	Wheat straw
			Other biomass (a trial of wood logs)
		Feedstock origin	From a local agricultural enterprise
		Markets for feedstock	Domestic
		Feedstock transformation pathways	12 kg cylindrical bales (used so far)
			40 cm*Ø130 cm cylindrical bales
			70 cm*50 cm*40 cm rectangular bales
			200-250 kg cylindrical bales of 150 cm*Ø180 cm, 300-380 tonnes per season
	Other	*Land*	Agricultural land operated by "Plyuty" enterprise
		Soil	Ash return to the soil is not yet arranged
		Air	Air emissions from straw combustion in a boiler
"Hard" (technical) components	*Infrastructure*	*Machinery and equipment*	A tractor and a lorry owned by "Plyuty" to carry 10 bales at a time
		Conversion and storage facilities	A 350 kW straw-fired boiler (2008), efficiency – 83%
			A straw storage near the boiler-house constructed by SEC "Biomass"
			Open straw storage in the field
			Covered straw storage
			Potential straw storage in a hay storage place
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating

"Soft" (non-technical) components	*Institutions*	*Juridical systems*	A permit for land acquisition
			A building permit
			An environmental permit
			A fire safety permit
			A permit from sanitary-epidemiological inspection
		Economy	Total cost - EUR 46 000
			Boiler cost - EUR 30 000
			Straw price - EUR 22.77 per tonne (including delivery and feeding in)
			Straw cost per season - EUR 774
			Boiler's payback - 2-3 years
			Revenues for straw paid at the end of the year
			Funds stay and circulate within the local budget
	Co-benefits	*Energy security/insecurity*	Fuel self-sufficiency (substitution of imported coal)
			171 000 m^3 of natural gas saved per heating season
		Rural development/impoverishment	Contribution to local employment (e. g., agricultural and construction companies)
			Creation of seasonal jobs (e. g., technicians, drivers, etc.) in straw harvesting, baling, storage and delivery
	Knowledge	*Actors' competence*	Boiler operators should educated on how to manage the boiler in normal and emergency conditions (not longer than 2 weeks)
		Recipes	A contract on Cooperation between Kagarlyk regional administration, SEC "Biomass", Stavy village council and Stavy secondary school
			A contract on Taking over and Transfer #9-09 between SEC "Biomass" and Stavy secondary school
			A contract on Straw Purchase regulating bale size, moisture content and straw price

The sources of funding for the installation of boilers are varied including state budget, sponsor support from educational organisations, and grant support from national/international programmes on the promotion of renewable energy.

Table 6-8. Agro-biomass based framework of Vyshnyuvate case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Agricultural production cooperative "Rosiya"
			Agricultural production cooperative "Rozagroprodukt"
		Feedstock handlers	Agricultural production cooperative "Rosiya"
			Agricultural production cooperative "Rozagroprodukt"
		First-hand users of straw for energy	Boiler operators
		Second-hand users of energy from biomass	Vyshnyuvate secondary school
			Local municipal buildings
	Indirectly involved in biomass chain		Vyshnyuvate secondary school teacher
			Rozivka regional administration
			Vyshnyuvate village council
			Vyshnyuvate secondary school students
			Ministry of Housing and Communal Services
			First vice prime-minister of Ukraine
			Zachativka coal storage station
			Donetskoblpalyvo company
			LLC "Chysta Energiya"
			SEC "Biomass"
			Ukrainian National Agency on Environmental Investments
			Foundation headed by First Lady
Natural resources	*Biomass feedstock*	*Types of feedstock*	800 kg of coal per day (150 tonnes per season)
			242 tonnes of straw per season (planned)
		Feedstock origin	Local agricultural cooperatives
		Markets for feedstock	Domestic
		Feedstock transformation pathways	Coal fuel
			Straw bales
	Other	*Land*	Operated by agricultural production cooperatives "Rossiya" and "Rozagroprodukt", and private farmers
		Air	Air emissions from coal combustion
			Air emissions from straw combustion in the field (2500-3900 tonnes of straw left in the field every year)
"Hard" (technical) components	*Infrastructure*	*Machinery and equipment*	Agricultural equipment owned by the cooperative "Rossiya"
			German straw bailers owned by "Rossiya" and "Rozagroprodukt"
		Conversion and storage facilities	Two coal-fired boilers КВУ5-М
			A 150 kW or a 300 kW straw-fired boiler
			Storage places owned by "Rossiya"
			Abandoned building of the school shooting gallery
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating

"Soft" (non-technical) components	Institutions	*Juridical systems*	A building permit from local authorities (not received yet)
		Economy	EUR 3700 from EUR 14 800 boiler cost to be supplied from local budget
			50% of boiler cost can be covered by LLC "Chysta Energiya"
			150 kW straw-fired boiler profitable at coal price of EUR 106-133 per tonne
			300 kW straw-fired boiler profitable at coal price of EUR 47 per tonne
			Straw cost – EUR 15.6 per tonne (EUR 5.5 baling and EUR 0.9 delivery)
			EUR 924 000 from local budget can be spent on the project
			Additional source of income for "Rossiya" from straw sales
			EUR 667 - estimated annual savings on fuel substitution
		Social systems	Established relationships with potential straw suppliers and investors
	Co-benefits	*Energy security/insecurity*	Substitution of imported coal and energy self-sufficiency
		Rural development/impoverishment	Creation of employment in the region
			Straw residue valorisation
		Ecological benefits/costs	Improved environmental quality in the region from coal substitution
			Reduction of GHG emissions by 325 t/year from coal substitution
		Recipes	Project descriptions and business plans
			Cost-benefit analysis

6.2.2 Agro-biomass use on medium scale

Two case studies – Zlatoustivka and Drozdy - constitute this category. ABFs for those cases are provided in Tables 6-9 and 6-10. Detailed case study descriptions can be found in Annex VII.

Both cases involve private agricultural enterprises that produce heat from their own straw resources combusted in their own boilers (Fig. 6-2 and 6-3), and sell it to a DH network in the village. Heat is supplied to local municipal buildings and dwelling houses that are connected to the grid, which is owned by local municipality (Lytvyn pers.comm. 2009; Yerkhov pers.comm. 2010).

Table 6-9. Agro-biomass based framework of Zlatoustivka case

<table>
<tr><td rowspan="10">Actors and their networks</td><td rowspan="8">Directly involved in biomass chain</td><td>Feedstock growers</td><td>LLC “Rossiya” (seed production and animal breeding)</td></tr>
<tr><td>Feedstock handlers</td><td>LLC “Rossiya”</td></tr>
<tr><td>First-hand users of straw for energy</td><td>Boiler operators at LLC “Rossiya”</td></tr>
<tr><td>Second-hand users of energy from straw</td><td>Citizens in municipal buildings in Zlatoustivka</td></tr>
<tr><td rowspan="3">Competitors for biomass use</td><td>Farmer managers for animal bedding and fodder</td></tr>
<tr><td>Mushroom industries in the region</td></tr>
<tr><td>Farmer managers for soil fertilisation</td></tr>
<tr></tr>
<tr><td colspan="2" rowspan="2">Indirectly involved in biomass chain</td><td>UTEM straw-fired boiler manufacturer</td></tr>
<tr><td>An engineer developing a heat generator for a grain-dryer</td></tr>
<tr><td rowspan="11">Natural resources</td><td rowspan="6">Biomass feedstock</td><td rowspan="2">Types of feedstock</td><td>Wheat straw (800 tonnes per year)</td></tr>
<tr><td>Sunflower residues (only trial burning)</td></tr>
<tr><td>Feedstock origin</td><td>Domestic</td></tr>
<tr><td>Markets for feedstock</td><td>No</td></tr>
<tr><td rowspan="2">Feedstock transformation pathways</td><td>Rectangular bales of 120 cm*80 cm*VAR cm, 12 per day</td></tr>
<tr><td>Round bales of 120 cm* Ø150 cm, 2 per day</td></tr>
<tr><td rowspan="4">Other</td><td>Land</td><td>10 000 ha of land rented from private users by LLC “Rossiya” (30% – grasses for animal fodder, 25-30% - sunflower, 35-40% – grain crops)</td></tr>
<tr><td rowspan="2">Soil</td><td>Straw left on the field is ploughed back</td></tr>
<tr><td>Ash from combustion is returned to soil (dry or mixed with manure)</td></tr>
<tr><td>Air</td><td>Air emissions from straw combustion in the boiler</td></tr>
<tr></tr>
<tr><td rowspan="8">“Hard” (technical) components</td><td rowspan="6">Infrastructure</td><td rowspan="4">Machinery and equipment</td><td>Four bailers owned by the enterprise</td></tr>
<tr><td>Two loaders owned by the enterprise</td></tr>
<tr><td>A grain dryer (50 t per hour) on fuel oil</td></tr>
<tr><td>Other agricultural equipment</td></tr>
<tr><td rowspan="2">Conversion and storage facilities</td><td>A 600 kW straw-fired boiler installed in 2005</td></tr>
<tr><td>A few covered storages owned by the enterprise</td></tr>
<tr><td rowspan="2">Technology</td><td>Conversion pathways</td><td>Combustion</td></tr>
<tr><td>End-use of energy from biomass</td><td>Heating of 10 000 m²</td></tr>
</table>

"Soft" (non-technical) components	Institutions	*Juridical systems*	No environmental or other permits required for the boiler operation
		Economy	Boiler cost - EUR 57 000, paid from the funds of LLC "Rossiya"
			Grain dryer on mixed fuel - estimated cost of EUR 40 000 (2010)
			Straw-fired boiler payback period of one year
			Cost of 1 Gcal from straw – EUR 5.3 (2008) (three times cheaper than from coal and five times cheaper than from natural gas)
			EUR 41 000 savings within the first heating season
			Expected payback for a grain-dryer – 1-1.5 years
	Co-benefits	*Energy security/insecurity*	Energy self-sufficiency due to coal elimination
		Rural development/impoverishment	No additional jobs created; the number of employees went down from 40 at a coal-fired installation to 10 at a straw-fired one
			Straw waste valorisation
		Ecological benefits/costs	Air quality in the village has improved
			Cleaner working conditions for the boiler operators
	Knowledge	*Actors' competence*	The boiler is very easy in operation and no additional skills are required (the only parameter to be set is the desired water temperature at the end)

Straw supply is completely organised by boiler owners, and they burn only straw produced on their farms (Lytvyn pers.comm. 2009; Yerkhov pers.comm. 2010) (Fig. 6-4). Mainly wheat straw is used. Ash from straw combustion is then spread on the farm fields as a natural fertiliser.

Figure 6-2. 600 kW straw-fired boiler RAU-2-600, Zlatoustivka, Donetsk province, Ukraine (Photo: courtesy of V. Belay)

Figure 6-3. 980 kW straw-fired boiler RAU-2-1210 in Drozdy village, Kyiv province, Ukraine

In Drozdy the boiler was produced by Danish company Passat Energi A/S and installed with technical and financial assistance of Danish partners (Lytvyn pers.comm. 2009). The boiler in Zlatoustivka was manufactured by UTEM and purchased at the company's own expense (Yerkhov pers.comm. 2010).

Figure 6-4. Field straw storage at agricultural enterprise LLC "DiM", Drozdy village, Kyiv province, Ukraine

Table 6-10. Agro-biomass based framework of Drozdy case

Actors and their networks	*Directly involved in biomass chain*	*Feedstock growers*	Farm managers of agricultural enterprise "DiM"
		Feedstock handlers	Farm managers of agricultural enterprise "DiM"
		First-hand users of straw for energy	3 operators at a straw-fired boiler
		Second-hand users of energy from straw	People in municipal buildings in the village of Drozdy
			Farmers of "DiM" for a pig breeding facility
		Competitors for biomass use	Farm managers for animal bedding and fodder
			Farm managers for soil fertilisation
			Farmers in the region for animal bedding and fodder
			Mushroom growing enterprises in the region
			Enterprises that purchase straw for compost in the region
	Indirectly involved in biomass chain		Danish manufacturer of straw-fired boilers Passat Energi A/S
			UTEM straw-fired boiler manufacturer
			A bread production company
			Danish Environmental Agency (Miljø and Energi)
			Danish Energy Agency (Energistyrelsen)
			Danish Technological Institute (DTI)
			SEC Biomass
Natural resources	*Biomass feedstock*	*Types of feedstock*	Wheat straw for combustion (4-5 tonnes per day, 1100 tonnes per year)
			Residues from soy and pea production for combustion
			Barley straw for animal fodder
			Buckwheat straw and corn residues for soil fertilisation
		Feedstock origin	Domestic (village of Drozdy and Mazepyntsi)
		Markets for feedstock	Regional
		Feedstock transformation pathways	Rectangular 320 kg straw bales of 120 cm*120 cm*240 cm
			Cylindrical 320 kg straw bales with Ø160 cm and 180 cm
			Annual straw production – 4000 tonnes
	Other	*Land*	3250 ha of land rented from private users in Drozdy and Mazepyntsi (1110 ha winter wheat, 560 ha buckwheat, 450 ha corn, 300 ha barley, grasses for fodder, 10 000 heads of animal livestock)
		Soil	Corn residues and buckwheat straw is ploughed back to soil
			Ash from straw combustion is mixed with animal manure and returned to the fields
		Air	Air emissions from straw combustion in the boilers
"Hard" (technical) components	*Infrastructure*	*Machinery and equipment*	New Holland bailer
			Krone bailer
			Several tractors
			Karpatets loader
			Ranger loader
		Conversion and storage facilities	A 980 kW straw-fired boiler RAU-2-1210 by Passat Energi A/S of 81% efficiency with a hot water accumulator
			A 150 kW straw-fired boiler by UTEM
			Open storage of straw on the field
			A straw barn near the boiler for 10-12 days of the boiler operation
	Technology	*Conversion pathways*	Combustion
		End-use of energy from biomass	Heating of 27 800 m^3
			Heating of pig and cattle breeding facilities

"Soft" (non-technical) components	*Institutions*	*Economy*	Straw price - EUR 21-25 per tonne
			Baling is the most expensive step (e.g. ropes cost EUR 1960)
			Big boiler investment cost– EUR 98 000 (funded by the project)
			Small boiler investment cost – EUR 19 800 (funded by "DiM")
			Reduced electricity consumption due to the substitution of 15 kW pumps with 5.5 kW ones
			Payback period - 4,7 years
			Cost savings - EUR 127 400
			Expenses on boiler maintenance (boiler flame tubes) - EUR 34 200
		Social systems	Tradition of straw and firewood burning in conventional ovens existed in rural areas in Ukraine in the past
	Co-benefits	*Energy security/insecurity*	Eliminating of dependence on imported natural gas (gas savings of at 1055-1560 m^3 per day, 280 000 m^3 per season)
			2.5 million m^3 of gas saved for all years of operation
			325 000 kW of electrical energy saved for all years of operation
		Rural development/impoverishment	Work load optimisation in winter (3 technicians and 3 tractor drivers who used to work only in summer are now employed)
			Straw and crop residue valorisation
	Knowledge	*Actors' competence*	Boiler is easy in operation and no additional qualification is required
		Recipes	Boiler operation instructions provided by Danish partners in Ukrainian

6.3 Classification of farm-based entrepreneurs

Analysis is presented in Table 6-11. It has the same logic as the one carried out to structure and describe the typology of Western European farm-based entrepreneurs (Sub-section 5.3) and follows the approach by Alsos *et al.* (2003). All three entrepreneur types are identified in Ukrainian context. This analysis is relevant only to the cases, in which agricultural entrepreneurs are the key actors in the system and have facilitated its transformation towards straw use for energy. Thus six cases out of nine are analysed here. Further discussion of Ukrainian entrepreneur types and their comparison with Western European examples is provided in Chapter 7.

Table 6-11. Analysis of farm-based entrepreneur types in Ukrainian case studies

Case study	***Entrepreneur type***	***Comments***
Strutynka	Resource exploiting farmer	• Interested to utilise unique resources on his farm (plans to research and test straw pyrolisys and gasification) • Used to produce biodiesel from rapeseed in a small reactor on his farm • Suggested selling heat to the village
Lebedyn	Pluriactive farmer	• Uses straw for energy only at his enterprise • Interested to expand production of bioenergy to substitution gas in grain dryers and thus increase farm income
Polkovnyche	Pluriactive farmer	• Uses straw for energy only at his enterprise • Interested to operate the boiler at its full capacity for the enterprise needs • Not interested to expand his business towards heat sale in the village
Dyagova	Resource exploiting farmer	• Uses biomass only for the farm's needs • Interested to utilise unique resources on his farm (e. g., to start up biogas production) • Constructed a gas network in the village at his own expense
Zlatoustivka	Portfolio farmer	• Open to new straw-based businesses and to purchasing new equipment • In his business is dependent on other actors (e. g., village citizens, local authorities) • A new business (heat sale from straw) has grown as big as his own business (farming) • Interested to expand biomass for energy to run his grain dryer (searching for options)
Drozdy	Portfolio farmer	• Open to new straw-based business and to purchasing new equipment • In his business is dependent on other actors • A new business (heat sale from straw) has grown as big as his own business (farming) • Has expanded straw use for energy on his own farm by installing another boiler

7 Case study analysis and discussion

Chapter 7 identifies, presents and analyses generic parameters of a range of agro-biomass based frameworks (ABFs) for organisation and action in Sweden, Denmark, Spain and Ukraine, which serve to transform local energy systems towards straw. Section 7.1 identifies five types of ABFs and compares them. Section 7.2 delineates facilitating and constraining factors for the establishment of an agro-industrial bioenergy sector in UA, and compares straw-to-energy realities in UA and the EU. An overall aim of Section 7.2 is to provide the basis for an answer to the 1st research question (i.e. *Why is biomass not established as a commercial energy carrier in Ukraine?*). Sections 7.3 and 7.4 seek to provide an answer to the 2nd research question (i.e. *How can Ukraine leverage agro-biomass for energy use?).* Both neoinstitutional and diffusion theories support the search for answers. Three pathways for the development of straw-to-energy activities in UA are suggested (Section 7.3) and a set of recommendations for key bioenergy actors in the country are put forward (Section 7.4). In addition, Section 7.4 suggests the construction of a demonstration straw-fired DH plant as one of the steps on the way towards the expansion and institutionalisation of Ukraine's bioenergy sector.

7.1 Agro-biomass frameworks for organisation and action

Sections 5.2 and 6.2 described Western European and Ukrainian case studies, classified them according to the scale and purpose of straw use for energy, and presented ABFs for each case. This Section identifies five different types of generic ABFs, which were found in both contexts, analyses and compares them. While these ABFs share the key components they differ markedly according to the local context and resources, the nature of goals, number of actors involved, complexity and degree of formalisation. The analysis also highlights key role of organisation and collective action in these frameworks.

The ABFs identified and analysed here include: 1) *ABF 1a: small scale local heat production*; 2) *ABF 1b: small scale local straw production for fuel sale to municipality*; 3) *ABF 2a: medium scale local heat provision with excess for sale*; 4) *ABF 2b: medium scale straw combustion for district heating*; 5) *ABF 3: large scale power or combined heat and power generation.* ABF 1b was the type specific for Ukrainian context. ABF 2a and ABF 3 are found only in the EU context, and have not emerged in UA yet. Key features of all ABFs are summarised in Table 7-1 and analysed along stages of the industry development by Aldrich and Fiol (1994) (Sub-section 3.4.2). Both tables provide a ground for comparison and contrast of EU and Ukrainian contexts (Section 7.1)

Table 7-1. Empirically derived agro-biomass based frameworks for organisation and action in Ukraine and Western Europe

Parameter	**ABF 1a: Small scale local heat production**		**ABF 1b: Small scale local straw production for fuel sale to municipality**	**ABF 2a: Medium scale local heat provision with excess for sale**	**ABF 2b: Medium scale straw combustion for DH**		**ABF 3: Large scale power or CHP generation**
I GENERAL PARAMETERS							
Region	**EU**	**UKRAINE**	**UKRAINE**	**EU**	**EU**	**UKRAINE**	**EU**
Case study	Pugerups (Pg), Falkenberg (F), Nöbbelöv (N)	Strutynka (Sn), Lebedyn (L), Polkovnyche (P), Dyagova (Dg)	Olgopil (O), Stavy (St), Vyshnyuvate (V)	Svenstorp (Sp) and Björnstorp (Bj), Horreby (H)	Trelleberog (T) and Löderup, Skurup (Sk), Svalöv (Sv), Horbelev (Hr), Hunseby (Hb), Stokkemarke (Sr)	Zlatoustivka (Z), Drozdy (D)	Örtofta (Ör), Avedøre (A), Sangüesa (Sg), aggregated Danish examples from reports
Farm size	<1500 ha	800-2000 ha 16 000 ha (L)	6000 ha (O)	2400 ha (Sp+Bj) 340 ha (H)	Varied	10 000 ha (Z) 3250 ha (D)	Varied
Energy type	Heat and hot water	Heat	Heat	Heat and hot water	Heat and hot water	Heat	Power or CHP
Energy end use	Farm heating (e.g. grain dryers, premises, facilities, etc.)	Enterprise (premises, facilities) or farm (e.g. a grain dryer) heating	Heating needs of a village school/ kindergarten	Farm heating (e. g., grain dryers, premises, facilities, etc.) with heat sale for DH	DH and hot water supply in a town or village	Heating of village municipal buildings on a DH grid	Electricity grid and DH distribution network
Distribution network ownership	Private	Private	Municipal	Private	Private, municipal or cooperative	Municipal	Company owned or municipal
II BOILER CHARACTERISTICS							
Capacity	<600 kW	250-600 kW	<350 kW	1-1.5 MW	1-6 MW	600 kW (Z), 980 kW (D)	>6 MW
Type	Batch load, in some - hot water accumulators	Batch load	Batch load	Continuous load, straw shredders, no water accumulators	Continuous loading, straw shredders, water accumulator (Hr)	Batch load, hot water accumulator (D)	Varied firing technologies (i.e. suspension, fluidised bed, grate)
Brand	LIN-KA (DK)	UTEM , NVT "Technology" (UA)	UTEM, AK "SATER" (UA)	LIN-KA (DK)	LIN-KA, Hollensen A/S, Weiss A/S (DK)	UTEM (UA), Passat Energi A/S (DK)	LIN-KA, FLS Miljø A/S, etc. (DK)
Fuels	Straw, crop residues, wood	Straw, other crop residues, wood	Mainly straw	Mainly straw	Mainly straw	Mainly straw	Straw (chopped, pelletised), straw with wood or coal

Parameter	**ABF 1a: Small scale local heat production**		**ABF 1b: Small scale local straw production for fuel sale to municipality**	**ABF 2a: Medium scale local heat provision with excess for sale**	**ABF 2b: Medium scale straw combustion for DH**		**ABF 3: Large scale power or CHP generation**
Ownership	Private	Private	Municipal	Private	Private, municipal, cooperative	Private	Private (energy companies)
Straw use, tonnes per year	140-400	<300	<380	<1300	450-12 000	800 (Z), 1100 (D)	40 000-160 000
III STRAW SUPPLY CHAIN							
Bailer ownership	Sub-contractors	Boiler managers or neighbours (L)	Sub-contractors	Sub-contractors or boiler manager	Plant managers or sub-contractors	Boiler managers	Sub-contractors
Actors who bale	Sub-contractors	Mainly boiler managers	Sub-contractors	Sub-contractors	Plant managers or sub-contractors	Boiler managers	Straw suppliers or sub-contractors
Bale size, kg	<500	About 300	<300	500	500	About 300	500
Storage	In own barns and on the field	In own barns and on the field	On the filed, in barns by feedstock growers, in other covered facilities	In own barns	Mainly on the field, also in plant barns	On the field, in own barns, in plant barns	Mainly on the field, also in plant barns
Distance, km	<10	<10	<10	<10	<40	<10	20-160
Straw purchase	No (own straw)	No (own straw)	By contract price	No (own straw)	For free or by negotiated price	No (own straw)	By contract price
Contracts with straw suppliers	No (own straw)	No (own straw)	Written (straw producers and users)	No	Written or agreement by mutual trust	No (own straw)	Written with farmers or farmer associations
Ash utilisation	On the farm as a natural fertiliser	On the farm as a natural fertiliser	Returned to the farmers	On the farm as a natural fertiliser	Returned to farmers for fertilisation	On the farm as a natural fertiliser	Returned to farmers, sent for treatment, landfilling, or to fertiliser producers
IV ECONOMY AND REASONS FOR TRANSFORMATION							
Source of funding	Private funds	Private funds	Municipal and project funds	Private funds	Private funds, municipal budgets	Private or project funds	Company own funds and bank loans
Investment cost, EUR	<150 000	<37 000, 5 200 (Dg)	Boiler <40 000, total <57 000	<310 000	0.3-1.2 mil	57 000 (Z), 98 000 (D)	>50-100 mil
Payback, ys	3	2-3	2-3	6-10	10-15	<4.7	>15

Table 7-2. Agro-biomass based frameworks for organisation and action in Ukraine and Western Europe structured along stages of industrial development

Framework type	***ABF 1a: Small scale local heat production***		***ABF 1b: Small scale local straw production for fuel sale to municipality***	***ABF 2a: Medium scale local heat provision with excess for sale***	***ABF 2b: Medium scale straw combustion for DH***		***ABF 3: Large scale power or CHP generation***
REGION	**EU**	**UKRAINE**	**UKRAINE**	**EU**	**EU**	**UKRAINE**	**EU**
Level of analysis[24]	Organisational	Organisational	Intra-industrial	Intraindustrial	Intraindustrial	Intraindustrial	Inter-industrial
Number and diversity of actors	Small, non-diverse	Small, non-diverse	Small to medium, medium diverse	Small to medium, medium diverse	Medium, medium diverse	Medium, medium diverse	Large, diverse
Role of collective action	None	None	Matters	Matters	Matters	Matters	Matters a lot
Degree of system complexity	Simple	Simple	Simple	Simple	Medium complex	Simple	Complex
Degree of formalisation (e.g. written contracts)	No	No	Yes	No	Some	Yes	High in the top of hierarchy
Reasons for transformation	Mainly economic	Energy security, economic	Energy security, economic, demonstration	Mainly economic	Economic, legislative, political	Energy security, economic, environmental, demo	Economic, legislative, political

[24] Following definition by (Aldrich & Fiol 1994)

7.1.1 ABF 1a: Small scale local heat production

This ABF type was encountered both in Western European (Sub-section 5.2.1) and Ukrainian (Sub-section 6.2.1) contexts. Analysis for both contexts is performed separately here (Sub-sections 7.1.1.1 and 7.1.1.2) while Sub-section 7.2.2 elaborates more on the comparison and contrast of the two. Organisational logic of this framework is presented in Fig. 7-1. Within this ABF type straw is produced on the farm and is used there for the farm's heating needs (e. g., to heat farm's premises, to run a grain dryer, etc.).

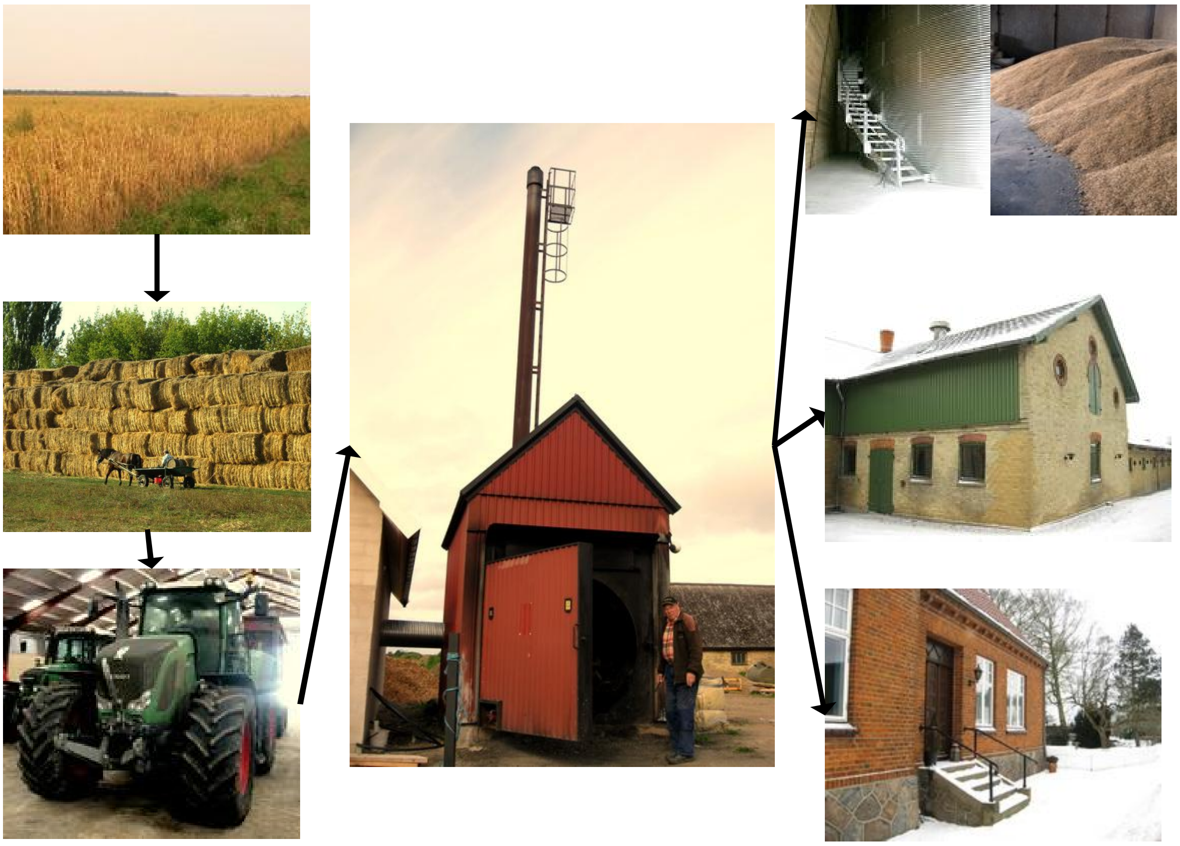

Figure 7-1. ABF 1a: Small scale local heat production

7.1.1.1 Western Europe

ABF 1a represents organisational level of analysis (Table 2-4 in Sub-section 2.5.1 and Sub-section 3.4.2) since the farm produces energy and uses it for its own needs (or within one organisation) (Table 7-2). As a consequence, not so many actors are involved in the activities along the straw supply chain. Key reasons to install a straw-fired boiler on the farm are purely economic: farmers are interested to reduce fuel costs by substituting expensive oil with locally sourced straw, which they get from their farms for free (Göransson pers.comm. 2009; Treschow pers.comm. 2009; Weden pers.comm. 2009). In all three cases the main energy user on the farm is a grain dryer.

7.1.1.2 Ukraine

ABF 1a also represents organisational level of analysis (Table 7-2) since the enterprise produces energy and uses it for its needs (within one organisation). Hence like in Western European context not so many actors are involved in the activities along the straw supply chain. Key reasons for transformation towards straw are of economic nature (Antonik pers.comm. 2010; Demydov pers.comm. 2009; Orlovskyi pers.comm. 2010; Butenko pers.comm. 2009) and also linked to the desire to reach energy self-sufficiency and get rid of dependence on a highly bureaucratic natural gas based heating system (Antonik pers.comm. 2010; Demydov pers.comm. 2009).

Currently ABF 1a is represented with up to 10 water-based straw-fired UTEM boilers (Svintsitskiy pers.comm. 2009) (which is nearly half of all functioning boilers of this type in UA– Table 6-1), at least 20 Bryg grain drying units (Kuzmin pers.comm. 2010) and up to 30 heat biomass-fired generators manufactured by NVT Technology (Toropets pers.comm. 2009). From personal communication with managers of agricultural enterprises (Antonik pers.comm. 2010; Butenko pers.comm. 2009; Demydov pers.comm. 2009; Orlovskyi pers.comm. 2010) and equipment producers (Kuzmin pers.comm. 2010; Svintsitskiy pers.comm. 2009; Toropets pers.comm. 2009) it is clear that a significant demand for similar farm-based heating systems exists in UA. The owners of grain dryers that function on natural gas (Demydov pers.comm. 2009) also note that in UA there are no national producers of grain drying units with the capacity larger than 1 MW, which has been a barrier for them to switch to agro-biomass firing in grain-dryers.

7.1.2 ABF 1b: Small scale local straw production for fuel sale to municipality

This ABF type was encountered only in Ukrainian (Sub-section 6.2.1.2) context. Its analysis is performed in Sub-section 7.1.2.1. Organisational logic of this framework is presented in Fig. 7-2. Within this ABF type straw is produced on the farm but is sold to the municipality, which is responsible for burning the straw in its boiler to satisfy local heating needs (e. g., heating of municipal buildings, schools, kindergartens, etc.).

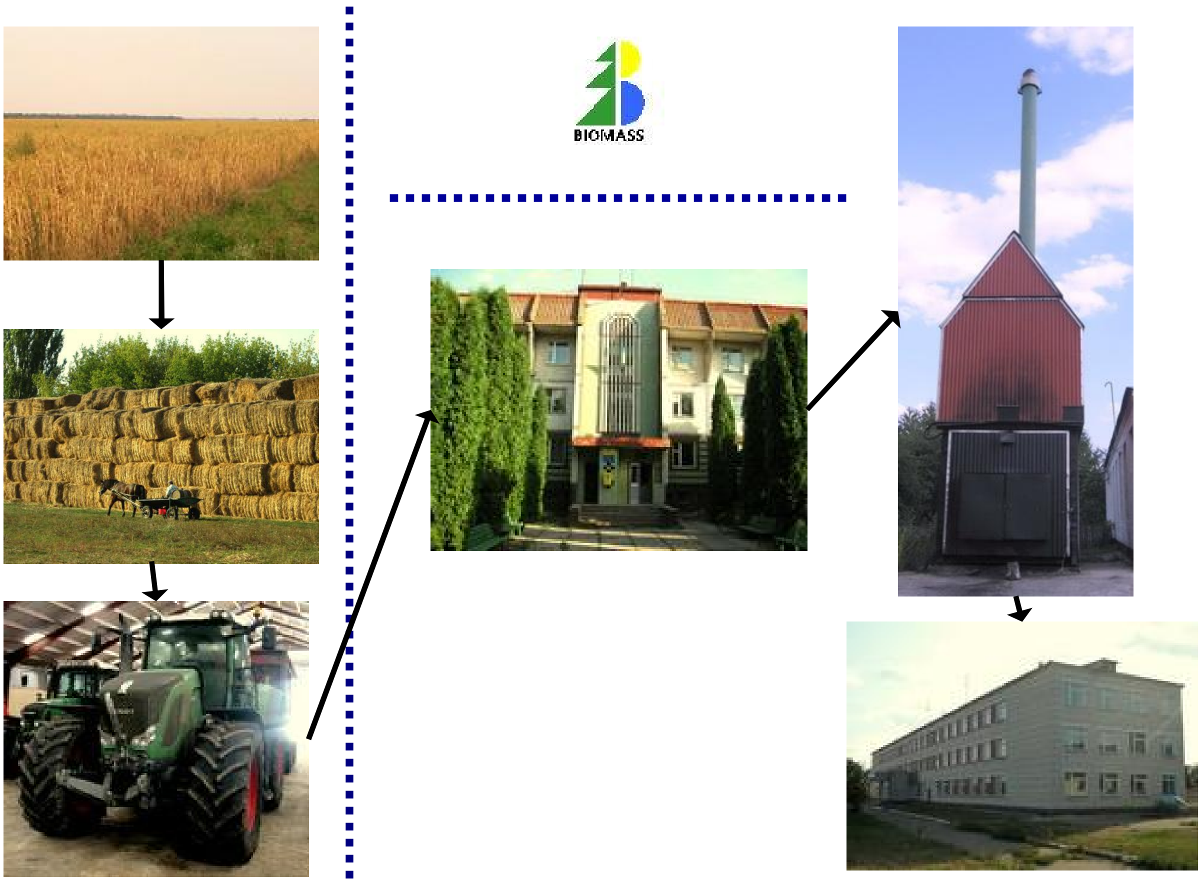

Figure 7-2. ABF 1b: Small scale local straw production for fuel sale to municipality

7.1.2.1 Ukraine

ABF 1b represents intra-industrial level of analysis (Table 2-4 in Sub-section 2.5.1 and Sub-section 3.4.2) as it involves relationships between various parties within the sector including farm entrepreneurs, municipalities, local authorities, village schools and kindergartens, and third parties (e. g., consultancies) (Table 7-2). Hence there are more actors involved in ABF 1b as compared to ABF 1a. They are also more diverse as they include not only buyers and sellers of straw feedstock but also researchers, consultants and other motivated enthusiasts.

Currently ABF 1b is represented with up to 10 examples of working UTEM boilers in different regions of UA (Oliynyk pers.comm. 2009; Svintsitskiy pers.comm. 2009). A need to expand energy from straw to supply village schools and other municipal buildings with heat is often recognised (Belay pers.comm. 2009; Oliynyk pers.comm. 2010; Oliynyk pers.comm. 2009).

In two cases within ABF 1b the leading actor to initiate the installation of a straw-fired boiler was a third party (i.e. consultants or potential consultants) (Belay pers.comm. 2009; Oliynyk pers.comm. 2009). Neither the owners of the installations (municipalities) nor the producers of straw feedstock (local agricultural companies) have become the prime movers to introduce a straw-fired system although they had demonstrated an overall support and engagement in the activities. Only in the case of Olgopil was it the municipality that catalysed the transition towards bioenergy. However, Vinnytsya province, where the boiler is located, is recognised to be rather exceptions in the sense of straw use for energy in UA (Oliynyk pers.comm. 2010; Konechenkov pers.comm. 2009; Belay pers.comm. 2009), and has the biggest number of functioning straw-fired boilers (seven) (Belay 2009a). Vinnytsya province has also a working state programme on the promotion of renewable energy sources, which is being implemented via straw-fired boiler installations (Tkachynskyi pers.comm. 2009).

In all cases straw handling and delivery is managed and organised either by feedstock growers or a third party (e. g., consultancy). Assigning this responsibility to the village school director in Stavy was not successful. On the contrary it constrained the project implementation (Oliynyk pers.comm. 2010), which demonstrated a need for the correct assignation of responsibilities between the actors in the system and the introduction of an efficient incentive-based system.

The case of Vyshnyuvate, which has not been implemented yet, faces numerous institutional barriers primarily caused by the constraining behaviour of market incumbents represented with the lobby of coal industry (Belay pers.comm. 2009). Also the lack of transparent vertical governmental influence (from top to bottom) was recognised as a barrier for the project implementation (Belay pers.comm. 2009).

In each example studied in UA the reasons for a transition to straw were of economic nature and also of a desire to increase the energy self-sufficiency in remote areas and provide continuous heat supply to village educational institutions. Since there are not so many working installations of ABF 1b in UA, the demonstration role of the projects has contributed to the justification of the reasons for their implementation.

7.1.3 ABF 2a: Medium scale local heat provision with excess for sale

This ABF type was encountered only in WE (Sub-section 5.2.2.1) and is analysed below. Organisational logic of ABF 2a is presented in Fig. 7-3. Straw is produced on the farm and is used there for the farm's heating needs (e. g., to heat farm's premises, to run a grain dryer, etc.). However, some excess heat is also sold to local municipality for its heating requirements.

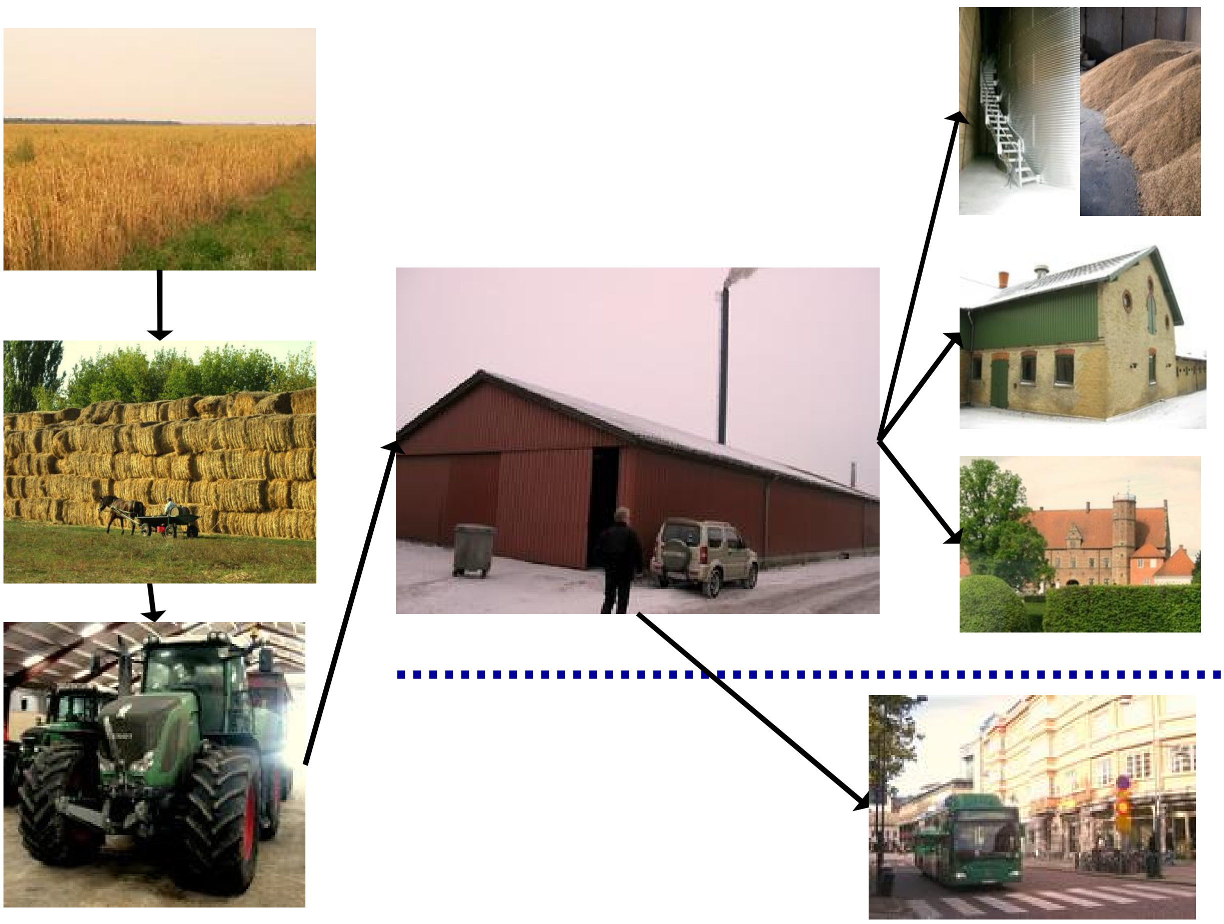

Figure 7-3. ABF 2a: Medium scale local heat provision with excess for sale

7.1.3.1 Western Europe

ABF 2a can be referred to the intra-industrial level of analysis (Table 2-4 in Sub-section 2.5.1 and Sub-section 3.4.2) as it involves relationships within an industrial sector, i.e. between farm boiler owners and energy companies or people in the village, who purchase heat from the former (Table 7-2). The main drivers for transformation towards straw are economic. Farm managers intended to save money on expensive diesel oil by substituting it with locally produced cheap straw and also viewed a potential business opportunity on additional heat sales to DH networks.

7.1.4 ABF 2b: Medium scale straw combustion for district heating (DH)

This ABF type was encountered both in WE (Sub-section 5.2.2.2) and UA (Sub-section 6.2.2). Analysis for both contexts is performed separately here (Sub-sections 7.1.4.1 and 7.1.4.2) while Sub-section 7.2.2 elaborates more on the comparison and contrast of the two. Organisational logic of ABF 2b is presented in Fig. 7-4. Straw is converted into heat at a DH plant, and the heat is then supplied to village houses and municipal buildings through a heat distribution network.

Figure 7-4. ABF 2b: Medium scale straw combustion for district heating

7.1.4.1 Western Europe

Intra-industrial level of analysis includes various types of relationships within an industrial sector (Aldrich & Fiol 1994). In comparison to ABF 1a and 2a, ABF 2b (Table 7-2) involves a bigger number of actors including boiler managers and owners, local municipalities, straw suppliers, residents in the area who purchase heat, etc. Key reasons to switch from conventional fuels to straw include legal requirements and political targets for substituting oil and/or gas due to economic and environmental considerations. The role, motivation, knowledge and experience of plant coordinators and municipal support are found to be important factors for the success of new systems.

According to Aldrich and Fiol (1994), collective action of different organisations within an industry defines further institutionalisation of an industrial field. Collective action starts to matter on intra-industrial level of analysis. In most examples within ABF 2b one of the key factors for the successful functioning of a straw-supply chain includes the establishment of collaborative relationships between plant operators and farmers. Moreover, the issue of mutual trust between straw users and suppliers is found to be of importance. Written contracts are not a necessary precondition in the 'boiler operator-farmer' relationships, and thus ABF 2b is not recognised as a framework with a high degree of formalisation.

7.1.4.2 Ukraine

In UA ABF 2b also represents intra-industrial level of analysis with a slightly bigger number and types of actors involved in the system as compared to ABF 1b (Table 7-2). Stakeholders include agricultural enterprises, municipalities, village councils, local secondary schools, kindergartens, community centres, hotels, dwelling houses, consultancies, project partners and executing bodies, etc.

The system has medium degree of complexity and formalisation. Written contracts exist between heat producers (agricultural enterprises) and heat users (local municipalities).

The installation of a straw-fired boiler for the provision of DH in villages replaced existing installations fired with natural gas (Lytvyn pers.com. 2009) or coal (Yerkhov pers.com. 2010). An important prerequisite for the success of the projects was the existence of quite extensive heat distribution networks, where no significant technological changes and investments were required. One of the evidences that a boiler has been a successful enterprise was the installation of an additional small (150 kW) straw-fired boiler by the managers of the agricultural company in Drozdy for their own needs on the farm a few years later (Lytvyn pers.com. 2009).

The owners of both installations are satisfied with their operation, and it is considered that the boilers were a success as they had brought a number of economic, social and environmental co-benefits in the villages. Firstly, the dependence of the village DH system on natural gas or coal was eliminated due to the fuel substitution with locally sourced straw. This enhanced local energy security and also resulted in cost savings from fuel purchase for the municipality, which buys heat at lower tariffs from the agricultural enterprises (Lytvyn pers.com. 2009; Yerkhov pers.com. 2010). Secondly, the enterprises created an additional source of their incomes by valorising their agricultural waste and selling the heat from straw combustion. Thirdly, in the social area some optimisation in local employment was achieved and a few seasonal jobs were created (Lytvyn pers.com. 2009; Yerkhov pers.com. 2010). Lastly, the installations brought climate co-benefits due to GHG emission reduction from fuel substitution (SEC Biomass 2009; Lytvyn pers.com. 2009).

The reasons for a transition towards straw use for energy were economic and environmental. Boiler managers had a desire to substitute expensive imported fuel with locally sourced biomass (Lytvyn pers.com. 2009; Yerkhov pers.com. 2010), and also improve environmental conditions in the village. In Drozdy the installation of a straw-fired boiler also had a demonstration purpose as it was the first straw-fired boiler installed in UA (SEC Biomass 2009).

7.1.5 ABF 3: Large scale power or combined heat and power (CHP) generation

This ABF type was encountered only in Western Europe (Sub-section 5.2.3). Its analysis is performed in Sub-section 7.1.5.1 and includes three case studies from SE, DK and ES as well as aggregated data from the reports on the development of Danish straw-to-energy sector. Organisational logic of this framework is presented in Fig. 7-5. In ABF 3 straw is produced on the farms and is then sold to large plants for the production and distribution of electricity or combined heat and power.

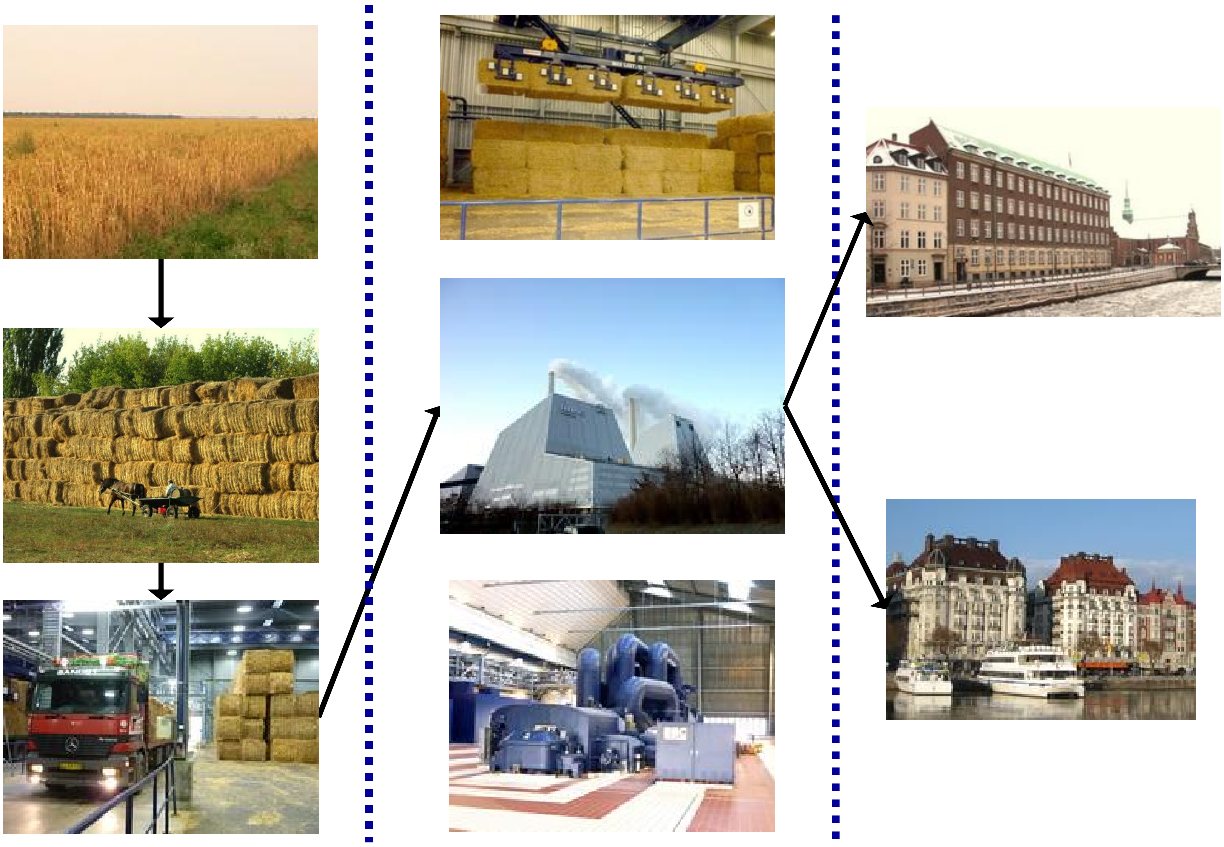

Figure 7-5. ABF 3: Large scale power or combined heat and power generation

7.1.5.1 Western Europe

With Örtofta being the only case in Sweden that represents ABF 3, this framework is clearly not developed in the country unlike ABFs 1a, 2a and 2b, which appear to be more common. On the contrary, straw use for energy in Denmark includes many large scale CHP installations, and thus can be regarded as a more mature industrial sector. Clearly it is the large scale plants that lead to straw market establishment in the region. For instance, in DK straw price formation is an important component for the functioning of large installations (Hinge 2009; M. Nielsen pers.comm. 2009) while in SE this is not yet a crucial factor, and straw can be obtained from farmers for flexible prices or for free (Ericsson 2009; Leire pers.comm. 2009; Steineck pers.comm. 2009). The reason for the latter phenomena is due to the fact that straw market in SE is not yet established and there is little competition. In SE straw is used for energy only on small and medium scale, and thus is purchased mainly by individuals or small groups but not large influential power companies. Sangüesa is the biggest functioning power plant of its type in Spain and one of the largest straw-fired installations in Europe (Acciona Energía 2009; Lerga pers.comm. 2009; BIOENER ApS 2009).

Inter-industrial level of analysis includes relationships between the studied industry and other industries including the phenomena of competition, negotiations and compromise (Aldrich & Fiol 1994). ABF 3 represents the inter-industrial level of analysis (Table 7-2) due to their higher complexity and bigger number of actors and organisations from various industrial sectors involved. Collective action between actors and organisations is important for the success of transformation towards bioenergy. One such example of collective action is DSSA (Sub-section 5.1.2), which was organised by farmers and machine pool companies (Hinge 2009). DSSA managed to secure straw market price establishment for the farmers by signing "codes of conduct" with major energy companies (Hinge 2009) and also put a pressure on politicians to ensure the enforcement of Danish Biomass Agreement (Hinge pers.comm. 2010).

Also in ABF 3 the roles of all actors within a straw supply-chain are clearly defined and put in a hierarchical order. At the bottom of the hierarchy there are many single feedstock producers who in the majority of cases sell straw or give it for free to a limited number of sub-contractors or farmer associations (M. Nielsen pers.comm. 2009; Palle pers.comm. 2010; Steineck pers.comm. 2009). Sub-contractors are responsible for all the processes within a straw supply chain including straw collection, baling, storage and transportation to the plant. They own or rent all necessary equipment for straw handling and are responsible for straw storage

(M. Nielsen pers.comm. 2009). Sub-contractors or farmer associations (more rarely individual farmers) sign official contracts with plants on terms and conditions of straw delivery, which also ensures the security of fuel supply to the plant. The conversion facility is at the top of the hierarchy, and delivers heat and electricity to cities and towns (Fig. 7-6).

Figure 7-6. Avedøre CHP plant, Southern Copenhagen, Denmark

In general, large plants are more sophisticated systems that require careful planning and assessments at every stage of a straw supply chain from ensuring the fuel supply (i.e. establishing contracts, discovering and securing volumes of fuel alternatives or source alternatives) to ash utilisation (i.e. returning to the field, treating, landfilling). For large CHP and power plants the acceptance by general public and local community is also important (Hinge 2009; Steineck pers.comm. 2009).

7.2 Agro-bioenergy experiences in Ukraine and Western Europe

This Section summarises the results on current practices of straw use for energy in Ukraine, and discusses constraining and facilitating factors (Table 7-3; Sub-section 7.2.1) for the sector development in the country classifying them in line with the categories of the conceptual framework (i.e. actors, natural resources, "hard" technical components and "soft" non-technical components) (Sub-section 3.4.1). Sub-section 7.2.1 also highlights the links to the diffusion theory via the analysis of the each factor's contribution to a TIS function (Table 2-5; Sub-section 2.5.2). These functions include: *entrepreneurial activities* (F1), *knowledge development* (F2), *knowledge diffusion* (F3), *guidance of the search* (F4), *market formation* (F5), *resource mobilization* (F6), and *support from advocacy coalitions* (F7). The enhancement of the function is market with '**+**', and its hindering – with '**-**'. The Section then compares Western European and Ukrainian realities (Sub-section 7.2.2) on straw use for energy.

Table 7-3. Facilitating and constraining factors to establishment of agro-industrial bioenergy sector in Ukraine

	Facilitating factors	***Constraining factors***
Actors and networks	• National bioenergy leader SEC Biomass; • Bioenergy networks via "Biomass for Energy" conference; • National biomass equipment manufacturers; • Local and sub-regional actors with energy needs; • Ukrainian and foreign actors with business interests; • Knowledgeable and enthusiastic prime movers.	• Market incumbents with opposing interests and lobbies for conventional fuels; • Local authorities with low level of cooperation and interest; • Limited funding institutions and potential sponsors; • Limited actors with sufficient funding capacities; • No strong Ukrainian Bioenergy Association; • No strong farmer associations; • No associations of straw suppliers.
Natural resources	• Sufficient straw resources; • Significant grain crop production; • Large potentials of lands for 2nd generation feedstocks.	• Soil impacts from excessive and uncontrolled straw removal and unsustainable agricultural practices.
"Hard" technical components	• Existing agricultural machinery (e. g., bailers); • Infrastructure in place (e. g., DH networks); • National production lines for biomass-fired equipment; • Conversion facilities on fossil fuels of varied scale.	• No baling tradition in straw handling; • No water distribution networks in rural areas; • No "cheap" domestic biomass boilers; • No national production of biomass-fired boilers above 2 MW and straw-fired boilers above 1 MW; • No national production of biomass CHP boilers.
"Soft" non-technical components	• Support schemes for bioenergy and renewables; • Low cost and competitiveness of agro-biofuels; • Fast payback of Ukrainian straw-fired boilers; • Traditional practices of straw-to-energy in villages; • Locally acquired co-benefits; • Equipment sharing between actors; • 'Good practice' examples on straw-to-energy in UA; • Practices of successful foreign cooperation; • First straw supply contracts.	• Imperfections in bioenergy support schemes; • No fossil fuel taxes or differentiated emission taxes; • Lack of access to funds and low paying capacity by key actors; • Prejudice against 'old' traditions of straw-firing for energy; • Lack of awareness, knowledge and expertise on bioenergy options among key bioenergy actors.

7.2.1 Straw-to-energy in Ukraine: reality and determining factors

7.2.1.1 Actors and networks

An important facilitating factor for the development of bioenergy sector in Ukraine is the existence of the national bioenergy leader SEC Biomass. The organisation is involved in bioenergy research and development (**+F2**) and business activities (**+F1**) in the country, carries out demonstration projects (**+F1, +F2**), conducts a continuous dialogue with politicians and government officials in Ukraine (**+F7**), organises and leads educational seminars and workshops dedicated to bioenergy, energy efficient technologies and Kyoto mechanisms (**+F3**), etc. SEC Biomass also organises annual international conference on "Biomass to Energy", which serves as a networking platform for many bioenergy actors not only in Ukraine but also in other EiTs in Eastern Europe.

On the other hand, one of constraining factors for bioenergy development is the absence of a strong and influential national bioenergy association in Ukraine (**-F3, -F7**) similar to those that exist in Sweden or Denmark. Moreover, the agricultural sector in UA lacks strong and well-established farmer associations (not surprisingly in the light of socialism till 1990), which could become precursors for the creation of local and national straw supplier associations as it happened in DK. As it is put forward by neoinstitutional theorists (Aldrich & Fiol 1994), institutional legitimacy can only be achieved collectively when founders of a new activity are no longer working as isolated individuals but form industry councils, cooperative alliances, trade associations, and other vehicles for collective action. Collective action ('running in packs') presupposes, however, a prior development of a TIS and the existence of initial markets (Bergek et al. 2008). In other words, collective action is a strategy to move the system from its formative phase of development to intermediate phase, which is required for Ukraine's bioenergy sector. Thus the establishment of meaningful forms of collective action (e. g., Bioenergy Association) is desired on the way towards the institutionalisation of bioenergy sector in Ukraine.

Significant internal market potential for commercialisation of straw-to-energy technology in UA (Sub-section 4.3.3) and existence of local and sub-regional actors with energy needs (**+F4**) are among important facilitating factors for the agro-bioenergy sector establishment. Not least important is the interest shown by national and foreign actors in the development of a bioenergy business in UA (**+F1**). In addition, Ukraine has its national producers of agro-biomass-fired boilers, heat generators and grain dryers, who could supply required equipment to the market (**+F3**).

Although some funding national bodies (e. g., National Environmental Investment Agency) and possibilities to participate in the international funding schemes (e. g., grants and programmes) exist, the number of potential funding institutions and sponsors is limited in Ukraine (**-F6**). In addition, the number of individuals with sufficient funding capacities to invest in an agro-biomass fired installation of a medium or large scale is relatively small (**-F1**).

Since the majority of existing straw-fired installations in UA are privately owned, there is not much participation observed from the side of local authorities (**-F7**). In many cases they demonstrate low degree of cooperation and low interest. Another complication to the agro-bioenergy sector establishment in Ukraine is the existence of market incumbents with opposing interests and lobbies for conventional fuels (i.e. coal, natural gas, oil, nuclear) (**-F7**). The later fact is also recognised by theoretical schools of thought, who find it particularly challenging to acquire legitimacy in energy and transportation sectors due to strong incumbents (Bergek *et al.* 2008).

It is clear that Ukrainian actors are currently working towards bioenergy sector legitimisation in it its formative phase. They conduct a number of studies on the assessment of performance and potential of biomass technologies, implement demonstration projects and in this way are constructing 'rational' arguments. Once this level of legitimacy is achieved, the country will move into intermediate phase of its bioenergy sector development, where familiarity, commitment and trust by various stakeholders becomes increasingly important, and where collective action becomes more significant (Bergek *et al.* 2008).

7.2.1.2 Natural resources

As it was shown earlier (e.g., Sub-section 1.1.4, Section 4.5), Ukraine has large and sufficient volumes of straw in rural areas, which are available for energy on a continuous basis due to high grain crop production in the country (**+F4**). A potential constraining factor is linked here to the risk of excessive and uncontrolled straw removal and unsustainable agricultural practices, which could contribute to negative impacts on soil and other environmental media (**-F4**).

Ukraine has also significant land resources available for the cultivation of so called 'feedstocks of the future' (i.e. perennial grasses) (**+F4**). Supply chains of perennial grasses (e. g., miscanthus, hemp, switchgrass, etc.) are of potential interest as they are to a large extent similar to these of straw with the only difference that these crops are grown specifically for energy purposes unlike grain crops (A. Gray pers.comm. 2009; Göransson pers.comm. 2009). Thus perennial grass plantations can become a next logical step in straw-based energy systems, which is one potential pathway for Ukraine's agro-biomass sector in case straw supply becomes limited in the future.

7.2.1.3 "Hard" technical components

Examples of Ukrainian initiatives on energy production from straw clearly demonstrate that straw-to-energy markets and the whole sector are in their latent phase of development (**-F5**), and straw is not commercialised as an energy carrier in the country yet. Working straw-fired installations do not exceed 1 MW. This is to a certain extent linked to the fact that in UA there are no technological production lines of straw-fired boilers or heat-generators larger than 1 MW (**-F1, -F2**). As it was pointed in Sub-section 4.4.2, Ukraine also lacks national producers of biomass-fired equipment above 2 MW including co-generation installations, and "cheap" domestic biomass-fired boilers of 10-50 kW (**-F1, -F2**). UTEM is the dominating straw-fired boiler manufacturer in the country (**+F1, +F2**).

The majority of straw-fired installations in rural areas in UA do not supply hot water along with the supply of heat. This can be explained by the scarcity of central water distribution networks and sewage systems in the villages (**-F4**). However, potentially all of the boilers could also supply hot water (**+F4**), which is planned with two latest UTEM installations (boilers 21 and 22 in Table 6-1) (UTEM 2009b; UTEM 2010). On the other hand, a more smooth and easy transition pathway towards straw-for-energy can be attributed to the existing DH networks (**+F4**) and old tradition of biomass use for energy in rural areas in UA (**+F2**). Also existing energy infrastructure (i.e. boiler-houses, small and medium co-generation units, and large power plants) that uses conventional fuels (i.e. coal, natural gas and oil) can be potentially converted to biomass. The later fact is a typical example of 'a technology spillover' described by Bergek *et al.* (2008). Clearly a new bioenergy system will emerge and get accepted easier, and will gain competitive advantage faster, if it utilises (either partially or fully) resources and/or infrastructure from the incumbent system, which is the most similar to it. In this case associated costs and uncertainty risks would also be lower.

In almost all straw-to-energy cases in UA bailers are owned by agricultural enterprises, who are feedstock growers and supply straw either to their own boilers or to the boilers owned and operated by local municipality. In two cases bailers are rented by the farmers from their neighbours, which is an example of an equipment sharing practice between the actors in a straw-supply chain (**+F6**). On the other hand, the absence of a baling tradition in Ukrainian straw handling practices (**-F2**) (Sub-section 4.4.2) and insufficient number of bailers in rural areas in UA (**-F6**) are among constraining factors for agro-bioenergy sector development in the country.

7.2.1.4 "Soft" non-technical components

The development of the first support schemes for bioenergy and renewable energy (Sub-section 4.2) is a significant step forward that creates preconditions for the bioenergy sector establishment in Ukraine. State documents and programmes define clear targets on biofuel production and use in UA by 2020 (**+F4**). With continuous increase in prices for natural gas from Russia (**+F5**), forecasted increase of natural gas tariffs for population (**+F5**) and removal of cross-subsidisation scheme (**+F5**) (Sub-section 4.3.2), and with the introduction of the Law *On*

Green Electricity Tariff[25] (**+F5**) (Sub-section 4.2.3) energy from biomass is more likely to become competitive with conventional energy sources in Ukraine. Feed-in-tariff for electricity establishes cost preferences for bioenergy production and use, and thus creates incentives for biomass-fired CHP installations. Existing tax exemptions on revenues of biofuel producers from biofuel sales and on enterprise income from co-generation of heat and/or power from bioenergy can create advantageous conditions for small and medium farm entrepreneurs (**+F6**).

While support schemes may be a significant step forward, they still have a number of imperfections. As such almost no attention is given to energy crops that form feedstock for second generation biofuels. *State Programme on Biofuel Development* (Sub-section 4.2.1) does not specify any sustainability criteria for biofuel production (**-F4**). The *Law on Support of Biofuel Use* (Sub-section 4.2.2) does not clearly include unprocessed biomass (e.g., wood and crop residues) and agricultural, forestry and other enterprises that are not biofuel producers per se (**-F4**). The *Law on Green Electricity Tariff* (Sub-section 4.2.3) has a number of apparently significant flaws due to incomplete definitions of bioenergy (**-F4**), the absence of price differentiation between bioenergy sources (**-F5**), exclusion of co-firing installations from the regulation and sophisticated procedure for the receipt of green electricity certificates (**-F6**). Also no fossil fuel taxes or differentiated emission taxes exist in the country today (**-F5**). The absence of transparent governmental influence (**-F7**) (see Annex VII, case study 7 for details) is another factor hindering the success of straw-based energy systems in the country.

Economic analysis of energy sources in UA (Sub-section 4.3.2) has shown that agro-biomass fuels are competitive with conventional ones (**+F5, +F6**). In addition, the payback for Ukrainian straw-fired boilers is relatively fast (about two years) (**+F6**). A constraining factor is linked to the biomass installation investment cost, which requires sufficient individual funding capacities of actors whereas finance markets are still poorly developed in Ukraine (**-F1, -F6**). As such, representatives of Ukrainian rural communities (i.e. farmers and municipalities), who are among

[25] In international terminology "green electricity tariff" is better known as 'feed-in-tariff' for electricity

key potential owners of such boilers, very often cannot afford their installation due to limited funds.

All experiences of straw use for energy in the country also involve a number of locally acquired co-benefits (e. g., achievement of energy self-sufficiency, economic savings from fuel substitution, funds circulation within local budgets, more efficient workload distribution, improvement of environmental situation, etc.) (**+F6**). In most cases it is reported that no additional jobs directly linked to the boiler operation and maintenance were created. However, a positive co-benefit observed in all cases is that money is kept and is circulating within the local economy (**+F6**). In all cases in UA valorisation of wasted straw, crop residues and sometimes wood waste was achieved with the installation of a straw-fired system (**+F6**).

The role of actors and human factor are important in the transition towards straw use for energy in UA. Many farm managers who own straw-fired installations have higher education and sometimes hold a PhD degree (**+F6**). Often a determining role for the success of the project can be attributed to its enthusiastic initiators and leaders (e.g., businessmen, researchers, consultants, school teachers, representatives of local municipalities, etc.) (**+F4**).

On the other hand, the lack of awareness, knowledge and expertise on bioenergy options among key potential bioenergy actors (e.g., representatives of rural communities including farmers, agricultural entrepreneurs, citizens with heating needs, etc.; business groups interested in bioenergy investments; local authorities and municipalities, etc.) are among key constraining factors for bioenergy business start up in Ukraine (**-F2**).

Despite prejudices by some representatives in Ukrainian rural communities who perceive straw-firing for energy as a step backwards in the national economic development, a number of 'good practice' examples already exist in the country (**+F1**) (Chapter 5). All of these involve knowledgeable and enthusiastic prime movers (**+F2**), successful foreign cooperation (**F1**), first attempts of equipment sharing (e. g., renting of bailers) (**+F6**) and first trials to develop written straw supply contracts (**+F1**, **+F5**). All of these are undoubtedly among facilitating factors for the establishment of Ukraine's agro-industrial bioenergy sector (Table 7-3).

7.2.2 Comparison of straw use for energy in Ukraine and Western Europe

Section 7.2 yielded evidence of five different generic frameworks for organisation and action. Two of those (ABF 1a and ABF 2b) were encountered both in Western European and Ukrainian context, one (ABF 1b) was specific for Ukrainian conditions and two (ABF 2a and ABF 3) were only found within straw-for-energy initiatives in the EU. All ABFs share key components but differ in accordance with the nature of goals and energy end-use needs, ownership of the installations, number of actors involved, degrees of system complexity and formalisation, and drivers for transition towards straw.

For all ABF types the sizes of farms in UA are larger on average than those in the EU. In UA the main users on small scale are not only grain-dryers but also enterprises. Besides, there are no grain-drying installations that use water-based boilers in UA.

Straw bales in the majority of Ukrainian cases have an average weight of 300 kg (Fig. 6-4) while in Swedish and Danish systems these are standardised 500 kg bales. However, this is also linked to the boiler scale in UA, which are smaller than those on Swedish and Danish farms for all ABF types. Annual straw requirements are quite similar among countries, and depend on the boiler capacity. Straw storage is different for all cases, and there is no specific trend observed depending on the size or type of the installation. Both in UA and in Western Europe, ash from straw combustion is mainly returned to the soil.

All straw-fired installations in UA are only generating heat due to their small capacity. Danish experiences show that CHP plants running on straw do not exist below 10 MW (Sander & Skøtt 2007). Most of Swedish initiatives use energy from straw at small or medium-scale (i.e. in the boilers of up to 6 MW).

All straw-firing equipment in SE and ES is of Danish manufacture, which also proves that DK has a longer experience and is more advanced in straw combustion technology. A number of factors can be attributed to the success of straw industry growth in Denmark (Sub-section 5.1.2). These include availability of biomass in large quantities, strong political will in the country and adoption of relevant and efficient policies on straw expansion with concrete targets, continuous review and adjustment of these policies, efficient mechanisms of economic support, important role of collective action, and extensive research in the field.

In Ukraine, unlike the EU no cooperative ownership of DH networks is encountered. For analogous installations in UA and Western Europe investment costs are lower in UA while the payback periods are relatively the same (about 2-3 years for comparable systems below 1 MW).

In UA energy security and a desire to achieve energy self-sufficiency in remote areas were observed to be some of the key driving forces for the transition towards straw. With increasing prices for natural gas imported from Russia (Sub-section 4.3.2) a trend towards an increased development of renewable energy alternatives is obvious in UA. Energy security has a continuous influence and is forecasted to become a facilitating factor for the development of renewables and bioenergy in particular. However, it is not likely to bring ground-breaking changes in the existing energy system until market distortions in the form of cross-subsidised energy tariffs are completely removed in Ukrainian system, and when private users will start paying the real price for conventional energy carriers (Geletukha & Zhelezna 2010a).

Since straw is mainly sold locally, the differences in straw prices within the country and between countries are significant (Sander & Skøtt 2007). As such the fuel price of straw in UA is EUR 1.70 per GJ (Geletukha & Dolinsky 2009), which is much lower than that in SE (EUR 2.59-3.76 per GJ) (Simmons 2008) and in DK (EUR 3.35-4.63 per GJ) (Palle pers.comm. 2009; Sander & Skøtt 2007). The most expensive stage in a straw supply chain in all countries is baling, which contributes up to 25% of the total straw cost as a fuel (Simmons 2008). Straw prices are also determined by the distances between producers and consumers (Sander & Skøtt 2007) and depend on who is responsible for straw handling (Palle pers.comm. 2009).

Importantly, all successful examples of transformation towards bioenergy include some types of co-benefits and links and cooperation or collaboration between actors in the biomass chain in the form of contracts, agreements or through shared co-benefits are crucial to progress. In UA similar to Western European context all successful examples of transformation towards straw/bioenergy include a number of economic, environmental and social co-benefits leveraged between the actors in one way or another.

Both in the EU and UA the degree of stakeholder engagement and commitment grows with the increased degree of the system complexity (Sub-sections 0 and 6.3). Portfolio farmers (Sub-section 3.4.3) occur only within the most complex existing agro-biomass framework type in Ukraine. In Western European examples the same trend is observed: while pluriactive farmers are encountered only at small scale level, portfolio farmers are more likely to be met in more complex and large systems.

7.3 Pathways for agro-bioenergy development in Ukraine

In this Section potential transformation pathways towards straw use for energy in Ukraine are delineated taking into account the 'best practice' examples from the EU (Chapter 5) and specifics of Ukrainian setting (Chapters 4 and 5). Each Sub-section first presents current development state of each of the three pathways in Ukraine, compares it to the EU context and discusses its relevance for UA. It then defines a set of key prerequisites for the country to follow, if UA decides to undertake one or more of the three principal pathways in the development of its agro-bioenergy potential. These pathways include 'straw for local heating' (Sub-section 7.3.1), 'straw for district heating' (Sub-section 7.3.2) and 'straw for combined heat and power' (Sub-section 7.3.3).

7.3.1 Pathway One: Straw for local heating

The first pathway of straw use for energy includes two agro-biomass frameworks for organisation and action, which were described in Section 7.1, namely *ABF 1a: Small scale local heat production* and *ABF 1b: Small scale local straw production for fuel sale to municipality*.

ABF 1a in UA is quite similar to the same ABF identified in SE and DK (Sub-section 7.1.1) with the only difference that in UA the main users of energy from straw are not grain-dryers but agricultural enterprises requiring heat for their premises. This is linked to the fact that UTEM being a leading straw-fired boiler manufacturer does not envision the use of their water-based boilers in grain drying units (Svintsitskiy pers.comm. 2009).

However, this research indicates that straw can be used in grain dryers in rural areas in UA because such demand exists. The introduction of biomass-fired grain drying technology in Ukraine on a broad scale is desired within Pathway One. In order to achieve this, market assessment of agro-biomass fired grain drying units that could be installed in Ukraine needs to be carried out, and the appropriate supplier of the necessary equipment should be found either inside the country (i.e. a potential manufacturer) or abroad (i.e. an existing manufacturer).

Also a general pattern observed is that in UA the installations within ABF 1a type are of smaller capacities than in Western Europe. Overall this framework type is a quite successful pathway for organisation of straw resources in Ukraine. This is, first of all, linked to the relative simplicity of the system, and the low number and diversity of actors involved (Table 7-2). However, currently the number of straw-fired installations that are below 1 MW can hardly reach 100 units while their market potential for commercialisation is assessed at 10 000 (Geletukha & Zhelezna 2010b) (Sub-section 4.3.3). Further expansion and commercialisation of such installations is desired in Ukraine. Not least important is the need for competitive equipment manufacturers to emerge to stimulate technology development, bioenergy industry growth and maturing.

ABF 1b (Sub-section 7.1.2) is identified only in Ukrainian setting and has not been encountered in selected EU countries. From Ukrainian experiences it can be concluded that private ownership of straw-fired installations is one of the important predetermining factors for the enterprise success. This is also noted by Ukrainian bioenergy experts (Oliynyk pers.comm. 2009). In UA in ABF 1a and 2b, where the majority of successful cases on straw for energy can be found, private business interests of actors or agricultural companies played the key role for the transition. In the initiatives within ABF 1b, where a straw-fired boiler is owned by local municipality, a wide range of problems were encountered. These problems were mainly linked to the commitment of actors, their interests and a desire to collaborate to achieve a common goal. For example, the main difference between the project case in Vyshnyuvate (see Annex VII, case study 7 for details) and the functioning case in Zlatoustivka (see Annex VII, case study 8 for details) was the fact that in Zlatoustivka a straw-fired boiler was owned by the agricultural enterprise and the DH provision was ensured by entrepreneurs among their business activities. In Vyshnyuvate the boiler was planned to be financed from the state budget and owned by local municipality, which did not show any commitment but rather opposed the idea. The opposition was mainly linked to the lobby interests of the decision-makers, who were in favour of keeping the functioning coal supply system in place.

This analysis provides evidences that the problems described are encountered where local authorities and municipalities play a key role as decision-makers. The root of the problem is in the absence of a robust and efficient incentive based system that would stimulate local governmental actors support and participate in the transition of the existing systems towards straw use for energy. In this sense, the case of Vinnytsya province, which has a functioning and effective state programme on the promotion of renewable energy sources, should be taken as a positive example of established incentive system for straw support by local authorities.

7.3.2 Pathway Two: Straw for district heating

The second pathway of straw use for energy includes two agro-biomass frameworks for organisation and action, which were described in Section 7.1, namely *ABF 2a: Medium scale local heat provision with excess for sale* and *ABF 2b: Medium scale conversion and district heating.*

ABF 2a was only encountered in Western European context and does not exist in Ukraine yet. Moreover this framework type does not look promising for UA's context. Its key factors of success include the ownership of a boiler and a distribution network by well-off rural citizens, who diversify their income by selling excess heat to local energy companies. First, in UA's setting it is not very likely that the owners of new straw-fired boilers would install significant excessive heat capacities since their paying capability and access to funds is quite limited. Second, even if this could occur, considering conservative approach of energy companies in the country and still existing lobbies for the fossil fuels (e.g., natural gas or coal), the sale of excessive heat to centralised grids by private producers can be complicated.

Comparing ABF 2b (Sub-section 7.1.4) in UA to Danish and Swedish experiences, it should be noted that "medium scale" is defined differently for Ukrainian and Western European context. In UA these are small installations up to 1 MW while in the EU medium scale implies that the boiler has a capacity of 1-6 MW and thus represents a more complicated technological system with automatic straw feed in and shredding. It is rather the nature and shape of organisational factors and forms that enables comparability and certain degree of analogy of this framework type between the systems in UA and the EU.

The reasons for transformation in SE and DK were somewhat different from those in UA, and included political and legal support in addition to economic gains achieved with fuel substitution. In UA one of the key drivers for transformation towards bioenergy on different scales except for economic benefits is the issue of energy security provision.

In Sweden and Denmark DH grids are less common than in Ukraine, which has a Soviet heritage of heat distribution networks in towns and cities. In SE this is one of the constraining factors for the expansion of straw use for private heating. In DK this problem was solved in many cases by private owners installing the boiler and the heat distribution network at their own expense.

In DK an important factor that stimulated the proliferation of straw-fired DH systems involved the actions by local farmers who united their efforts in straw supply associations (Hinge pers.comm. 2010). These associations coordinated straw supply chains, negotiated straw prices between farmers and DH plants, established platforms for securing the best possible quality of straw and ensuring its timely delivery, etc. Straw supply associations also play an important role as knowledge and assistance providers to local farmers as they help farmers understand how much straw they can sell for energy, how much benefit they can get, etc.

European experiences show that medium scale installations for neighbour and district heating, if privately owned (which is quite widespread in DK), require significant private investments (in the range of EUR 0.5-1.3 million[26] per 1 MW of installed thermal capacity) both for the boiler installation and the DH network construction (Table 7-1, Sub-section 7.1.4). Financial constraints in Ukraine can be quite significant at this level taking into account a relatively low purchasing capacity of Ukrainian farm-based entrepreneurs. In this case funding schemes would be required for the expansion of straw use for energy at medium scale in UA and to ensure its continuity. These can involve grants from governmental and non-governmental structures, various forms of foreign assistance (e. g., international funding schemes, foreign business investments, etc.), state subsidies on the equipment purchase, bank loans with favourable interest rates, etc. It is also important to attract the interest of business groups with sufficient funds who could support the expansion and proliferation of the industry. This, for example, can be aided with a construction of a 5-10 MW demonstration straw-fired DH plant in the country (Sub-section 7.4.4), which could potentially serve as a local 'best practice' example.

While the country has introduced a number of policies that were recognised by Bauen *et al.* (2009) as supporting early bioenergy markets (e. g., tax exemptions, 'feed-in-tariff' for electricity), Ukraine has "missed" those instruments that support R&D phase in bioenergy technology development. The later include investment related subsidies, e. g. for the realisation of demonstration projects, to reduce the initial barrier on investment cost (Bauen *et al.*2009).

In Ukraine the market potential for 1-10 MW straw-fired DH plants was assessed to be significant. It is deemed feasible to introduce 1000 of such installations in the country by 2015, which will require UAH 1.2 billion[27] of investments (Section 4.3.3) (Geletukha & Zhelezna 2010b). However, there is only one installation of 1 MW (see Annex VII, case study 9 for details) and no larger straw-fired boilers exist in UA. Therefore it is important to define key factors that determine the rate of adoption of similar installations (i.e. *Pathway Two*) in the country and in which such installations can become the most optimal solution. These factors are delineated

[26] In Ukraine estimated figures on investment requirements for 1-10 MW straw-fired boilers are EUR 0.062 million per 1 MW of installed thermal capacity (Sub-section 4.4.1) (Geletukha & Zhelezna 2010b), which is astonishingly lower and thus is a subject for further scrutinisation.

[27] UAH 1.2 billion = EUR 123 million (EUR 1 = UAH 9.78 as of 1 June 2010)

from successful Western European examples and from the first Ukrainian attempts to create a straw-fired DH plant (i.e. Zlatoustivka and Drozdy), and are discussed below.

First, on the demand side, the heat distribution network with substantial heating requirements is desired to be in place to make the transformation less intensive in economic and technological sense. In other words, 'technology spillovers' (Bergek *et al.* 2008) are desired to be encouraged.

Second, an important factor identified by Radchenko *et al.* (2009) is the area availability for construction works and straw storages (or existing straw storage places). In Ukraine the problem of quite dense constructions in rural areas and the lack of space were recognised as a mechanical barrier to the transformation towards local straw use for energy.

Third, more knowledge is needed in regards to the optimal and available sources of funding and potential funding schemes (e. g. international grants, bank loans, leasing, etc.) of such installations in Ukraine.

Fourth, relevant technology needs to be developed in the country to ensure the expansion of straw-fired DH plants. Currently in Ukraine there exist only one straw-fired boiler producer, and the maximum capacity of the manufactured boilers is 860 kW. The equipment needed for bigger installations, can in the first instance be purchased from abroad, which can also be achieved at lower cost with the functioning law of Ukraine that exempts such equipment from customs tax. However, to ensure the continuity of similar installations and reduce their costs, local equipment manufacturers will be necessary.

Fifth, a reliable straw supply chain should be organised to ensure the security of the fuel supply to DH plants. In this sense it appears desirable that local straw supply associations are formed following the Danish experience. This would also enhance socio-political legitimacy of bioenergy systems at intra-industrial level (Table 2-4, Sub-section 2.5.1) Successful Western European examples (Chapter 4) show that for smaller installations (up to 6 MW) there is often no need for any formalised procedure between straw suppliers and buyers, and all relationships can be based on mutual trust. For bigger systems, however, written contracts would be required.

Sixth, municipalities must show commitment for the switch to straw-for-energy. While governmental incentives for the transformation of local energy systems towards bioenergy can be a significant driver for such transformation (Sub-section 7.3.3), it is not a necessary precondition for Pathway Two and may indeed be insufficient without municipal support. The latter is desired to enhance the 7th function of the bioenergy system namely "support from advocacy coalitions" (Table 2-5, Sub-section 2.5.2). On the other hand, any governmental assistance (e. g., subsidisation schemes, support and involvement in demonstration projects, etc.) should be viewed as an additional facilitating factor for the transition towards straw-fired DH systems as it enhances a number of bioenergy system functions (e. g., resource mobilisation, knowledge development, knowledge diffusion, etc.).

7.3.3 Pathway Three: Straw for combined heat and power

The third pathway of straw use for energy is represented with *ABF 3: Large scale power or combined heat and power generation* (Sub-section 7.1.5). This does not exist in Ukraine yet. In Europe functioning plants are found in Denmark, Spain, England, etc. In Sweden the plant of the kind (i.e. Örtofta – see Annex VI, case study 12 for details) is only planned to be constructed.

It is shown that large energy plants are responsible for the establishment of straw markets in the region. Swedish (Sub-section 5.1.1) and Danish (Sub-section 5.1.2) examples reveal that medium and large scale straw-fired installations often require political support with targeted incentives in addition to purely economic reasons for the transformation. In addition, the role of collectives is found to have played a crucial role in DK, where local straw supply associations stimulated the proliferation of energy from straw at medium scale and the national association helped to increase the use of straw for energy at large scale in CHP plants (Sub-section 5.1.2). As it was outlined in Sub-section 2.5.1, an important set of constraints, which entrepreneurial emerging industries face, is in the lack of collective mechanisms to reshape industry and institutional environments (Aldrich & Fiol 1994). As such, the lack of collective action and availability of alternative fuels (primarily wood) in Sweden are found to be the main reasons for the absence of functioning large scale straw-fired installations.

Another important factor of a successful straw use at large scale is a well-established straw-supply chain. The security of fuel supply in large installations is ensured with long-term written contracts. The ways to organise these contracts can be different (Sub-section 7.1.5): either the energy company concludes contracts with each individual straw supplier or the contracts have a limited number of undersigned (i.e. are concluded between the energy company and a sub-contractors or a farmer association).

Pathway Three will be quite challenging for Ukraine to uptake as it is the last step in agro-biomass industry establishment and straw-to-energy market formation. There are a number of prerequisites that should be in place in the country before Pathway Three can emerge.

First and foremost, a targeted governmental policy with specific targets on straw use for energy/electricity production needs to be in place. It would positively contribute to 4th TIS function (i. e. "guidance of the search") (Table 2-5, Sub-section 2.5.2). In addition to existing "green electricity tariffs", a carbon tax on fossil fuels or similar policy intervention will be required to be introduced to create cost preferences for biomass use for energy, stimulate market formation and resource mobilisation (**F5** and **F6** respectively in Table 2-5). Subsidy schemes for the construction of large scale straw-fired plants would further stimulate the development of straw-to-energy sector via enhanced resource mobilisation (**F6**). All of these actions are supposed to enhance socio-political legitimacy of bioenergy systems at institutional level (Table 2-4, Section 2.5.1).

Second, there is an ultimate need of technology transfer from experienced Danish producers of straw-fired co-generation equipment to Ukrainian manufacturers. Due to its climate features and existence of DH distribution networks Ukraine is more likely to follow Danish rather than Spanish scheme in the introduction of large scale straw-fired technology.

Third, as for Pathway Two, it is crucial to identify feasible funding schemes and forms of ownership for large scale straw-to-energy systems. In addition, it is important to assess market potential for the introduction of straw-fired CHP installations that are bigger than 10 MW.

Fourth, secure straw supply chains need to be ensured. Long-term written contracts on fuel supply to large CHP plants will be required. Following Danish experience, the formation of collectives that will be responsible for straw supply on local and sub-regional levels is also desired. Such associations are likely to support local producer interests and create a counterbalance against fossil fuel and nuclear lobby groups in the country. They are supposed to positively contribute to knowledge diffusion (**F3** in Table 2-5, Sub-section 2.5.2) and to the enhancement of socio-political legitimacy of bioenergy options in Ukraine at intra-industrial level (Table 2-4, Sub-section 2.5.2).

For Ukraine it will be easier to follow *Pathway Three* once installations suggested in *Pathway Two* have become common in the country. Increasing the cognitive legitimacy of straw-to-energy options via, for example, the construction of a demonstration straw-fired DH plant in Ukraine, would help mobilise resources, form demand and help involved actors acquire political strength (Sub-section 2.5.1) (Bergek *et al.* 2008). The consequent transition from Pathway Two to Pathway Three would entail a number of learning experiences in terms of technology, straw supply chain organisation, straw supply associations built up, counterbalancing against fossil fuel and nuclear lobbies, etc.

Pathway Three may not, however, turn out to be the most optimal for Ukraine in the long run, in case the country is interested to utilise biomass for heat and electricity production at large scale. Since UA has a well-developed natural gas network, the strategies on transition to biogas application instead of biomass combustion can eventually turn out to be more feasible. However, these opportunities need further scrutinising as biomass gasification technology is still in demonstration/early commercial phase elsewhere and remains cost-intensive (Bauen *et al.* 2009).

7.4 Recommendations: Moving forward

Taking into account the discussion of the pathways in Section 7.3 and criteria for their implementation in Ukraine a number of recommendations are presented in this Section. These recommendations are focused at target audience groups to this study (Sub-section 1.2.4) including Ukrainian policy makers, local and sub-regional authorities in the country, non-governmental actors, academia representatives and researchers in UA, EiTs and other countries, in case they desire to pursue the use of straw for energy. Section 7.4 concludes with a suggestion to construct a 5-10 MW demonstration straw-fired DH plant in Ukraine in order to increase knowledge and awareness about agro-bioenergy options, attract potential national and foreign investors, and try new technologies.

7.4.1 Policy makers in Ukraine

The following prerequisites are desired to be pursued by governmental leaders and local and sub-regional authorities, if they wish to achieve the transition towards straw-based energy systems of various scales and stimulate agro-bioenergy development in Ukraine. Most of these recommendations are targeted at the protection of market spaces for bioenergy as the later fact is recognised to be a crucial factor in the formative phase of an emerging industry defining its further survival (Bergek *et al.* 2008).

1. Support the implementation of the first demonstration 5-10 MW straw-fired DH plant (Sub-section 7.4.4) in a Ukrainian town with financial and technical resources. This activity should positively contribute to the expansion of entrepreneurial activities (**F1**) and knowledge development (**F2**) in the bioenergy sector. Such plant can potentially serve as 'the best practice' example for the future expansion of similar technology systems in Ukraine, encourage "convergence around a dominant design" and thus stimulate faster legitimisation by key actors.
2. Seek for potential sites to implement other demonstration and pilot agro-bioenergy projects, which could increase awareness, knowledge and understanding of various actors in the area (i. e. stimulate knowledge development (**F2**) and guide the search (**F4**), and improve attractiveness of bioenergy options to national and foreign investors.

3. Remove cross-subsidised tariffs for natural gas between population, communal services and industrial sector. Creating cost preferences for and promoting renewable energy sources (including energy from biomass) in this way would stimulate market formation (**F5**) and resource mobilisation (**F6**) in bioenergy systems in UA.
4. Introduce a carbon tax for fossil fuels or similar policy intervention to encourage more streamlined formation of bioenergy markets (**F5**), mobilisation of resources (**F6**) and in this way enhance socio-political legitimacy of bioenergy at the institutional level.
5. Introduce a state subsidy on the purchase of biomass-fired equipment/machinery to increase its affordability for potential owners and operators and thus stimulate resource mobilisation (**F6**).
6. Develop and stimulate the implementation of regional state programmes on the promotion of renewable energy and bioenergy use in order to create efficient incentive based schemes for local and sub-regional authorities and improve guidance of the search by them (**F4**).

7.4.2 Non-governmental actors

Since the variety of non-governmental actors is significant, and it includes both national and international audiences (Sub-section 1.2.4), the recommendations for those desiring to pursue straw-to-energy pathways are structured according to the different actor groups and include the following:

1. Non-governmental actors with *business interests* in bioenergy in UA and *bioenergy consultants* should seek for potential energy objects to be converted to agro-biomass. Such objects should be primarily located in the regions with the highest estimated potentials for crop residues (Section 6.1), significant heat demand and functioning heat distribution networks. To stimulate entrepreneurial activities (**F1**) the actors should develop concrete business ideas about transformation of such objects to bioenergy.

2. *Farmers* and other representatives of *rural development audiences* should strengthen local farmer associations and seek to form local associations of straw suppliers. The later could further unite their efforts in a National straw supply association. An ultimate goal of straw supply associations is to create a powerful counterbalance in the country against fossil fuel and nuclear lobbies (**F7**), stimulate knowledge diffusion (**F3**) and eventually increase the legitimacy of bioenergy options (i.e. improve knowledge and understanding of those).
3. National *manufacturers* of firing equipment should seek ways (e. g., via technology transfer from Western Europe) to produce grain dryers on biomass in the capacity range of at least up to 2 MW, straw-fired boilers larger than 1 MW and co-generation units of 10 MW on biomass. This will stimulate entrepreneurial activities (**F1**) and knowledge development (**F2**) and facilitate the transition into Pathways Two and Three in Ukraine.
4. *SEC Biomass* should promote its annual Biomass for Energy conference among and encourage participation of rural development audiences including farmers, municipal leaders, etc. It should also find ways to continue its educational seminars on bioenergy targeted at various actors in UA. All these actions are expected to improve the knowledge and understanding of bioenergy options among these actors (i. e. contribute to knowledge diffusion (**F3**) and thus enhance cognitive legitimacy of bioenergy at the inter-industrial and institutional levels of analysis.
5. *Bioenergy and environmental NGOs* should establish a meaningful National Bioenergy Association in Ukraine. Such Association should include a unit or body responsible for carrying fund raising activities for bioenergy projects in UA and providing advice on potential sources of funding for all potential bioenergy implementers. This action is targeted at overcoming financial and cognitive barriers to bioenergy in Ukraine, and also at establishing prerequisites for a more efficient goal achievement via collective action. Collective action is a strategy to move the system from its formative development phase to the intermediate one, which is required for Ukraine's bioenergy sector now.

6. All potential *bioenergy leaders* should search for foreign partnership in carrying out demonstration and real projects. Foreign support in terms of knowledge and technology transfer is required as it helps building up experience, stimulates knowledge development (**F2**) and diffusion (**F3**) and creates opportunities for external funding of bioenergy projects thus activating entrepreneurial activities in the sector (**F1**).

7.4.3 Academia and researchers

Academia, bioenergy research groups and networks have an important role to play for the development (**F2**) and diffusion (**F3**) of knowledge on bioenergy options in the country and the feasibility of their implementation. Thus the following steps are recommended for them:

1. Identify and systematise all potential sources of funding and financial schemes for biomass installations in Ukraine to reduce economic barriers to bioenergy, which are in many instances linked to the low purchasing capacity of the actors in the country. This will stimulate resource mobilisation (**F6**) and market formation (**F5**) around bioenergy systems.
2. Conduct country specific research on the levels of crop residue removal from soils in different parts of Ukraine to identify those that can be acceptable from sustainability perspective and in this manner guide the search (**F4**) of bioenergy practitioners.
3. Assess the current market potential for grain dryers in Ukraine, and a possibility to use crop residues in such in order to develop improved knowledge (**F2**) on the prospects of expansion for biomass-fired grain dryers in the country.
4. Estimate the market potential for straw-fired CHP installations above 10 MW to obtain a better understanding (**F4**) of Pathway Three feasibility in Ukraine.
5. Identify potential suppliers of economically affordable biomass-fired equipment, which is not produced in Ukraine at the moment, to reduce the technological barrier towards Pathways Two and Three, and stimulate resource mobilisation (**F6**) and entrepreneurial activities in the bioenergy sector (**F1**).

6. Seek for potential sites to implement demonstration and pilot agro-bioenergy projects, which could increase awareness and knowledge of various actors in the area (**F2** and **F3**), and improve attractiveness of bioenergy options to national and foreign investors.

7.4.4 Demonstration district heating plant in Ukraine

A boiler in Drozdy (see Annex VII, case study 9 for details) was the first straw-fired installation in Ukraine and remains the biggest functioning one. It was introduced as a demonstration project in 2000 resulting from a successful cooperation between Ukrainian and Danish partners. It proved that straw-to-energy systems were feasible in Ukraine. In the last 10 years about 25 smaller straw-fired boilers were installed all over the country.

In Drozdy case (see Annex VII, case study 9 for details) an important precondition for the success of a biomass installation was the competent piece of advice from SEC Biomass as well as technical assistance and financial support provided by Danish partners. Not the least factor of success was the enthusiasm and desire of the managers to transform the existing system towards bioenergy. Awareness and knowledge of biomass options and clear understanding of their profitability by the actors (i.e. well-established incentive system) formed another important determinant for the transformation.

To demonstrate the feasibility of Pathway Two in UA and to encourage convergence around a dominant design in the field (Table 2-4, Sub-section 2.5.1) it is desirable to construct a demonstration straw-fired DH plant of 5-10 MW, which among other things would provide a functioning example of straw-supply chain organisation in the country. Construction works can be carried out by national boiler producers, who have experience with straw firing technology (e. g., UTEM). Alternatively the needed equipment can be purchased from abroad with the application of the Law on reduced customs tax for such installation. Technical assistance from international straw-fired experts who have been working with medium or large scale systems (e. g., Danish or the like) will be required during the construction works. An expert advice of a knowledgeable bioenergy consultant (e. g., SEC Biomass) is important in the planning stage to carry out a feasibility study of the project and organise straw supply chain for the future plant. The funding of the first straw-fired DH plant in Ukraine can be supplied from the state (e. g., potentially under the framework of the Biofuel Programme) or through international funding schemes (e. g., European Commission).

It is believed that a successful demonstration project will contribute to the development and enhancement of knowledge (**F2**) around straw-to-energy systems in UA and thus increase its cognitive legitimacy in the eyes of key bioenergy actors in the country (Aldrich & Fiol 1994; Bergek *et al.*2008). In addition, it is expected that knowledge diffusion (**F3**) will be achieved and further mimetic processes in the field will occur (DiMaggio & Powell 1991), which will in turn lead to the emergence and expansion of similar straw-fired technologies in Ukraine.

8 Conclusions

Chapter 8 concludes this study. Section 8.1 presents its main findings underlying the answers to key research questions. It summarises important findings from field research, constraining and facilitating factors for bioenergy development in Ukraine and outlines key recommendations for Ukraine, if the country is to follow any of the three suggested pathways for the establishment of agro-industrial bioenergy sector. Section 8.2 explains how this research contributes to knowledge and theory. Section 8.3 suggests ideas for future work.

8.1 Main findings

8.1.1 Introduction

This research investigated a number of pathways for Ukraine to develop its agro-bioenergy potential. It started with articulating the need for the establishment of an agro-industrial bioenergy sector in the country. This, on the one hand, was justified by a number of economic, social and environmental *co-benefits* that bioenergy could deliver for Ukraine and problems it could help to tackle. The most important of the latter include the low level of energy security in UA and high dependence on energy imports mainly from a single supplier (i.e. Russia), poor development of the country's agricultural sector (especially after the collapse of the Soviet Union) and environmental challenges associated with the functioning of traditional energy systems. Despite all the opportunities that bioenergy could offer for Ukraine, biomass is not established as a commercial energy carrier in the country yet, and the whole bioenergy sector in UA is *not yet institutionalised.*

On the other hand, Ukraine was shown to have *significant potential* for all bioenergy sources, and agro-bioenergy in particular. Crop residues and straw were identified as the most promising to be developed in the first instance considering their abundance, low handling costs, relative simplicity of conversion technology and fewer and less complex entailed sustainability challenges as compared to other biofuel options.

This research sought to provide answers to two main ***research questions*** including:

1. *Why is biomass not established as a commercial energy carrier in Ukraine?*
2. *How can Ukraine leverage agro-biomass for energy use?*

The basis for the answer to RQ 1 was provided via a detailed analysis of Ukraine's current bioenergy status, identification of constraining factors for its development and related trends. Answers to RQ 2 were sought via identification of facilitating factors for agro-bioenergy development in Ukraine and delineation of specific pathways for Ukraine to follow, in case its policy makers, local and sub-regional authorities, representatives of non-governmental sector (e. g., business entrepreneurs, consultants, NGOs, farmers, etc.) and academia would like to establish an agro-industrial bioenergy sector in the country.

Prior to the presentation of key findings that contributed to answer these two research questions (Sub-sections 8.1.3 and 8.1.4) the major observations from the field data collection in Ukrainian and Western European contexts are summarised (Sub-section 8.1.2).

8.1.2 Main observations from the field

8.1.2.1 Ukraine

Straw-to-energy is in the latent (formative) phase of bioenergy system development in Ukraine. All existing installations are below 1 MW and there are no technology production lines for larger straw-fired boiler capacities. Currently only heat is produced from straw in Ukraine.

There is no significant political support of straw-to-energy activities in the country, which is found to be a key prerequisite for large-scale straw use and is important on medium scale. Feasible funding schemes that could help mobilise resources and expand the scales of straw use for energy in the UA are not present yet.

Energy security is a driving force that is promising to have further influence on straw sector development on local, regional and national level in UA. Cross-subsidised tariffs for natural gas are still in place.

All three farm-based entrepreneur types - *pluriactive*, *resource exploiting* and *portfolio* - are found within case studies analysed. A higher degree of portfolio-related activity and income diversification is found as systems become more complex.

8.1.2.2 Western Europe

So far in Sweden most of straw-to-energy initiatives are small with only a few of medium scale. There are no working large straw-fired installations. All straw-firing equipment in SE is of Danish manufacture. The straw market in Sweden is *emerging* while in Spain it is *intermediate*, and in Denmark - *established*.

Large CHP plants have underpinned the creation and expansion of straw market in Denmark. Economic policy instruments (i.e. carbon and fossil fuel taxes) influenced a continuous increase in the use of biomass in Swedish and Danish DH systems.

The success of straw industry growth in Denmark is attributed to a combination of strong political will, adoption of effective policy instruments supporting straw use for energy, collective action (in particular that of DSSA), large available volumes of agro-biomass and extensive research in the field. All successful examples of transition towards bioenergy were found to deliver co-benefits, and collaboration between actors in the biomass chain in the form of contracts, agreements or through shared co-benefits are crucial to progress. In line with theoretical propositions outlined in this work, collective action was found to be an important factor for the success of a new straw-to-energy activity at the intra-industrial level and beyond. Organisation and forms of organisation become increasingly important at larger scale.

Mutual trust and personal relationships between farmers and farm-based entrepreneurs are important factors for the functioning of a straw-supply chain at all scales. Contracts are vital for larger installations but these generally need to limit the number of signatories in order to maintain consistency and effective control.

All three farm-based entrepreneur types - *pluriactive*, *resource exploiting* and *portfolio* - are found within case studies analysed. Similar to Ukrainian context, a higher degree of portfolio-related activity is found as systems become more complex.

8.1.3 Constraining and facilitating factors for bioenergy in Ukraine

The delineation of constraining and facilitating factors for bioenergy in Ukraine was guided by neoinstitutional theory with specific inputs from the theory on the legitimisation of new activities and diffusion theories via the analysis of functions in UA's straw-to-energy system. The main ***constraining factors*** to the expansion of energy from straw in Ukraine found in this work include:

- flaws and omissions in bioenergy related legislation;
- imperfections of incentive-based systems for renewable energy/bioenergy (e. g., perverse incentives due to cross-subsidised energy pricing, lack of incentives for municipal leaders to switch to bioenergy, etc.);
- existence of market incumbents lobbying for conventional fuels;
- lack of collective action between bioenergy actors (e.g., absence of a meaningful Bioenergy Association, lack of strong farmer associations, etc.);
- lack of national technology production lines (e. g., absence of national manufacturers of straw combustion systems above 1 MW and biomass-fired installations above 2 MW);
- low access to funds, knowledge and technology by local and sub-regional actors.

The major ***facilitating factors*** for agro-bioenergy development in UA identified in this work include:

- significant grain production with large volumes of available crop residues and availability of large land resources for energy crops;
- existence of a national bioenergy leader (i.e. SEC Biomass) with a potential for network establishment, knowledge development and diffusion in bioenergy field;
- existence of national biomass equipment producers with learning potential towards technology development;
- low cost of agro-biofuels, their competitiveness with fossil fuels for the production of heat and fast (2-3 years) payback of biomass boilers;

- competitiveness of power generation from biomass with that from conventional energy sources due to 'feed-in-tariff';
- interest of foreign actors (e. g., businesses, researchers, consultants, etc.) in biomass-to-energy activities in Ukraine and examples of successful Ukrainian-foreign partnership.

8.1.4 Pathways for Ukraine

This research suggested three major *pathways* for Ukraine to follow, in case its leaders are interested to pursue the use of straw-to-energy at various scales. These pathways logically evolved from five types of *agro-biomass frameworks for organisation and action (ABFs)*, which were constructed, described and analysed in this work via case study analysis of 23 initiatives on straw use for energy in Sweden, Denmark, Spain and Ukraine. These ABFs share key components but differ markedly according to local context and resources, the nature of goals, the number of actors, complexity and degree of formalisation.

Each case study was analysed via the *conceptual framework* developed by the author with the inputs from neo-institutional theory, theoretical considerations for the diffusion of new technologies and practical elements suggested in the literature on the forms of organisation for bioenergy.

Key findings within each Pathway and some of the actions to move forward are summarised below.

8.1.4.1 Pathway One: Straw for Local Heating

- This Pathway exists in Ukraine but is desired to be further pursued. The installation and commercialisation of straw-fired farm units below 1 MW should be expanded as their market potential is shown to be significant.
- The introduction and expansion of straw and crop residue use in grain dryers on a country scale is needed. This is not the case in UA yet, however, this research has revealed an existing demand for such installations. One of the key constraints here is in the lack of relevant national equipment manufacturers.

- The case of Vinnytsya province, which is a national leader in straw use for energy due to its effective programme on the promotion of renewables, should be taken as a positive example for the establishment of a robust incentive system for straw support by local authorities and "guide the search" of bioenergy practitioners.
- Competitive equipment manufacturers are desired to emerge to stimulate biomass technology development and thus bioenergy industry growth and maturing.

8.1.4.2 Pathway Two: Straw for District Heating

- *ABF 2a "Medium scale local heat provision with excess for sale"* does not look feasible for Ukraine's reality and thus in order to circumvent numerous potential barriers is not recommended for the country.
- To pursue the transition towards *ABF 2b "Medium scale straw combustion for district heating"* in Ukraine and overcome some of knowledge and technology barriers to medium scale straw-fired technology (and thus stimulate entrepreneurial activity, resource mobilisation and bioenergy market formation) it is desired to construct a 5-10 MW demonstration straw-fired DH plant in the country.
- Important factors determining successful transition towards Pathway Two include:
    - existence of DH networks that would stimulate technology spillovers between conventional energy systems and bioenergy, and of significant heat demand;
    - availability of sufficient space for the construction of a plant and a barn, and for access routes and pathways;
    - feasible funding schemes for the expansion of straw use for energy on medium scale in UA and for the stimulation of bioenergy market formation;
    - availability of straw-fired boilers above 1 MW in the country (i.e. either through imports of foreign equipment to UA with the application of customs tax reduction or via starting up the national production lines);

- reliable straw supply chains (local associations of straw suppliers are desired; written contracts are not necessary for installations below 6 MW, if mutual trust between straw suppliers and buyers exists);
- commitment of local municipalities to the transformation towards straw heating;
- introduction of investment related subsidies (e. g., for the realisation of demonstration projects), which are found crucial during R&D phase of bioenergy technology development, and should stimulate bioenergy resource mobilisation.

8.1.4.3 Pathway Three: Straw for Combined Heat and Power

- *ABF 3 "Large scale power or combined heat and power generation"* appears quite challenging for UA as there are a number of determinants that need to be leveraged in an optimal way. These include:
  - Targeted state policies with specific economic incentives (e. g., 'feed-in' tariff, carbon tax or the like, state subsidies on equipment purchase and installation, etc.) for biomass use for energy need to be in place in order to guide the search in bioenergy field, stimulate market formation and resource mobilisation.
  - Transfer of straw combustion technology from Denmark is desired to build up knowledge and enhance entrepreneurial activities.
  - Feasible funding schemes for large scale bioenergy installations need to be found, and optimal forms of ownership for those need to be suggested. Market potential for straw-fired CHP plants should be assessed.
  - Straw supply chains need to be organised with long-term written contracts. Straw supply associations (with a potential to form a national association) are desired to be established to stimulate knowledge diffusion and advocacy support of bioenergy options.
- Pathway Three is viewed as a more feasible for Ukraine to follow once the installations within Pathway Two have become common in the country.

- In the long run Pathway Three may not turn out to be the most optimal for Ukraine as the country has extensive natural gas grid in place. Biomass gasification technology once established may eventually step in as a more valid strategy within Ukrainian context.

8.1.4.4 Recommendations

A set of recommendations was put forward for the target audience groups of this thesis including policy makers, non-governmental actors, academia and researchers, who are interested to pursue agro-biomass-to-energy activities in the country and participate in the establishment and/or expansion of new bioenergy systems in Ukraine.

Among other steps, the construction of first demonstration 5-10 MW straw-fired DH plant in Ukraine is recommended. Such plant could potentially become the first and the 'best practice' example for medium scale straw-fired technology in Ukraine. It could also demonstrate the feasibility of Pathway Two in UA, attract potential national and international investors to the bioenergy sector in the country, and facilitate the learning process for bioenergy actors (i.e. increase their cognitive legitimacy) about new technology introduction and its application, the organisation of straw supply system, various forms of collaboration within a bioenergy chain, etc.

8.2 Core research contribution to knowledge and theory

An important outcome of this research involves newly constructed frameworks for organisation and action of agro-biomass based energy systems, the main purpose of which is to demonstrate a clear suite of benefits to key stakeholders once they engage into bioenergy practices. This study is the first of its kind that attempts to structure forms of organisation around straw use for energy and systematically describe their structural elements in a range of contexts that have different levels of straw-to-energy market development. This work is also unique in its kind not only for Ukraine but also for the whole spectrum of countries with economies in transition.

Achievement of a meaningful engagement of the Ukrainian agricultural sector via well-structured frameworks for organisation and action is envisaged as one pathway towards the development of the country's agro-biomass potential. In addition, a clearer picture of opportunities that agro-biomass can offer for the country is drawn.

This study contributes to scientific knowledge and originality in four main directions:

1. Suggestion of a conceptual agro-biomass framework for organisation and action that can be applied in a great variety of contexts and settings for the analysis of bioenergy initiatives and degree of bioenergy sector development.
2. Establishment of prerequisites for a legitimate agro-industrial bioenergy sector in the context of Ukraine and, with limited generalisability, in other EiTs.
3. Discovery of pathways and exploration of strategies to legitimise and institutionalise the emerging agro-industrial bioenergy sector in Ukraine's setting.
4. Engagement of various stakeholders in the establishment of a bioenergy sector in Ukraine with the help of new frameworks for organisation and action.

This study also contributes to theoretical knowledge as it seeks to answer the research questions of *"why?"* and *"how?"* (Sutton & Staw 1995). The work looks for the links between the variables in agro-biomass based frameworks for organisation and action and aims to establish causal paths between them explaining *how* and *why* some variables are connected, and *why* others are not, *why* a particular set of variables are stronger predictors than others (Sutton & Staw 1995). As George and Bennett (2005) put it, such examination of causal paths and researchers' efforts to study the order of steps in these paths can lead to "a plethora of new observable implications for a theory".

The study contributes to the *diffusion theory* by providing a ground for better understanding of the boundaries between emerging/formative, intermediate and established phases in the development of a TIS via the analysis of bioenergy systems. Another meaningful contribution to the theory on the diffusion of new technologies is in the area of 'technology spillovers'. From numerous case studies analysed in this work it is concluded that due to potential technology spillovers new TIS that have more similar features with their incumbents will emerge, get accepted and gain competitive advantage easier and faster than those that do not embed such similarities.

This study also contributes to the *theory on the legitimisation of new ventures*. It shows that improved (enhanced) legitimacy of new systems/areas not only stimulates their proliferation by reducing constraining factors on their development route (e. g., Aldrich & Fiol 1994) but also supports the emergence of new activities within such systems by helping "unlock" the system potential and bring it into motion. In other words, enhanced legitimacy of new ventures leads to unlocking of the potential for the proliferation of new ventures.

8.3 Future research

Some of the areas for future research are directly linked to knowledge gaps identified in this study, and were suggested as a set of recommendations for academia and researchers in Sub-section 7.4.3. These include:

- market assessments for agro-biomass fired grain drying units and straw-fired CHP installations above 10 MW that could be introduced in Ukraine;
- identification and systematisation of potential funding sources and financial schemes for bioenergy projects;
- identification of appropriate potential suppliers of biomass equipment in the country or abroad;
- country specific research on acceptable levels of crop residue removal from soils in different parts of Ukraine;
- identification of potential sites for demonstration and pilot bioenergy projects in Ukraine.

One more important area for future research includes mapping of specific regions within Ukraine and identification of those bioenergy options the development of which can become the most feasible and sustainable pathway within each region.

In addition, *other bioenergy options* than straw need to be scrutinised for Ukrainian reality. It was shown that Ukraine has significant areas of arable land and potentials for the utilisation of lands with low opportunity costs to grow energy crops. As such future research on developing perennial grass plantations in the country is desired as *perennial grasses* form another step in a straw-based energy system (for example, in case crop residue feedstock becomes limited). Calculations need to be made to estimate energy crop production costs and their distribution along biomass value chain in Ukrainian conditions. Currently only projections can be made from similar studies in other contexts; however, a more detailed research is needed for Ukrainian setting.

Ukraine was also shown to have an extensive established natural gas grid. Further research on *progressive development of advanced biofuel technologies such as biomass gasification* with a consequent use of biogas in the national natural gas grid is desired. Such research should among other things explore the plans and forecasts for the deployment of gasification technology, entailed costs for its commercialisation, etc.

Emerging bioenergy sectors in EiTs in Eastern Europe (e. g., Ukraine, Belarus, etc.) face technical, political, financial, and capacity-based constraints. This study provided an evidence that international technology transfer (e.g. technology, software and institutional) support could help reduce such constraints. Exploration of *exogenous influences on the establishment of bioenergy industries in Ukraine and other EiTs* is another potential area for future research.

Theory on the diffusion of new technological systems can be enriched with a study that aims to establish a more distinct boundary between the formative, intermediate and mature phase in the development of the system. Empirical data accumulated in this work can be used for *measuring the phases of technology development* from the example of straw-to-energy system.

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Annex I. Participation in bioenergy related events

#	Date	Place	Event	Role of the author
1	27-29 Sep 2007	Lund, Sweden	IIIEE Alumni Network Conference, Energy for Sustainable Development workshop	Speaker
2	1-3 Oct 2007	Graz, Austria	Bioenergy NoE Annual Researchers' Meeting	Speaker
3	27-29 May 2008	Jönköping, Sweden	World Bioenergy 2008: Conference and Exhibition on Biomass for Energy,;	Co-author of a paper and a poster
4	2-6 Jun 2008	Valencia, Spain	16th European Biomass Conference & Exhibition - From Research to Industry and Markets	Co-author of a paper
5	22-24 Sep 2008	Kyiv, Ukraine	4th International Conference on Biomass for Energy, workshop on Biomass Action Plan for Ukraine	Speaker, group leader in the workshop
6	20-22 Oct 2008	Stratford upon Avon, UK	Bioenergy NoE Annual Researchers' Meeting	Poster presenter
7	14-15 Feb 2009	Lyngby, Denmark	Workshop on Sustainable Energies, Technical University,	Participant
8	2 Jun 2009	Kyiv, Ukraine	5th International Conference on Alternative Fuel: New Types of Motor Fuels in	Participant
9	29 Jun – 3 Jul 2009	Hamburg, Germany	17th European Biomass Conference & Exhibition - From Research to Industry and Markets,;	Speaker
10	Sep 2009	Kyiv, Ukraine	5th International Conference on Biomass for Energy	Speaker
11	26-28 Oct 2009	Ankara, Turkey	UN FAO Central Asian Agricultural and Rural Development Policy Forum	National expert on bioenergy, speaker, author of a country study on Ukraine
12	12-15 Oct 2009	Copenhagen, Denmark; Lund, Sweden	Workshop on Planning for Energy Security and Sustainability in a Changing World	Participant
13	2-3 Nov 2009	Brussels, Belgium	Bioenergy NoE Annual Researchers' Meeting and Conference	Speaker, author of a journal paper
14	25-27 May 2010	Jönköping, Sweden	World Bioenergy 2010: Conference and Exhibition on Biomass for Energy	Speaker, poster presenter, author of a conference paper
15	14-15 Sep 2010	Kyiv, Ukraine	6th International Conference on Biomass for Energy	Speaker
16	30 Sep 2010	Copenhagen, Denmark	The Green Gap Roundtables Paving The Way for Fossil Fuel Independence	Participant
17	22 Oct 2010	Lund, Sweden	LU Biofuels Retreat: Cross-disciplinary research opportunities	Participant

Annex II. Analytical framework that guided questionnaire construction

#	Factor	Description
1	*Integration and infrastructure*	How is the bioenergy business integrated upstream to feedstock production and downstream to consumers? What is the type of integration: formal or informal? Is the bioenergy industry integrated with another industry that generates biomass by-products? (e.g. forestry or agriculture) How is the integration regarding: - fixed assets (equipment)? - knowledge? - infrastructure?
2	*Scale effects (network externalities, learning, R&D)*	Are there scale economies for the whole biomass industry regarding: - production? - R&D? - reduction of transaction costs through quality tests, standards, contracting conventions, etc.? - learning by doing by the market participants? Does the biofuel have potential for positive scale effects (homogeneous, energy dense)? How is the business taking advantage of this potential?
3	*Competition in bioenergy sector*	Are there many sellers (of bioenergy equipment, biomass fuel etc.)? Are there many buyers? Are there market imperfections in any market where the biomass industry is operating? (competition requires an unregulated market with several players) Are there other regulations that influence competition in the bioenergy industry?
4	*Competition with other business*	Are there competing/hostile industries in the selling market (oil, natural gas)? Are there competing/hostile industries in the feedstock market or in other markets (forest industry, agro-industry, etc.) How do other businesses compete? What are the possibilities for the bioenergy sector to compete in technology? What are the possibilities for the bioenergy sector to compete in contracting?
5	*National policy and policy influence*	What are the national policy goals concerning bioenergy (i.e. market regulations, R&D funding, subsidies, taxes, information)? Lobbying strength of competing industries? ("barriers to entry") Lobbying strength of biomass organisations (membership, money, commitment)? Does the bioenergy industry have coalition partners for lobbying efforts (other renewables, environmentalists, etc.)? What are the policy risks (likelihood of policy shifts)? What is the legitimacy of the policy (is the policy the sum of pressure group lobbying or a way to provide common goals)?
6	*Local policy and opinion*	Is the local population knowledgeable about bioenergy? Are local policy makers knowledgeable about bioenergy? What do local policy makers think about the bioenergy business? What is local opinion about the bioenergy business? Does bioenergy create conflicts in the local society?

Source: Roos et al. 1999

Annex III. Cases on straw use for energy in Western Europe

#	*Name/place*	*Country*	*Boiler size, MW*	*Purpose*	*Informants*
1	Nöbbelöv (Lund)	SE	0.35	Heat for the farm	A farmer and a boiler operator; a researcher
2	Pugerups (Eslöv)	SE	0.6	Heat for the farm	A farmer and a boiler operator
3	Falkenberg	SE	0.6	Heat for the farm	A farmer and a boiler operator
4	Svenstorp and Björnstorp	SE	1.5 & 1.2	Heat for the farm with excess for sale	A farmer and a boiler operator
5	Trelleborg and Löderup	SE	1 & 2	District heating (DH)	A farmer and a boiler operator
6	Horreby	DK	1	Heat for the farm with excess for sale	A farmer and a boiler operator
7	Hunseby	DK	1	District/neighbour heating	A farmer and a boiler operator
8	Horbelev	DK	1.6	District/neighbour heating	A farmer and a boiler operator; a straw supplier
9	Stokkemarke	DK	2.5	District/neighbour heating	A farmer and a boiler operator
10	Skurup	SE	5	DH	A boiler operator; a straw supplier
11	Svalöv	SE	6	DH	A farmer and a boiler operator; representative from the municipality
12	Örtofta (Lund)	SE	45	Combined heat and power (CHP)	A technical manager and a project coordinator; a biofuel purchase manager
13	Avedøre (Copenhagen)	DK	50	CHP	Plant information officer; mechanical engineer; fuel purchase manager
14	Sangüesa (Pamplona)	ES	25	Power plant	Operations and maintenance manager of Acciona Energía biomass plants

Annex IV. Sample questionnaire for interviews

	Sample questions to a farmer who operates a straw-fired boiler or supplies straw to such
1	**Information about agricultural enterprise** 1. What does your enterprise produce? What is the size of the farm? What is the business set up and state of the enterprise ownership? 2. How big is your farm? Which crops do you grow on the farm and in which quantities?
2	**Use of straw and other crop residues** 3. How much straw and other crop residues is produced on your farm every year? How do you use these residues? 4. Do you sell any straw that you produce? If yes, where to and in which quantities? 5. What are the energy needs on your farm? For which purposes do you produce energy from straw (e. g., which buildings do you heat with produced energy)? 6. Which straw do you use for energy production and why? 7. Did you have any tradition of straw burning for energy in your family, village etc.?
3	**Straw-fired boiler** 8. Who owns a straw-fired boiler? Could you tell more about the boiler installation? 9. Where does the idea to install a straw-fired boiler come from? Whose initiative was it? What was the reason for its installation? 10. When was the boiler installed? How much energy has it produced from straw? How big were the savings of natural gas and money savings after the boiler installation? 11. How big were the investment costs and what was the source for funding? What was the payback of the boiler? 12. Are there any environmental permits required for the boiler operation?
4	**Impact of a straw-fired boiler on farm activity and income** 13. How many additional jobs (if any) were created after the boiler installation in the village? 14. How did the boiler installation influence your income? 15. Which skills are required to manage such a boiler?
5	**Straw supply chain** 16. Which equipment do you use for straw harvesting, transportation and storage? Who owns this equipment? 17. What is the most expensive stage of a straw supply chain? 18. How is the ash used after burning? Is it sold as a fertiliser?
6	**Energy supply in the village** 19. What is the main source of heat for the houses in the village?
7	**Lands not suitable for the growing of agricultural crops** 20. In your farm do you have any lands that are not used for the growing of agricultural crops for some reason?
8	**Government support** 21. Do you have any governmental support of your activities?
9	**Future plans and personal opinion** 22. Are you satisfied with the work of the boiler and do you plan to expand energy generation from straw in the future? 23. Do you think Ukraine has a potential to use straw for energy? 24. In your opinion, what do you think is needed for Ukrainian farmers to install straw-fired boilers?
9	**Similar boilers in the region/country and further contacts** 25. Do you know about any similar straw-fired installations that exist in your region/country?

Annex V. Cases on straw use for energy in Ukraine

#	*Village (region, province)*	*Boiler size, kW*	*Purpose*	*Informants*
1	Strutynka, (Lypovetsk, Vinnytsya)	250	Heat for agro-enterprise "Rapsodiya" and a mill	Director of the agro-enterprise
2	Lebedyn, (Shpola, Cherkasy)	250	Heat for agro-enterprise "Lebedyn Seed Plant"	Leading energy expert
3	Olgopil (Chechelnyk, Vinnytsya)	300	Heat for the local secondary school	1st deputy head of local administration
4	Stavy, (Kagarlyk, Kyiv)	350	Heat for local secondary school and kindergarten	Project coordinator
5	Vyshnyuvate, (Rozivka, Zaporizzhya)	150 or 350 (project)	Heat for local secondary school and (possibly) to local municipality	Project coordinator
6	Polkovnyche, (Stavyshche, Kyiv)	600	Heat for trading company and agro-enterprise "ROPA Ukraine"	Director of the agro-enterprise
7	Zlatoustivka, (Volnovakha, Donetsk)	600	DH to municipal buildings in the village	Director of agro-enterprise
8	Drozdy (Bila Tserkva, Kyiv)	980 and 150	DH to municipal buildings in the village; for pig-breeding facility on the farm	Deputy director of the agro-enterprise
9	Dyagova (Mena, Chernihiv)	250	Heat for a grain dryer on the farm	A farmer and a boiler operator

Annex VI. Narratives of case studies in Western Europe

1. Pugerup estate, Eslöv, Sweden

The farm estate Pugerups is located close to the village of Hurva in Eslöv region, Scania (Weden pers.comm. 2009). Its size is around 1500 ha, 1100 ha of which are used for growing crops. Significant areas are also covered with forest. Buildings on the farm include an office, living houses, pig breeding facilities, a fuel storage for wood logs and straw, a grain dryer building and a boiler house. Five people are involved in the grain production on the farm and 10 people are responsible for pig breeding.

All straw, which is produced on the farm, is used for the farm's own needs. In particular, it is used for heat production in a straw-fired boiler and for pig bedding. Some of the straw is returned to the field to maintain the fertility of the soil. Forest on the farm is mainly maintained for timber sale to paper industry. Only the trees that are damaged from storms are processed into wood chips and then fed into the boiler together with straw. Wood chips are stored in open air. However, according to the manager of the farm (Weden pers.comm. 2009), the combustion of pure straw is more efficient.

Figure VI-1. 600 kW straw-fired boiler in Pugerup estate, Eslöv, Sweden

Heat from the straw-fired boiler is used only for the farm needs (e. g., to run a grain dryer, to warm up houses, administrative buildings and pig breeding facilities). The boiler is of 600 kW in slow combustion with a round fire-chamber and a hot water accumulator (Fig. VI-1). Straw is ignited with natural gas and is the main fuel for the boiler. However, sometimes wood chips and other combustible substances are added to the boiler. The farm has also a natural gas-fired boiler, which supplies heat to the grain dryer in addition to the straw-fired one. The farm owns loaders, trucks and a few tractors. They hire subcontractors to bale the straw in rectangular bales of 500 kg each. Ash collected after straw combustion is used on the field as a fertiliser.

The boiler was installed together with a grain dryer in 2003. The idea evolved from the owner, who was interested to build a new grain dryer. According to the manager (Weden pers.com. 2009), they were aware of the fact that such installation would require a lot of heat and entail high fuel costs. They explored various options, and straw appeared to be the cheapest alternative. A similar straw-based heating system was installed on another farm in close vicinity, which is also in the property of the same owner (Weden pers.com. 2009).

In future farm managers plan to sell some of their straw to Örtofta CHP plant, which will be constructed by the utility company Lund's Energy in the village of Örtofta between Lund and Eslöv (Weden pers.com. 2009). They already had preliminary discussions with the managers of the project. In addition, farm managers are evaluating the possibility to produce electricity from biogas as they have significant amounts of pig manure produced on the farm. The estimated investment cost for a biogas production facility is about SEK 5-6 million. Farm managers expect a 30% state subsidy for such installation (Weden pers.com. 2009).

Pugerup case is presented in the form of an agro-biomass based framework in Table 5-1.

2. Falkenberg, Sweden

The farm is located to the south from the city of Gothenburg in 15 km from the city of Falkenberg. Farm manager specialises in grain farming and forestry, and manages 1260 ha of cropland, 75 ha of grassland and 1000 ha of forestry (Treschow pers.comm. 2009). He owns 500 ha of land while the rest of the farmland belongs to other owners. The purpose of renting the land is to increase the scale of grain production, and in this way reduce the production costs and achieve higher competitiveness on the grain market (Treschow pers.comm. 2009). The main crops grown on the farm include rapeseed, wheat, barley, oat, triticale, and green beans, which are sold in Sweden. The forest is mainly comprised of pine trees.

The farm business results in the production of about 5000 tonnes of straw from rapeseed every year. Small amounts of straw are sold to bull breeding stations for bedding while about 3500-4000 tonnes are used for heat production on the farm. According to the manager, the best straw for burning is that from wheat and triticale while straw from oats and barley has worth properties (Treschow pers.comm. 2009).

Heat on the farm is supplied from 600 kW straw-fired boiler. Both the boiler and the distribution network were manufactured by Danish company LIN-KA and are owned by the farm manager, who bought them from his own funds for SEK 1.5 million[28] and installed in September 1998. Straw burning helps to substitute 92 m^3 of oil every year, which results in a 3-year payback period of the system (Treschow pers.comm. 2009). Only straw that is produced on the farm is used in the boiler for heat production.

During the harvesting period, which continues for a few days in August, the entrepreneur rents a bailer that produces square 500 kg bales. All bales are stored in a special covered storage. According to the manager (Treschow pers.comm. 2009), it is not cost efficient to own a bailer as it is required only for a short period of time. All ash after burning is returned to the field.

Heat from straw is used to run a grain dryer, in the equipment on the farm that requires heat, and to warm up eight houses on the farm (Treschow pers.comm. 2009). All these buildings belong to the manager, some of which he lets to people and farm workers. The heat is used both in heating radiators and for hot water supply.

The main reason to introduce a straw based heating system was a need to reduce energy costs. The manager exchanged experiences with several farmers, who had installed such systems before.

Falkenberg case is presented in the form of an agro-biomass based framework in Table 5-2.

[28] SEK 1.5 million = USD 189 000 (USD 1 = SEK 7.95 as of 1 September 1998)

3. Nöbbelöv, Lund, Sweden

This case unites three farms located on 80 hectares of land in close proximity to each other in Nöbbelöv in the west of Lund (Göransson pers.comm. 2009). A farmer and his son carry out all works there. Some land is owned by the farmer, and some is rented from other farmers. The main crops grown on the farm include barley, sugar beets, and wheat for bread production. 1 ha of land is occupied with trial plantation of hemp.

About 80 tonnes of straw are produced on 20 ha of the farmland every year. Some of it is ploughed back into soil, and the rest is used in a straw-fired boiler on the farm. No straw is sold. The farmer owns a combine harvester, ploughs, fertilising equipment, spraying machines, tractors, sugarbeet harvesters, etc. However, he does not own straw or hemp bailers. Straw baling is provided by subcontractors, who produce small straw bales of 200 kg each, which are then loaded into the boiler in pairs. Hemp baling is provided by Swedish University of Agricultural Sciences (SLU, Sveriges lantbruksuniversitet) in Alnarp.

Researchers from SLU started a 1 ha trial plantation of hemp on the farm together with the utility Lund's Energy, who were interested to try herbaceous energy crops as a future feedstock for the straw-fired boiler at Örtofta CHP plant (see Annex VI, case study 12 for details) (Göransson pers.comm. 2009). Also recycled water from Lund sewage system is tried for the irrigation of hemp plantations. Waste water has significant content of nitrogen, phosphorus and potassium, which serve as mineral fertilisers for hemp (Svensson pers.comm. 2009). There are about 15-17 allotment areas in Lund, which produce waste water that could be used for hemp irrigation. Hemp requires about 400 m^3 of irrigation water per ha annually (Svensson pers.comm. 2009). The main problem with such irrigation system is linked to the perceptions of farmers who are afraid to use waste water for irrigation due to sanitary concerns (Svensson pers.comm. 2009).

There is also an intention to produce biogas from hemp (Svensson pers.comm. 2009). A trial was done in September-October 2008. Maize chopper can be used for hemp harvesting. The farmer's desire is to use existing machines to manage the energy crops instead of purchasing new ones (Göransson pers.comm. 2009).

With regards to cultivation techniques, growing of hemp does not require any additional knowledge, if one has experience in barley or sugar beet cultivation (Göransson pers.comm. 2009). The fertilisation is similar to that of barley (Svensson pers.comm. 2009). Hemp cultivation does not require any herbicides, it is a natural weed control plant and thus is favourable for crop rotation practices. After two years hemp is able to destroy all weeds in the plot (Svensson pers.comm. 2009).

First hemp harvesting was carried out on the farm in 2008 and yielded 10 000 tonnes of hemp (Göransson pers.comm. 2009). Hemp harvesting can be done with rapeseed swarth machines and conventional straw bailers (Svensson pers.comm. 2009). The harvesting of hemp seeds is performed in mid-April, and the tops of hemp are cut down in September (Svensson pers.comm. 2009). Fibres' can be cut down but should lay on the soil till February-March to get dry. Winter harvesting can be problematic when the soil is not frozen and gets compacted under the equipment (Göransson pers.comm. 2009). In Southern Sweden it is difficult to get the proper weather for hemp harvesting as the frosts are not very common in winter. In April the harvesting is not optimal either as it is already a season for new plantings (Göransson pers.comm. 2009).

Both straw and hemp is baled in small 200 kg bales, which are stored in a covered 250 m^2 barn. Bales are burnt in a 350 kW straw-fired boiler located on the farm (Göransson pers.comm. 2009). The boiler was produced by Danish company Faust and has a 20 m^3 hot water accumulator. In addition, an 80 kW wood-fired boiler, which was produced by Austrian company HDG Compact, is installed on the farm. It is self-ignited by electricity, and has a 5 m^3 hot water accumulator (Göransson pers.comm. 2009).

The manager owns a distribution network and heat exchangers in farm houses on all three farms. All straw is obtained from the farm. Wood chips are delivered by sub-contractors from Lund municipality. Hemp is only used in the boiler on the farm. In 2009 there is, however, a plan to try hemp burning in Denmark to test its properties (Svensson pers.comm. 2009). All ash from the combustion process is returned to the soil.

Straw- and wood-fired boilers supply heat to the grain dryer, and heat and hot water to the buildings on the farms. Wood-fired boiler is used in summer months. The reason for its installation is to ensure the continuity of heat delivery when there are operation disruptions in the functioning of the straw-fired one (Göransson pers.comm. 2009).

Total cost of the system was SEK 750 000[29] in 1996. About 20 m^3 of oil is substituted annually. The main reason for the transformation towards biomass-fired system was to reduce the costs for the heat use both in the grain dryer and in the heating of premises (Göransson pers.comm. 2009).

The establishment cost for hemp plantations is approximately the same as for barley. Total cost includes the cost of hemp seeds, that of crop rotation, fertilisation and cultivation. For hemp harvesting no additional equipment is needed, and there are no spendings on herbicides (Svensson pers.comm. 2009). However, the farmer admits that today it is not really profitable to use hemp for energy. His desire is to use it for fibre and seeds (e.g. for the production of cosmetics, extraction of nutrients for cattle, etc.) (Göransson pers.comm. 2009).

Nöbbelöv case is presented in the form of an agro-biomass based framework in Table 5-3.

[29] SEK 750 000 = USD 113 000 (1 USD = 6.64 SEK as of 1 January 1996)

4. Svenstorp and Björnstorp, Lund, Sweden

These cases are united for the analysis of activities on straw use for energy that are carried out in two estates - Svenstorp and Björnstorp. Björnstorp estate is located 20 km to the east from Lund, and is a combined agricultural and forestry company. Svenstorp estate is located 5 km to the northeast from Lund and 25 km from Björnstorp estate, and is a typical lowland farm, where the main premises are centrally located in the centre of the property (Gyllenkrok 2009). Total area of Svenstorp and Björnstorp is 2400 ha (Gyllenkrok 2009). They grow wheat, barley, rapeseed, sugarbeets, and grass (Skovsted pers.comm. 2009). 26 people are employed on two farms.

In both estates energy is produced from straw and is used for the supply of heat and hot water to the farms, and heat for the grain dryer (Skovsted pers.comm. 2009). In Svenstorp 18 buildings and a castle are supplied with locally produced heat. The heat generated in Svenstorp estate is also sold to the utility Lund's Energy for DH in Lund and Eslöv (Skovsted pers.comm. 2009). Since the DH pipe passes close to Svenstorp, an agreement was made with Lund's Energy to sell heat to them during the heating season (Skovsted pers.comm. 2009). Because of this agreement the amount of heat produced at Svenstorp is 60% over capacity (Skovsted pers.comm. 2009). In summer heat is only produced for the estate's own needs, which makes the boiler work at 9% of its capacity from May till August. In September and October (for some 6-8 weeks) the heat is required to run the grain dryer, and in this way about 120 m^3 of oil is substituted from straw combustion on the farm (Skovsted pers.comm. 2009). In 2004 the houses were built in Björnstorp, and 120 m^3 of oil was substituted by heating them with straw (Skovsted pers.comm. 2009). They also started selling heat to nearby village there (Skovsted pers.comm. 2009).

There is a 1.5 MW straw-fired boiler in Svenstorp and a 1.2 MW straw-fired boiler in Björnstorp estate (Skovsted pers.comm. 2009). A pipeline in Svenstorp is 2.5 km long (Skovsted pers.comm. 2009). There are no hot water accumulators in the system. In Svenstorp

25 000 litres of water circulate constantly through the system (Skovsted pers.comm. 2009). All equipment was manufactured by Danish company LIN-KA.

Before the straw is fed into the boilers, it is cut down by a shredder, which minimises the material losses (Fig. VI-2). 14 of 500 kg straw bales are used daily, which is equivalent to 220 litres of oil (Skovsted pers.comm. 2009). Only wheat straw is combusted. All straw produced in both estates is used locally, and no straw is sold (Skovsted pers.comm. 2009). About 15 kg of ash from burning one 500 kg straw bale is produced. All ash is collected in ash containers and returned to the field on the farms (to about 1100 ha). No ash is sold (Skovsted pers.comm. 2009).

Figure VI-2. A straw conveyor and shredder supplying fuel to the boiler at Svenstorp estate, Scania, Sweden

They do not own straw bailers but purchase bailing services from sub-contractors. All the rest of conventional farming equipment is owned by the estates (Skovsted pers.comm. 2009). Two straw storages of 1600 bales capacity each exist in two estates.

The case of Svenstorp and Björnstorp is presented in the form of an agro-biomass based framework in Table 5-4.

5. Horreby, Denmark

Ellehavegaards Varmeforsyning I/S is a 1 MW straw-fired plant (Fig. VI-3) located on a farm in Horreby, Falster, Denmark. It supplies heat and hot water to the buildings on the farm (i.e. a farmhouse and a pig breeding facility), a school, two kindergartens and 50 private houses connected to the DH network (Nikolaisen *et al.* 1998; Palle pers.comm. 2009). There is a plan to expand the grid and connect 30 buildings more (Palle pers.comm. 2009).

Figure VI-3. 1 MW straw-fired boiler on Horreby farm, Denmark

The farm is 340 ha, 27 ha of which are rented. 140 ha of land are covered with wheat, 80 ha with barley, 80 ha with sugarbeet, 20 ha with rapeseed and 20 ha with grass grown for seed production (Palle pers.comm. 2010). About 1000 tonnes of straw is produced annually on the farm (Palle pers.comm. 2010). 3000 pigs are grown on the farm.

The project plan on establishing neighbour heating plant at Ellehavegaard was drafted in 1995 for the Danish Energy Agency (Nikolaisen *et al.* 1998). The plant was organised in the form of partnership with a farmer and his wife as the owners, and was started up in January 1996 (Nikolaisen *et al.* 1998). In the past the owner had a smaller (about 300 kW) boiler on his farm, which was used to warm up three dwelling houses on the farm and a pig breeding facility (Palle pers.comm. 2010). The boiler owner also used to sell some of his straw to a bigger plant, however, this plant changed from straw to wood, and the farmer was left with significant excess of straw (Palle pers.comm. 2010). In 1995-1996 he started to expand his business and also sell heat to municipal buildings, which were interested to purchase it. It was a reason to install a 700 kW boiler (Palle pers.comm. 2010). In 2005 a 700 kW boiler was replaced with a 1 MW boiler (Palle pers.comm. 2010).

The project on the boiler installation at Ellehavegaard was approved by the Municipal Housing and Building Agency (Nikolaisen *et al.* 1998). No formal agreements were made with local population on heat purchase. According to the plant owner, "it was a word of mouth", and people realised the cost-efficiency of energy from straw as compared to individual oil-fired or electricity heaters (Palle pers.comm. 2010). The heat from straw costs about 30% less than the heat from oil (Palle pers.comm. 2010). Among energy consumers only the school installed a heat exchanger where while all other consumers have direct connections with the DH water circulating in the internal central heating system (Nikolaisen *et al.* 1998).

The boiler was manufactured by Danish company LIN-KA. The company installed the system in one week (Palle pers.comm. 2010). The owner of the plant was responsible for the construction of buildings and straw storage, which was carried out by a local construction company (Palle pers.comm. 2010). A straw-fired boiler uses about 600-700 tonnes of straw (or 1200 Hesston bales with dimensions of 1,25 m x 1,25 m x 2,4 m) with 11-12% moisture content annually, and is operational throughout a year except for 4-5 days of maintenance (Nikolaisen *et al.* 1998; Palle pers.comm. 2009; Palle pers.comm. 2010). According to the boiler owner, the plant is not difficult to operate, and he learnt how to manage it on his own (Palle pers.comm. 2010). In addition, three more people help to run the plant and work on the farm (Palle pers.comm. 2010).

The farmer owns a big bailer (Fig. VI-4), a combine harvester, four tractors, a straw shredder with a conveyor belt, and some other machines. All straw that is used for heating is stored in barns (Palle pers.comm. 2010). There is a straw barn next to the boiler-house from which straw bales are transported on a conveyor belt to a double-blade shredder and then fed into the boiler. It has a capacity to keep straw reserve for two weeks (Palle pers.comm. 2009). Another covered storage for straw is a barn on the farm in a close proximity to the boiler-house. The straw that is purchased from other farmers and later resold is stored in the field wrapped in plastic (Palle pers.comm. 2010).

After straw bales are placed on the conveyor belt, they are shredded and fed into the boiler. Only wheat and rapeseed straw is used in the boiler while barley straw is sold due to its higher energy content (Palle pers.comm. 2009). The boiler does not have any flue gas abatement equipment since Danish legislation does not require it for the installations up to 1 MW (Palle pers.comm. 2010). The ash from straw combustion is removed and spread on the fields (Nikolaisen *et al.* 1998; Palle pers.comm. 2010). In the past the farmer used to mix bottom ash with pig slurry and produce fertilisers. However, the ash settled down in slurry tanks and created congestions (Palle pers.comm. 2010).

The plant runs satisfactorily, and since the project start up more private consumers were connected to the grid (Nikolaisen *et al.* 1998). The only problem encountered is linked to the disruptions in the work of a straw shredder. The owner of the plant had to replace it in 2009 (Palle pers.comm. 2010).

Figure VI-4. Bailer, Horreby, Denmark

The plant manager owns a heat distribution network in Horreby and invested in its installation. He constructed all the pipes in the town together with a hired entrepreneur (Palle pers.comm. 2009). In addition to the straw boiler, the farmer owns a 750 kW oil-fired boiler. The latter consumes about 3 000 litres of oil per year, and is turned on in case there are any operational disruptions of the straw-fired one (Nikolaisen *et al.* 1998; Palle pers.comm. 2009). In 1996 a total of DKK 2.2 million[30] was spent to install the boiler. The boiler itself cost DKK 800 000[31], the buildings – DKK 300 000[32], electrical power installations – DKK 80 000[33], distribution net and service pipes – DKK 820 000[34]. Consumer installations were paid by the municipality and cost DKK 220 000[35]. The operation costs are approximately DKK 430 000[36] per year including straw expenditure (Nikolaisen *et al.* 1998).

The installation was funded 50% via a mortgage loan, 25% via subsidies from Danish Energy Agency (DEA), and 25% from the owner's funds (Nikolaisen *et al.* 1998). DEA also provided 80 hours of free advice as a part of its subsidy package (Palle pers.comm. 2009). The payback of the boiler was 10 years, and 20 years for the network (Palle pers.comm. 2009).

The plant owner produces 1000 tonnes of straw, out of which 600-700 tonnes are used for heating, 30-50 tonnes for pig bedding and the rest is sold to Dong Energy power plants. In addition, the entrepreneur buys straw from other farmers, bales it and sells to Dong Energy and to a straw-fired neighbour heating plant in Horbelev (located close to Horreby). Thus the farmer handles about 4000 bales of straw annually (Palle pers.com. 2010).

The price for harvested (not baled) straw is DKK 200[37] per tonne. The price at which the farmer sells the straw to Dong Energy is different. In Denmark there is a special system for straw price

[30] DKK 2 200 000 = USD 396 000 (USD 1 = DKK 5.56 as of 2 January 1996)

[31] DKK 800 000 = USD 144 000 (USD 1 = DKK 5.56 as of 2 January 1996)

[32] DKK 300 000 = USD 54 000 (USD 1 = DKK 5.56 as of 2 January 1996)

[33] DKK 80 000 = USD 14 400 (USD 1 = DKK 5.56 as of 2 January 1996)

[34] DKK 820 000 = USD 147 500 (USD 1 = DKK 5.56 as of 2 January 1996)

[35] DKK 220 000 = USD 39 600 (USD 1 = DKK 5.56 as of 2 January 1996)

[36] DKK 430 000 = USD 62 700 (USD 1 = DKK 6.86 as of 2 January 1998)

[37] DKK 200 = EUR 26.88 (EUR 1 = DKK 7.44 as of 4 January 2010)

establishment when a farmer or entrepreneur sets a retail price in a closed letter. In 2009 the owner of Ellehavegaard sold his straw at DKK 460-500[38] per tonne (Palle pers.comm. 2009).

The main reason to start up the business on heat sale from straw was the interest of the plant owner in the regional sustainability (Palle pers.comm. 2009). He intended to use all residues that were left from farming as well as to provide neighbours with cheaper source of heat (Palle pers.comm. 2009).

Nikolaisen *et al.* (1998) identify a number of success factors for the case of Ellehavegaards Varmeforsyning I/S. These include the following:

- Good technology basis and sound experience of the farmer in different steps of a straw supply chain;
- Commitment and support by Stubbekøbing Municipality of biomass-based DH in Horreby;
- Central location of Ellehavegaard and heat demand in the region with prospects for its increase;
- Subsidy support schemes from DEA.

Horreby case is presented in the form of an agro-biomass based framework in Table 5-5.

[38] DKK 460-500 = EUR 61.83-67.20 (EUR 1 = DKK 7.44 as of 3 August 2009)

6. Trelleborg and Löderup, Sweden

These cases are united to analyse the activities of a farm-based entrepreneur and an owner of the company *Bal & BobCat*, who is involved in varied businesses on straw use in Scania. A 1 MW straw-fired boiler supplies heat for 180 houses and a big school in Trelleborg. The boiler manager also bales straw for other farmers, stores, transports and resells it to Skurup straw-fired DH plant (see case study 7 for details) and to about 12 other farmers for their needs (e.g., for bedding and fodder, for the farmers' heating purposes, for covering vegetables, etc.) (Ericsson pers.comm. 2009). The entrepreneur also sells 300 tonnes of straw to Avedøre CHP plant in Copenhagen, Denmark (see case study 13 for details), and owns a 70 kW straw-fired boiler on his farm. He also organised a delivery of 15 000 tonnes of straw to the Netherlands in 2008.

The boiler manager started straw business in 1983 with baling straw for pellet production (Ericsson pers.comm. 2009). In 2005 he received an approval from Trelleborg's municipality to install a straw-fired boiler, and started supplying heat to the City of Trelleborg in 2006. According to the entrepreneur (Ericsson pers.comm. 2009), the reason for the new business was little winter workload and a desire to get additional income by producing and selling heat.

The boiler in Trelleborg requires 450 tonnes of straw per year (Ericsson pers.comm. 2009). In winter both heat and hot water are supplied to the houses while in summer only hot water is provided. The ash from straw combustion is returned back to the soil.

The entrepreneur constructed the boiler-house in Trelleborg himself with the help of technicians. He also collected experience from site visits to similar installations (Ericsson pers.comm. 2009). All equipment was manufactured by Danish company LIN-KA. The investment cost of the installation in Trelleborg was SEK 3-4[39] million, and the payback period is estimated of about 10 years (Ericsson pers.comm. 2009). Net income from selling 1 MW of heat from straw combustion is SEK 850[40] while the equivalent price of 1 MW of heat

[39] SEK 3-4 million = EUR 335 200 – 445 000 (EUR 1 = SEK 8.95 as of 1 January 2005)

[40] SEK 850 = EUR 78.63 (EUR 1 = SEK 10.81 as of 1 January 2009)

from oil is SEK 1250[41] (Ericsson pers.comm. 2009). The entrepreneur plans to increase heat production in Trelleborg to 3-4 MW by installing one more boiler in the existing building.

The entrepreneur owns four bailers, one of which produces chopped straw; five tractors and a BobCat machine (Fig. 2-7), which is used to load and transport bales to the storage (Ericsson pers.comm. 2009). The boiler manager works with individual straw suppliers. There are no contracts between them, and all business activities are based on mutual trust. One third of straw the boiler manager obtains for free while two thirds he buys for a varied price (Ericsson pers.comm. 2009). Straw of higher quality is stored in the field wrapped in plastic and then delivered directly to the plant (Fig. VI-5) (Ericsson pers.comm. 2009).

The entrepreneur has also received an approval from Löderup municipality, where he plans to construct a similar 2 MW straw-fired system. It will provide heating for a local school, a church, a fire station, a grain dryer, municipal buildings and about 150-200 houses (Ericsson pers.comm. 2009). A distribution network in Löderup will need to be constructed since all the buildings use private oil or electricity heaters. Heat exchangers in every house will also need to be installed. The entrepreneur plans to purchase all needed infrastructure and a land plot for the construction (Ericsson pers.comm. 2009). Farm fields with straw production are located in the vicinity (Ericsson pers.comm. 2009).

Figure VI-5. Straw storage in the field close to Trelleborg, Scania

[41] SEK 1250 = EUR 115.63 (EUR 1 = SEK 10.81 as of 1 January 2009)

Trelleborg case is presented in the form of an agro-biomass based framework in Table 5-6. Conceptual framework is not applied to the case of Löderup since all activities are only planned there, and the information is not sufficient for the compilation of a similar table.

7. Skurup, Sweden

Skurup is a town in Scania with a population of 7 000 inhabitants. A 5 MW district heating (DH) plant is located outside Skurup and is owned by farmers cooperative Lantmännen (Wallin pers.comm. 2009). It supplies heat and hot water to several administrative buildings in Skurup, which have heat exchangers installed (Wallin pers.comm. 2009). According to the plant's manager (Wallin pers.comm. 2009), about 12 000 tonnes of straw are used annually to operate the boiler. In colder seasons there is a need to burn oil additionally in a separate boiler to satisfy heating needs but the goal is to switch the plant to straw completely.

All straw is supplied to the plant from the nearby fields located in 20-30 km radius. The maximum distance, from which straw is delivered, is 40 km but this straw is obtained for free (Wallin pers.comm. 2009). There are three sub-contractors of straw delivery to the DH plant and two operating managers (Wallin pers.comm. 2009).

Skurup DH plant was put in operation in 1998. All equipment was provided by Danish company LIN-KA. According to one of the plant sub-contractors (Ericsson pers.comm. 2009), the payback period of the plant is about 10 years. The initiative to start up a DH plant on straw came from the municipality of Skurup and was linked to the ban on straw burning in the field (Ericsson pers.comm. 2009). Local politicians contacted one of the current straw suppliers to the plant as they were planning straw logistics at the future plant (Ericsson pers.comm. 2009).

Skurup case is presented in the form of an agro-biomass based framework in Table 5-7.

8. Svalöv, Sweden

A 6 MW DH plant in Svalöv was built in 1985 by the company Setab. According to the former manager of energy projects in Svalöv municipality (Ekholm pers.comm. 2009), Setab made a contract with the City of Svalöv on the construction of a plant that would sell energy to Svalöv municipality. Hollensen A/S was a Danish company that delivered plants components (Leire pers.comm. 2009).

In 1985 Svalöv DH plant was run on oil. However, the contract between the municipality and Setab determined a later switch to straw fuel, which was in accordance to the oil reduction plan by Svalöv municipality (Ekholm pers.comm. 2009). In 1982-1990 Swedish government set a goal to substitute oil in the national consumption due to its increasing price (Ekholm pers.comm. 2009). The City of Svalöv set an objective to substitute 2000 m^3 of oil (i.e. to reduce the oil consumption in municipal buildings and industrial plants by about 50%) (Ekholm pers.comm. 2009). The City of Svalöv assessed different alternatives and reached a conclusion that straw was cheap and accessible fuel, which could be found in significant quantity in close proximity to the plant and was also a reliable source of energy as it was produced locally every year (Ekholm pers.comm. 2009).

Setab rebuilt the plant so that it could use straw to produce heat, however, the price for oil went down, and Setab lost its incentive to use straw as a fuel (Ekholm pers.comm. 2009; Leire pers.comm. 2009). In 1987 the plant was sold to Scandinavian Technological Engineering, which started its operation on straw (Leire pers.comm. 2009).

The plant supplied heat and hot water to about 1000 buildings in Svalöv municipality. All of those were municipal houses, business offices, greenhouses or industrial buildings. No private homes were supplied with heat from the plant as they were not connected to the grid, and most of private houses continue to use individual oil burners or electricity for heating (Leire pers.comm. 2009). Svalöv DH plant was in the operation till May 2008, when it was sold to E.On company, which rebuilt the plant and installed a wood-fired boiler there (Leire pers.comm. 2009).

Scandinavian Technological Engineering bought Svalöv DH plant for SEK 12 million[42] from the company's own funds (Leire pers.comm. 2009) while the distribution network remained in the property of Svalöv municipality. The plant was producing and selling hot water at 90ºC to Svalöv City. The payback of the plant is estimated at 15 years (Leire pers.comm. 2009). The plant employed 3 people on a permanent basis and 20 people more during the straw harvesting season (mainly for straw collection, baling and storage) (Leire pers.comm. 2009).

Svalöv DH plant received about 7 000 tonnes of straw (i.e. 95% of that from wheat and 5% from rye and rapeseed) per year from about 50 farmers in the radius of up to 20 km from the plant (Leire pers.comm. 2009). According to the energy manager at Svalöv municipality, they have never had any problems with straw supply (Ekholm pers.comm. 2009). When the farmers required higher price for straw, the plant manager was ordering straw from slightly further distances at a lower price (Ekholm pers.comm. 2009). He also received a price discount on straw purchase in return of baling services provided to the farmers (Leire pers.comm. 2009). According to the plant manager, they did not have any contracts on straw delivery with the farmers, and the relationship was built on mutual trust. He phoned the farmers in spring to plan and negotiate future straw supply (Leire pers.comm. 2009).

Scandinavian Technological Engineering owned 10 Hesston bailers, which produced about 25 000 of 500 kg square straw bales every year. Plant manager owned eight tractors with a big truck; three conventional straw loaders and a big telescope loader (Leire pers.comm. 2009). The straw was stored outside in 10 meter high storages since this option was considered to be the most economically acceptable (Leire pers.comm. 2009). There were a few storage facilities in the proximity of maximum 10 km to the DH plant. Two people were helping along the straw chain (i.e. with harvesting, baling, transportation and storage).

Some of the straw was returned to the farmers for their heating systems. According to the plant manager (Leire pers.comm. 2009), a few farmers in the neighbourhood were burning straw in

[42] SEK 12 000 000= USD 1 926 000 (USD 1 = SEK 6.23 as for 2 January 1990)

their houses for heating. Farmers used about 1000-2000 tonnes of straw for burning while the rest was used as the pig and cattle bedding (Leire pers.comm. 2009).

The key motivation for the plant manager to purchase and run straw-fired DH plant was his desire to continue straw-fired business, in which the plant manager has had experience (Leire pers.comm. 2009). In addition, all the necessary infrastructure was at his service as he had owned a machinery park for two years before the plant purchase (Leire pers.comm. 2009).

One of the reasons to sell the plant to E.On was the aging of the equipment and distribution network, and a consequent need for significant investments to renovate the system (Ekholm pers.comm. 2009; Leire pers.comm. 2009). On the other hand, Svalöv municipality did not have substantial funds to rebuild it. In addition, in Svalöv there were no other competent people to run the plant except for the former manager of the plant, who was about to retire (Ekholm pers.comm. 2009). However, the City of Svalöv was interested to continue straw use for heat production and started looking for a partner who could renovate the pipe system and the DH plant in Svalöv. In 2008 the company E.On turned out to be the best alternative (Ekholm pers.comm. 2009) but they decided to use wood chips as a fuel in the renovated plant. According to the former manager of energy projects in Svalöv municipality (Ekholm pers.comm. 2009), the reason why E.On switched to wood fuel was the relative easiness of the fuel operation and less labour intensity as compared to straw. Currently E.On is expanding the distribution network, increasing heat production and connecting private houses to the grid (Ekholm pers.comm. 2009).

The former plant manager continues producing about 1 MW of heat from straw for his own farm, the neighbour farm and for the premises of business companies that are rented from him (Leire pers.comm. 2009).

The case of Svalöv is presented in the form of an agro-biomass based framework in Table 5-8.

9. Horbelev, Denmark

A 1.6 MW straw-fired plant is located in the village of Horbelev in the South East of Denmark. It supplies 1.3-1.6 MW of heat and hot water to 205 houses in the village and stores additional 0.3 MW in a 550 m^3 hot water tank for back up purposes (Fig. VI-6) (Palle pers.comm. 2010). In future 50 other private houses are planned to be connected to the grid in Horbelev (Palle pers.comm. 2010).

Figure VI-6. 550 m^3 hot water accumulator at Horbelev neighbour heating plant, Denmark

Before 1986 people had been using electricity and oil in the village for private heating. In 1986 a boiler fired with wheat straw was installed and a DH network was constructed. 205 houses were connected to the grid. Later in 1990s a new chairman of the village council substituted a straw-fired boiler with a wood-fired one, and started to use wood pellets (Palle pers.comm. 2010). However, heat produced from wood pellets turned out to be quite expensive so they returned to a straw-fired boiler again. Then one of the farmers and a manager of a similar neighbour heating plant in the close-by village of Horreby took the leadership over the plant (Palle pers.comm. 2010). In 2003 a new 1.6 MW straw-fired plant was built and is described here. This boiler is cooperatively owned by the citizens in the village while the distribution network is owned by Horbelev municipality (Palle pers.comm. 2010). The idea to install the boiler came from a group of citizens in Horbelev. According to one of straw-suppliers and shareholders at Horbelev plant, in 2004 the price for heat from straw was much lower than that from oil or electricity so it was a good investment for citizens (Palle pers.comm. 2010). Municipality acted as a guarantee for a bank loan. Every citizen in Horbelev pays 500 DKK[43] to keep the boiler in operation, and saves up to DKK 3000-7000[44] per year on heating (Palle pers.comm. 2010). Local authorities supported the project since they had long-term goals to eliminate the use of oil and electrical heating (Palle pers.comm. 2010). In addition, straw based heating seemed attractive to local authorities as there is no natural gas in the area (Palle pers.comm. 2010). No certificates for the boiler operation were required as it is low pressure equipment, and no difficulties were encountered with the system installation (Palle pers.comm. 2010).

The boiler was manufactured by Danish company Weiss A/S, which is one of the leading producers of combustion systems in Scandinavia. The company carried out the installation in about one month. Local construction companies were responsible for the building of all premises (Palle pers.comm. 2010).

Figure VI-7. Straw moisture content measurement at Horbelev neighbour heating plant, Denmark

The plant uses about 1600 tonnes of straw per year, which is burnt in big Hesston bales of 500-600 kg each (Palle pers.comm. 2010). Wheat and barley straw is used while wheat straw is considered to have better combustion properties by the managers of the plant (Palle pers.comm. 2010).

43 DKK 500 = EUR 67 (EUR 1 = DKK 7.46 as for 29 January 2009)

44 DKK 3000-7000 = EUR 400-940 (EUR 1 = DKK 7.46 as for 29 January 2009)

The straw is supplied by five farmers, who have written contracts with the plant (Palle pers.comm. 2010). The contracts regulate the bales weight and the moisture content. The bales are accepted, if the moisture content does not exceed 20% but ideally is around 11.5% or less (Fig. VI-7) (Palle pers.comm. 2010).

Straw baling is either carried out by the farmers or by sub-contractors who bale straw for them (Palle pers.comm. 2010). Most of the straw is stored by fuel suppliers in open storages on the field or in straw barns (Palle pers.comm. 2010). The barn at the plant has reserves of up to 70 tonnes of straw, which is sufficient for seven full days of the boiler operation in cold weather (Palle pers.comm. 2010). The straw in the plant barn is stored in several layers. The crane lifts the bales (Fig. VI-8), which are transported to a bale conveyor in one row. The bale conveyor transports a straw bale to the shredder, from where the straw is automatically fed into the boiler. Bottom ash is collected in an ash separator and then returned to the fields (Palle pers.comm. 2010). It is given back to farmers, who deliver straw to the plant, which is regulated in straw supply contracts. The amount of ash produced is about 5-6% of the straw weight (Palle pers.comm. 2010).

Figure VI-8. Crane lifting straw bales at Horbelev neighbour heating plant, Denmark

Danish regulations require environmental permits and flue gas abatement equipment for installations above 1 MW (Palle pers.comm. 2010). The installation in Horbelev has a system of bag filters in it, which cost about DKK 1 million[45]. There is also a requirement to replace bags every two years, which results into spendings of up to DKK 100 000[46] (i.e. DKK 70 000 for the filters and DKK 30 000 for the work) (Palle pers.comm. 2010).

Total investment cost in a straw-fired system in 1986 was about DKK 10 million[47]. In 2004 DKK 4.5 million[48] were invested in a new boiler. The payback period is about 10 years for the boiler and 20 years for the network (Palle pers.comm. 2010).

Currently there is only one operator who runs the plant (Palle pers.comm. 2010). Danish labour legislation requires more people to be employed and work in shifts. According to one of the plant shareholders and fuel suppliers, in future they plan to organise some kind of partnership with another plant in the vicinity so that plant operators could share their time between two installations (Palle pers.comm. 2010).

The plant is run satisfactorily, and the only problems encountered were linked to the risk of a backfire in the system, which was eliminated when the new one was put in place (Palle pers.comm. 2010).

Horbelev case is presented in the form of an agro-biomass based framework in Table 5-9.

[45] DKK 1 million = EUR 134 000 (EUR 1 = DKK 7.46 as for 29 January 2009)

[46] DKK 100 000 = EUR 13 400 (EUR 1 = DKK 7.46 as for 29 January 2009)

[47] DKK 10 million = USD 1 250 000 (USD 1 = DKK 8.0 as for 1986)

[48] DKK 4.5 million = EUR 603 000 (EUR 1 = DKK 7.46 as for 2004)

10. Hunseby, Denmark

A 1 MW straw-fired plant is located in the village of Hunseby in the South East of Denmark. It supplies heat for neighbour heating and hot water to 150 houses including a local school and a kindergarten in the village (Sejdenfaden pers.comm. 2010). The boiler and the network are owned by a farmer, who installed the system in 2008 and aimed at using straw for energy locally instead of selling it to Dong Energy in Copenhagen. Besides the plant owner was looking for the options to utilise his straw (Sejdenfaden pers.comm. 2010). Village citizens and local authorities supported this idea (Sejdenfaden pers.comm. 2010).

The boiler was manufactured by Danish company LIN-KA, which installed it in one week. The owner of the plant was responsible for the construction of all boiler-house premises and a straw barn (Sejdenfaden pers.comm. 2010).

All straw is produced on a 500 ha farm, which is owned by the plant manager, who grows wheat, barley, rapeseed and sugarbeets. About 1500 tonnes of straw is produced on the farm annually, of which 1400 tonnes is used for energy and 100 tonnes is sold (Sejdenfaden pers.comm. 2010). The plant uses annually about 1400 tonnes, which is burnt in big Hesston bales of 500-600 kg each (Sejdenfaden pers.comm. 2010). Only wheat straw is used as it is considered to have the best combustion properties by the manager of the plant (Sejdenfaden pers.comm. 2010). No straw is reported to be ploughed back to the soil by the farmer (Sejdenfaden pers.comm. 2010).

Straw baling is carried out by the plant owner, who rents a bailer from his neighbour. All straw is stored in two barns: one on the farm and another one near the boiler (Fig. VI-9) (Sejdenfaden pers.comm. 2010). Straw bales from the plant barn are put in a one level row on the conveyor belt and are automatically transported to a three-blade shredder, after which the fuel is fed into the combustion chamber. Ash is collected in the ash separator and then spread on the fields (Sejdenfaden pers.comm. 2010). There is no flue gas abatement equipment installed as Danish regulations do not require it for the installations below 1 MW (Palle pers.comm. 2010).

The investment cost in the boiler and the grid was about DKK 9.5 million[49]. In addition, DKK 1.2 million[50] were invested in buildings. An expected payback is about 13 years (Sejdenfaden pers.comm. 2010).

Figure VI-9. Plant straw storage at Hunseby neighbour heating plant, Denmark

Currently a straw-fired plant is operated by its owner and one more employee, who helps with all the work on the farm. The boiler owner reports that its installation has brought a better work distribution throughout the year (Sejdenfaden pers.comm. 2010).

The plant runs satisfactorily, and only minor problems were encountered during its years of operation (Sejdenfaden pers.comm. 2010). The plant manager also owns a 1 MW oil-fired boiler for back up in case any disruptions in the operation of a straw-fired one occur. There are no plans to expand energy production from straw in future although 30 more houses could have been connected to the plant (Sejdenfaden pers.comm. 2010).

The case of Hunseby is presented in the form of an agro-biomass based framework in Table 5-10.

[49] DKK 9.5 million = EUR 1.28 million (EUR 1 = DKK 7.46 as for 2008)

[50] DKK 1.2 million = EUR 161 000 (EUR 1 = DKK 7.46 as for 2008)

11. Stokkemarke, Denmark

A 2.5 MW straw-fired plant is located in the village of Stokkemarke in the South East of Denmark. It supplies heat for neighbour heating and hot water to 145 houses including a local school, a church and a house for elderly people in the village (Rasmusen pers.comm. 2010).

The boiler and the network are owned by the farmer, who updated the straw combustion system in 2008. The history dates back to 1982 when the father of the farmer built up the first straw-fired installation in Denmark. Later the current boiler manager bought the farm and put a 1 MW straw-fired system in place, which supplied heat and hot water to 45-50 houses in the village of Stokkemarke (Rasmusen pers.comm. 2010). In 2008 the heat production was expanded by substitution of the existing boiler with a 2.5 MW one. According to the plant owner, he was advised to have a 2 MW boiler but decided to install a bigger one so that there would be an opportunity to expand the heat production (Rasmusen pers.comm. 2010).

An idea to construct a straw-fired plant and a distribution network came from the owner of the plant, and was supported by the village citizens and the municipality. No difficulties are have been encountered with the plant installation (Rasmusen pers.comm. 2010).

The boiler was manufactured by Danish company LIN-KA, which carried out its installation in 1.5 months (Rasmusen pers.comm. 2010). They also provided a two year warrantee on the plant operation. Local companies were responsible for the construction of all buildings. According Network installation took about half a year (Rasmusen pers.comm. 2010).

The plant burns about 1500 tonnes of straw per year in the form of 500 kg Hesston bales (Rasmusen pers.comm. 2010). The plant owner uses different straw mixtures, which he obtains both from his farm and buys from other 7-8 farmers in the region (Rasmusen pers.comm. 2010). The price for the straw is about DKK 200[51] per tonne while the cost for straw handling is about DKK 180[52] per tonne (Rasmusen pers.comm. 2010). There are no contracts with straw suppliers to the plant, and everything is based on mutual trust (Rasmusen pers.comm. 2010). About

[51] DKK 200 = EUR 26.7 (EUR 1 = DKK 7.46 as for 29 January 2010)

[52] DKK 180 = EUR 24.1 (EUR 1 = DKK 7.46 as for 29 January 2010)

400 tonnes of straw is produced on a 300 ha owned by the plant manager, who grows sugarbeets, barley, wheat, rapeseed and grasses there. He also sells some of his straw to a turkey farm (Rasmusen pers.comm. 2010). No straw is reported to be ploughed back to the soil on the farm (Rasmusen pers.comm. 2010).

Straw baling is carried out by the plant manager, who owns a bailer and other agricultural equipment including one small and three big tractors, and a CASE combine harvester (Rasmusen pers.comm. 2010). The straw is stored in the barn next to the boiler, which has a capacity for 3000-4000 tonnes of straw (Rasmusen pers.comm. 2010). It is loaded with a loader on two conveyor belts (Fig. VI-10), which are located one above the other. Each conveyor belt carries 18 bales at a time. From conveyor belts straw is fed into the shredder, which cuts the bale into four equal parts. Each part is then fed into the combustion chamber. Bottom ash is collected in the ash separator in a separate room. It is then spread on the fields either on the farm owned by the plant manager or, in case a local municipality sets such requirements, is returned to straw suppliers (Rasmusen pers.comm. 2010). Fly ash is cleaned with a bag filter (Fig. VI-11).

Figure VI-10. Straw conveyor belts at Stokkemarke neighbour heating plant, Denmark

Total investment cost in the system was about DKK 17 million[53] including DKK 7.5 million[54] spent on firewalls and DKK 7.2 million[55] for the boiler. An expected payback period is more than 10 years (Rasmusen pers.comm. 2010).

Figure VI-11. Flue gas cleaning and reserve oil boiler at Stokkemarke neighbour heating plant, Denmark

Currently a straw-fired plant is operated by its owner and one more employee, who helps the owner with all the work on the farm. During the harvesting season the plant owner hires one or two employees in addition (Rasmusen pers.comm. 2010). The plant is reported to be quite easy in operation, however, according to the owner he learns managing it every day. In addition, LIN-KA representatives help the plant operator with advice upon inquiry (Rasmusen pers.comm. 2010). The plant owner thinks it is a good idea to produce heat from straw, is satisfied with the work of the boiler and plans to increase energy production in future by connecting more houses in the village to the grid (Rasmusen pers.comm. 2010).

Stokkemarke case is presented in the form of an agro-biomass based framework in Table 5-11.

[53] DKK 17 million = EUR 2.3 million (EUR 1 = DKK 7.44 as for 2008)

[54] DKK 7.5 million = EUR 1 million (EUR 1 = DKK 7.44 as for 2008)

[55] DKK 7.2 million = EUR 970 000 (EUR 1 = DKK 7.44 as for 2008)

12. Örtofta, Eslöv, Sweden

The utility Lund's Energy, which is owned by the municipalities of Lund (82.4%), Eslöv (12.0%), Hörby (3.5%) and Lomma (2.1%) and is responsible for all supplies of energy in the region, plans to construct a new combined heat and power (CHP) plant in the village of Örtofta between the towns of Lund and Eslöv close to a sugar mill (Ottosson pers.comm. 2009; Steineck pers.comm. 2009). With the help of this plant Lund's Energy would like to increase their capacity of electricity production to 300 GWh (Ottosson pers.comm. 2009). Currently the commissioning of the plant is postponed till 2011 because Lund's Energy was not able to obtain environmental permit for the construction (Steineck pers.comm. 2009).

The plant will have two biomass fired boilers. A 110 MW boiler will operate on wood chips, waste wood and peat. A 45 MW boiler will burn straw (Ottosson pers.comm. 2009). The turbine will have a capacity of 53 MWe and 100 MW steam (Steineck pers.comm. 2009). The funding of the project is ensured via bank loan in addition to the funding from Lund's Energy. The expected payback period is estimated to be 12 years (Steineck pers.comm. 2009).

By postponing the construction of the straw-fired boiler and of the office the company ended up with a need of about SEK 800 million[56] for its initial investment (Ottosson pers.comm. 2009). Lund's Energy expects that within the following 3-4 years of operation they will have an improved funds flow, which will allow putting the straw-fired boiler in operation. Its installation is now planned for 2013 and the start of operation - for 2015 (Ottosson pers.comm. 2009).

The decision to start the plant construction with the wood-fired boiler is due to a higher certainty in wood-based energy systems (Ottosson pers.comm. 2009). One of the project coordinators considers straw to be an interesting and quite new fuel for Sweden (Ottosson pers.comm. 2009). However, since Lund's Energy aims to obtain the maximum profit with initial investments, the decision was made towards the investment into a more certain activity. The market for wood chips is already established, and thus it should be easier and less risky to put a wood-fired boiler into operation first (Ottosson pers.comm. 2009).

A straw-fired boiler at Örtofta CHP plant is a specially designed roster boiler with low ash melting point. It requires about 80 000 tones of straw per year (Ottosson pers.comm. 2009; Steineck pers.comm. 2009). The moisture content of straw should be optimally 10-15% but not higher than 25% (Steineck pers.comm. 2009). Lund's Energy biofuel purchase manager identifies wheat as the fuel with the best combustion properties (Steineck pers.comm. 2009).

The area of the plant is 17 ha. It is projected to have a large wood fuel storage and a straw barn of 100 m long and 30 m wide (Steineck pers.comm. 2009). One lorry with straw will be unloaded automatically during approximately two minutes. The straw will then be fed into the boiler with a conveyor belt, and the lorry will be cleaned with a vacuum cleaner. In parallel there will be a manual unload on the other side of the straw barn for the bales with unconventional shape. The capacity of each lorry will be 16 bales placed in 3 layers (Steineck pers.comm. 2009).

The plant straw storage will have a straw reserve for three full days of the plant's operation. The most economically efficient solution is when the straw is transported directly from the field to the boiler-house (Steineck pers.comm. 2009). However, this is only possible during the harvesting season (Steineck pers.comm. 2009). That is why Lund's Energy plans to have 10 storages more, the maintenance of which will be either in responsibility of individual sub-contractors or separate companies/businessmen letting their storages to Lund's Energy (Steineck pers.comm. 2009). It is planned that every year a straw-fired boiler at Örtofta CHP plant will use 25% of straw from the storage of the previous year (Steineck pers.comm. 2009).

The utility Lund's Energy plans to use different options to store straw including covered storage, open storage and storage in the field with bales wrapped in plastic (Steineck pers.comm. 2009). On-site barns will have tin stands, a concrete floor and no walls (Steineck pers.comm. 2009).

In case the storages are filled by sub-contractors, their responsibility will be to ensure straw supply and negotiate terms of straw delivery with the farmers (Steineck pers.comm. 2009). The biofuel purchase manager considers this to be a much more efficient way of straw supply than when the representatives of Lund's Energy would negotiate directly with the farmers

[56] SEK 800 000 000 = EUR 85 400 000 (EUR 1 = SEK 9.37 as of 2 June 2008)

(Steineck pers.comm. 2009). Ash from straw combustion will be sold back to farmers. The price for ash from biofuels is SEK 500[57] per tonne (Steineck pers.comm. 2009).

The most cost-efficient distance for straw collection is 20-30 km, which Lund's Energy aims to ensure for Örtofta plant (Steineck pers.comm. 2009). The price for straw should be established as a market price. However, since there is no market for straw in Scania, Lund's Energy is considered be responsible for its establishment (Steineck pers.comm. 2009).

With regards to future straw supplies, Lund's Energy had a discussion with one of the fuel suppliers to Skurup DH plant (Steineck pers.comm. 2009). Also a boiler manager at Pugerup estate mentioned a possibility to supply straw to Örtofta plant (Weden pers.comm. 2009).

Lund's Energy prefers to rather conclude contracts with sub-contractors, who in turn would be responsible for the negotiations with farmers (Steineck pers.comm. 2009). This strategy is explained by the better trust between sub-contractors and farmers, their established personal relationship and knowledge (Steineck pers.comm. 2009). Sub-contractors should also own and/or rent straw handling equipment and be responsible for all activities related to straw harvesting and handling. Ideally the subcontractors should also own some of the straw storages (Steineck pers.comm. 2009).

According to one of the project coordinators, the main reason to construct of a biomass-fired CHP plant in Örtofta is economic (Ottosson pers.comm. 2009). In the beginning of 1990s a carbon tax was put on conventional fuels in Sweden, which resulted into higher production costs for electricity and heat. In 2000 a biomass plant became a cost efficient option for the utility Lund's Energy. In 2004 Lund's Energy carried out a new feasibility study considering new electricity prices. In 2005 a pre-study was done, which resulted in the establishment of a company Eslöv Lund Kraftvärmeverk A/B, which is now responsible for Örtofta project (Ottosson pers.comm. 2009).

Örtofta case is presented in the form of an agro-biomass based framework in Table 5-12.

[57] SEK 500 = EUR 47.13 (EUR 1 = SEK 10.61 as of 30 January 2009)

13. Avedøre, Copenhagen, Denmark

Avedøre CHP plant, Southern Copenhagen, with installed capacity of 810 MW electricity and 900 MW heat supplies electricity to 1.3 million households in the northern grid and district heat to 200 000 homes in Greater Copenhagen area (Dong Energy 2009; Sørensen pers.comm. 2009). District heating grid covers Gentofte to the North, Solrød to the South and Roskilde to the West.

Avedøre CHP plant consists of two units: Avedøre 1 and Avedøre 2. Avedøre 1 was built in 1990 and uses coal as the primary fuel but may also use oil (up to 50 tonnes per hour) (Dong Energy 2009). Annual coal consumption is about 500 000 tonnes (i.e. 85 tonnes per hour). Energy output of Avedøre-1 is 250 MW electricity and 580 MW heat.

Avedøre 2 is a multi-fuel CHP plant, which was put into operation in 2001, and is one of the most energy efficient plants in the world (BWV 2008; Sørensen pers.comm. 2009). Total output of Avedøre-2 is 570 MW electricity and 560 MW heat. The plant can exploit up to 94% of energy in the fuel, and its electrical efficiency is at least 46-47% (Sander & Skøtt 2007; Dong Energy 2009). Avedøre-2 is a supercritical plant with steam pressure of 250-300 bars and a temperature of 540-600^{o}C (Sørensen pers.comm. 2009).

Avedøre-2 consists of a main boiler, which can be fired with oil, natural gas and/or wood pellets, a straw boiler (Skøtt & Hansen 2000b), a steam turbine and two natural gas turbines (Dong Energy 2009). The main boiler uses 100 million m^3 of natural gas, 160 000 tonnes of oil and 300 000 tonnes of wood pellets per year (Sander & Skøtt 2007). Hourly consumption of these fuels at the plant is 60 tonnes of natural gas, 70 tonnes of oil and 120 tonnes of wood pellets (Dong Energy 2009). The straw-fired boiler burns 170 000 tonnes of straw annually (or 25 tonnes per hour). Gas turbines use up to 135 million m^3 of gas per year.

The main boiler in Unit-2 is represented with a 70 m tower and is a corner fired boiler with 16 burners in four levels (Jansen pers.comm. 2009; Sørensen pers.comm. 2009). It uses a mixture of fuels including wood pellets, oil and natural gas. Fly ash is also used to reduce the corrosion of the superheaters caused from chlorine in wood pellets (fly ash is highly alkaline) (Sørensen pers.comm. 2009).

Wood pellets are transported via covered conveyors from the harbour. They are milled and wood dust is fed into the burner with about 2% of excess air supply (Jansen pers.comm. 2009).

Straw-fired boiler at Avedøre 2 is a Benson boiler with hanging superheaters in the combustion chamber and a vibrating grate divided intro 3 air zones for each of the four feeding lines (Jansen pers.comm. 2009). Boiler capacity is 45 MW electricity and 50 MW heat. Steam from the boiler is supplied to the main turbine.

Straw bales from the storage are transported to the boiler in 4 lines. First the strings are cut before the straw proceeds to a shredder. A new type of shredder is used, which cuts the loosened straw bale layers between two cylinders (Sander & Skøtt 2007). Screw stockers transport the straw into the boiler.

Straw is delivered to the plant in trucks that carry 24 big Hesston bales placed in two layers. Two trucks are unloaded simultaneously with the help of automatic overhead travelling cranes that pick up 12 bales at a time (Fig. VI-12). Cranes can only unload the bales located on a truck in a certain order so a truck or a truck with a trailer is a necessary precondition for straw delivery. Normally straw delivery is either carried out by sub-contractor transportation companies or straw handling companies but can also be arranged by the farmers who own trucks (M. Nielsen pers.comm. 2009).

After straw unloading trucks are cleaned by truck drivers with brooms and vacuum cleaners (Fig. VI-13).

Figure VI-12. Straw unloading at Avedøre plant, Copenhagen, Denmark

The capacity of the straw storage is about 3000 big bales (Sander & Skøtt 2007), which is sufficient for two days of full-time operation. Four sub-contracting companies are responsible for straw delivery to the plant. 65 trucks arrive each day. Farmers are responsible for straw handling and baling (Sørensen pers.comm. 2009).

Figure VI-13. Truck cleaning after straw unloading at Avedøre plant, Copenhagen, Denmark

Dong Energy always purchases straw on the farm or as delivered to the plant. In case the straw is purchased from the farm, Dong Energy makes contracts with transportation companies. If the straw is purchased at the plant, the farmers are responsible for all straw handling procedures (i.e. baling, storage, and delivery) (Nielsen pers.comm. 2009). Normally straw is purchased during the heating season (i.e. from October till April). Straw bales are refused, if the moisture content is higher than 24% (Nielsen pers.comm. 2009), however, at Avedøre plant this is a very rare occasion (Jansen pers.comm. 2009).

The distances for straw delivery are different. Normally they should not exceed 80-100 km, however, a few extra kilometres do not influence the overall cost much as the most expensive stage is truck loading (Nielsen pers.comm. 2009).

Dong Energy signs contracts with individual farmers but ensure that the principle of producer equity is fulfilled (Jansen pers.comm. 2009; Nielsen pers.comm. 2009). No advantages are given to bigger suppliers (Nielsen pers.comm. 2009). The company defines product specifications and characteristics, and then announces a tender. All offers received by Dong Energy are evaluated equally, and then a purchase decision is made (Nielsen pers.comm. 2009).

According to Dong Energy policy, straw price levels cannot be disseminated (Nielsen pers.comm. 2009). Since they are a large consumer in Danish straw market, the company is cautious pf creating disturbances for price establishment by suppliers.

All bottom ash is returned to the farmers (Jansen pers.comm. 2009; Nielsen pers.comm. 2009). Dong Energy contracts specify free ash delivery to the farmers. If a farmer prefers Dong Energy to utilise the ash, they have to pay DKK 27 per each tonne of straw sold to the company (Nielsen pers.comm. 2009). Dong Energy in the majority of cases sells this ash to other farmers, who have capacities to use it (Nielsen pers.comm. 2009). Fly ash is sent to Komunekemi in Nyborg where it is processed into fertiliser (Skøtt & Hansen 2000b).

Both Avedøre 1 and 2 are equipped with advanced flue gas cleaning units. There are two 50 m high hot water accumulators and a 24 hour common control room (Jansen pers.comm. 2009). 130 people are employed at the plant (Sørensen pers.comm. 2009).

In 1998 Babcock and Wilcox Vølund A/S (BWV) was awarded a contract for the construction of a steam turbine, and in 1999 - for the construction of an ultra supercritical straw-fired boiler plant (BWV 2008). Other companies including FLS Miljø and BWE (Sander & Skøtt 2007) were also involved in the process. Dong Energy and Vattenfall, who owned 40% of the plant when Avedøre-2 was built, invested DKK 3.5 billion (Sørensen pers.comm. 2009). Now Dong Energy is a single plant owner. The main reason to construct a new unit at the existing plant was due to the increase in demand for DH (Sørensen pers.comm. 2009).

Green electricity tariff allows Dong Energy to sell its renewable electricity at higher prices (see Sub-section 5.1.2). In addition, the heat from biomass is not taxed in Denmark (Sørensen pers.comm. 2009). Besides, Dong Energy is paid a levy for straw handling by Danish government per each tonne of straw handled (Nielsen pers.comm. 2009).

In 2011 co-firing tests of coal and wood pellets are planned at Unit 1. There is also a plan to co-fire wood chips and straw in a straw-fired boiler (Sørensen pers.comm. 2009).The ultimate goal is to convert Avedøre CHP plant to 100% use of biomass (Sørensen pers.comm. 2009). The case of Avedøre is presented in the form of an agro-biomass based framework in Table 5-13.

14. Sangüesa, Navarre, Spain

A 25 MW is located in the industrial estate of Rocaforte near Sangüesa, Navarre region, Northern Spain (Acciona Energía 2009b). In terms of its size it is a pioneer plant in Southern Europe that uses straw for energy production (Acciona Energía 2009c). Since 2002 it has been owned and operated by Acciona Energía, which is a European leader in renewable energy technologies (Acciona Energía 2009a).

The plant operates 8000 hours and uses 160 000 tonnes of cereal straw to produce 200 GWh of electricity per year (Acciona Energía 2009b; Acciona Energía 2009c). This is sufficient to cover the power consumption of 50 000 households (Acciona Energía 2009a). The plant helps to reduce about 200 000 of CO_2 emissions per year (Acciona Energía 2009a). 100 direct and indirect jobs were created after it has been put into operation (Acciona Energía 2009b). Also during the plant construction about 200 people were working on the site within 18 months (EC Energy 2009). The investment cost of the plant was EUR 51 million, out of which the European Commission (EC) provided EUR 3 million and the Spanish Institute for Energy Diversification and Savings (IDAE) contributed with EUR 2.4 million and a 10% share in the total investment (EC Energy 2009). The payback period is estimated at about 15 years (EC Energy 2009).

The power plant has a constructed surface area of 10 108 m^2, and consists of three buildings, i.e. a warehouse (5 120 m^2), a boiler house (1 900 m^2), a turbine, control and office area (2 635 m^2) and some other facilities (453 m^2) (Acciona Energía 2009c; Acciona Energía 2009a). All buildings are linked architecturally through a unified design, and have steel roofs and facades. There is also a visitor's gallery that allows the production process to be observed without interfering with it (Acciona Energía 2009c).

The straw-supply chain includes harvesting, baling, storage and transportation of straw to the plant. About 90% of all straw is stored in the field on the farms while 10% is kept in the barns (Lerga pers.comm. 2009). According to the operation and maintenance manager of Acciona Energía biomass plants, the company obtains its straw from 120 km distances on average (Lerga pers.comm. 2009). The straw warehouse at Sangüesa plant has a capacity to secure fuel supply for three full days of the plant operation (Lerga pers.comm. 2009). Harvesting and baling machinery is normally owned by straw suppliers, and baling is provided by them (Lerga pers.comm. 2009). The plant is located in a close proximity to the main road, which facilitates the arrival of the trucks (Acciona Energía 2009b). Straw from the field is transported by the trucks to the plant, where three overhead travelling cranes weigh the bales, check their moisture content and, if the bales are accepted, send them to the storage areas (Acciona Energía 2009b). From there an automatic control system collects the bales and puts them on a conveyor belt to be transported to the boiler. Before entering the boiler straw bales are shredded, and then fall on a vibrating grill, where the combustion process starts (Acciona Energía 2009b). The whole boiler and feeding system were produced by Danish company FLS Miljø (EC Energy 2009; BIOENER ApS 2009).

The water flows through the walls of the boiler and is heated during the combustion process. After it is converted into 540ºC steam, the steam is sent to a superheater, and then to a turbine connected to a generator that produces electricity (Acciona Energía 2009c). First electricity is transformed from 11 kV to 66 kV at the grid located on the plant site (Acciona Energía 2009b), and then it is sent via network cables to a sub-station in Sangüesa, from where it is sold to the national grid (Acciona Energía 2009c). The steam that has passed through the turbine is taken to a condenser. It is cooled by the water from the irrigation channel of Irati river, which runs through the industrial estate, and is again converted into water. This water is transported through pipes to the walls of the boiler to start the process all over again (Acciona Energía 2009a; EC Energy 2009). The water that has been used for cooling is returned to the channel (Acciona Energía 2009c).

The plant does not utilise waste heat from electricity production, which is linked to the regional specificity, i.e. the fact that the weather conditions in Spain have not created a demand for the construction of DH networks (Lerga pers.comm. 2009). However, the plant efficiency is increased by so called “internal co-generation” when the condensate from the steam turbine is fed in back to the preheating stages and reused in the process of steam generation (EC Energy

2009). Fly ash from straw combustion is collected in the smoke filtering system at the plant. Unburnt residues are deposited at the bottom of the boiler. Bottom ash constitutes 5% from the fuel used (Acciona Energía 2009b). Both the residues and the ash are sent to hoppers and are later used as agricultural fertilisers (Acciona Energía 2009c). Acciona Energía pays for the ash utilisation and delivers it to a fertiliser producing factory.

The main technical challenge for the company was to avoid the risk of boiler corrosion from straw combustion (Acciona Energía 2009a), which was achieved by an efficient system of superheaters produced from resistant materials (EC Energy 2009). It was also important to guarantee the continuity of straw supply by establishing contracts with farmers, co-operatives and other sector professionals (Acciona Energía 2009a). The company started signing long-term contracts with the farmers in the area in 1998 (Lerga pers.comm. 2009). These contracts are signed either with individuals or with farmer associations, if the latter are available in the region, and the latter are preferred by .plant managers (Lerga pers.comm. 2009).

Straw price is determined by the market but for the supplier of Sangüesa it is lower than when short-term contracts are made (Lerga pers.comm. 2009). Total cost of straw supply is estimated at about EUR 36 per tonne including all logistics expenses until straw reaches the plant (EC Energy 2009). Straw characteristics regulated in the contracts mainly include those of bale size parameters and straw moisture content.

In Navarre region straw combustion in the field is prohibited by the legislation (Lerga pers.comm. 2009). There used to be a pulp and paper industry in the region, which utilised straw in its processes. However, it was shut down in 1990s, which significantly increased straw supply on the market. Hence an idea to use straw for electricity production emerged (Lerga pers.comm. 2009). In addition, Spanish Renewable Energy Plan for 2005-2010, which was approved by the government on 26 August 2005, set a target to increase the use of electricity from biomass from 1139 GWh in 1998 to 14 015 GWh in 2010 (Acciona Energía 2009b; Acciona Energía 2009c). Spain has also to comply with the targets put in the European Union White Paper on Renewables, which requires to increase the electricity production from biomass from 22 TWh in 1995 to 230 TWh in 2010, thus further biomass options in the region need to be explored (Acciona Energía 2009c). For future other fuel alternatives are also investigated including energy crop plantations at demonstration scale and opportunities to burn mixtures of straw and wood chips (up to 50% in heat values) (EC Energy 2009).

The main objectives by Acciona Energía for Sangüesa power plant construction include restriction of CO_2 emissions, reduction of energy dependence and creation of a major productive sector in the field (Acciona Energía 2009c). The company has now three functioning installations in Spain. Except for the described plant, two 4 MW straw-fired facilities are located in the regions of region of Castilla y León and Castilla La Mancha (Acciona Energía 2009d). Also two 16 MW straw-fired power plants are under construction, and are planned to be launched in 2010, and five plants with a total installed capacity of 82 MW are currently under development (Acciona Energía 2009d).

Sangüesa case is presented in the form of an agro-biomass based framework in Table 5-14.

Annex VII. Narratives of case studies in Ukraine

1. Strutynka village, Lypovetsk region, Vinnytsya province

A 250 kW straw-fired boiler RAU-2-301 was installed in 2005 at the agricultural enterprise LLC "Rapsodiya" in the village of Strutynka, Lypovestk region, Vinnytsya province, Ukraine. (Antonik pers.comm. 2010). It supplies heat to the enterprise premises (e. g. administrative buildings, changing rooms, houses on the network rout, etc.) and also to the mill, which was built in 2005. The mill is of Danish manufacture and is a building of 6 m x 24 m x 36 m parameters (Antonik pers.comm. 2010). It is located on the field and requires minimum temperature of +12-15^{0}C, which is provided by the straw-fired boiler (Antonik pers.comm. 2010).

Agricultural enterprise "Rapsodiya" operates on 1500 ha of farmland rented from private owners (Antonik pers.comm. 2010). The farm grows wheat for sale and flour production, soy, barley, sunflower for seeds, rapeseed and kidney beans. Rapeseed is sold either for vegetable oil or for biodiesel production (Antonik pers.comm. 2010). According to the director of the enterprise, they have good established connections with V-Oil Agro – a company that owns oil processing plants in Chernivtsi and Vinnytsya provinces, and in Russian Federation (Antonik pers.comm. 2010). The enterprise also produces its own flour (Antonik pers.comm. 2010).

In 2004 LLC "Rapsodiya" was planning to gasify their enterprise and calculated the project budget at UAH 40 000[58] (Antonik pers.comm. 2010). They planned to construct a 6 km gas pipeline to supply gas for their purposes and to other houses on the transportation route in Strutynka, which had not been gasified yet (Antonik pers.comm. 2010). However, in 2004 the uncertainty level of gas price establishment for industrial users in Ukraine was high, which made the director of LLC "Rapsodiya" concerned (Antonik pers.comm. 2010). This resulted in the

[58] UAH 40 000 = EUR 6 000 (EUR 1 = UAH 6.62 as of 1 March 2004)

assessment of different energy supply alternatives for the enterprise. Since the company produces significant amounts of straw, it was selected as a feasible fuel alternative (Antonik pers.comm. 2010).

The agreement about straw-fired boiler purchase was made between LLC "Rapsodiya" and UTEM manufacturing company (Antonik pers.comm. 2010). UTEM was responsible for all works and provided drawings for the construction of the foundation to LLC "Rapsodiya". 30% of the boiler cost was prepaid in advance while 70% were paid 10 days after the boiler had been installed (Antonik pers.comm. 2010).

No permits were required for the boiler installation as it works without pressure, and no environmental permits are required for its operation (Antonik pers.comm. 2010). The cost of energy production in January 2005 was UAH 53[59] per Gcal (Antonik pers.comm. 2010). According to the owner of the boiler, operational costs can be decreased with the increase of baling efficiency (Antonik pers.comm. 2010).

The heating season lasts for 180 days, during which three round bales (from 360 to 420 kg each) are burned daily. Mainly soy straw is used as it has revealed the best combustion properties (Antonik pers.comm. 2010). Some rapeseed, wheat and barley straw is also combusted. All straw that is used for energy production in the boiler is produced on the farm. From 1 kg of straw about 4 kW of heat is generated with boiler efficiency of 85-89% (Antonik pers.comm. 2010).

LLC "Rapsodiya" owns a bailer of Belarusian manufacture, which cost about EUR 6000 (Antonik pers.comm. 2010). The director of the enterprise is not satisfied with the functioning of the bailer, which has broken after one season of operation (Antonik pers.comm. 2010). The agricultural enterprise also owns other equipment and machines including heavy and light tractors of Ukrainian and Belarusian manufacture, three American combine harvesters CASE IH, and several seeding machines. They also have a small vegetable oil extraction line, and produce vegetable oil on their own (Antonik pers.comm. 2010).

[59] UAH 53 = EUR 7.58 (UAH 1 = EUR 6.99 as of February 2005)

The installation of a straw-fired boiler at LLC "Rapsodiya" has not created any additional jobs (Antonik pers.comm. 2010). The boiler is very easy in operation, and according to its owner, any person can learn how to manage it (Antonik pers.comm. 2010).

Local authorities learned about the straw-fired boiler at LLC "Rapsodiya" approximately two months after its installation, and conducted a site visit to the enterprise (Antonik pers.comm. 2010). No problems with local authorities have been encountered (Antonik pers.comm. 2010). The only problem faced was linked to the boiler transportation and delivery since the boiler stack is overdimensioned (i.e. 4,35 m in height). An agreement with Vinnytsya traffic police was actually required (Antonik pers.comm. 2010).

Managers of LLC "Rapsodiya" also suggested to the head of the village council to install three similar straw-fired heat generators in Strutynka instead of gas pipeline construction. The cost of gas pipeline construction was about EUR 110 000, which would have been enough to purchase and install three 250 kW straw-fired boilers (Antonik pers.comm. 2010). The village council refused the idea providing an argument that they would depend on the agricultural enterprise for straw supply (Antonik pers.comm. 2010). This is, however, a debated argument since LLC "Rapsodiya" leases the land from the village council (Antonik pers.comm. 2010). The village council representatives also questioned the problem of domestic cooking without natural gas supply to the houses (Antonik pers.comm. 2010). Some opposition came from local elderly people who claimed that straw use for energy would be a return to "the years of war" when it was a traditional way of heating (Antonik pers.comm. 2010).

Overall the boiler owner is satisfied with its work, and considers it to be very reliant and easy to use equipment. He claims that "it is the best purchase" of his life (Antonik pers.comm. 2010). Fuel self-sufficiency is recognised as one of the most significant achievements of the project (Antonik pers.comm. 2010). No disruptions in the boiler operation have been encountered (Antonik pers.comm. 2010).

The owner of the boiler is interested to research, develop and test pyrolisys process for liquid biofuel production from straw. Such fuel could be mixed with conventional diesel used in agricultural machinery on the farm (Antonik pers.comm. 2010). Another idea is to try gasification pyrolisys. In the past the director of LLC "Rapsodiya" used to produce biodiesel on his farm from rapeseed in a small reactor, which he constructed himself. However, biodiesel production turned out to be not cost-efficient as compared to conventional diesel so the production was stopped (Antonik pers.comm. 2010).

Strutynka case is presented in the form of an agro-biomass framework in Table 6-2.

2. Lebedyn village, Shpola region, Cherkasy province

Lebedyn is a village located in Cherkasy province, central Ukraine, and has a population of 4700 inhabitants (Galata 2009). It has three schools and kindergartens, an ambulance station, a local hospital, a pharmacy, a centre for elderly people, a community and recreation centre, three libraries, a museum and more than 20 stores (Galata 2009). In 1990s with the reform on land privatisation one collective farm terminated its existence while two others were reorganised in a LLC "Agro-Vidrodzhennya" (Galata 2009).

The village is gasified but sometimes people use traditional fuels to heat their houses not least due to increases in natural gas prices (Demydov pers.comm. 2009). DH network existed in Lebedyn in the past but was eliminated with privatisation reform in 1990s, and individual natural gas heaters were installed (*Demydov pers.comm. 2009*).

The village is famous for its seed breeding plant, which was functioning there since 1937 and had been processing beetroot seeds and preparing them for planting. In 1994 the plant was reorganized in OJSC "Lebedyn Seed Plant" and started to rent up to 16 000 ha of land from private owners and to grow grain and technical crops, which made OJSC "Lebedyn Seed Plant" an agricultural enterprise (Galata 2009; Demydov pers.comm. 2009).

A 250 kW straw-fired boiler RAU-2-301 was installed at the plant in 2008 and is used for the heating of an administrative building with a total area of 2400 m^2. Some heat is also used to maintain a temperature of +12-14^{o}C in winter at the seed packaging line (Demydov pers.comm. 2009).

The boiler is owned by OJSC "Lebedyn Seed Plant". It was manufactured by UTEM, who supplied the boiler and its parts to the village. UTEM representatives installed the system (Demydov pers.comm. 2009) in two days and taught the operators to manage the boiler. The seed plant constructed the boiler foundation in accordance with drawings supplied by UTEM (Demydov pers.comm. 2009). No permits were required for the boiler installation and the village council did not demonstrate any opposition (Demydov pers.comm. 2009). The boiler cost was

UAH 240 000[60] paid at once from the company's funds. The boiler's payback was estimated at 2-2.5 years (Demydov pers.comm. 2009).

The boiler is fired mainly with wheat and barley straw produced on the land managed by the agricultural enterprise. In 2007 200 tonnes of straw were harvested while only 140-150 tonnes were used in the boiler during the 2007-2008 heating season (or about 8 bales 200 kg each per day), when the lowest temperature was -15^{0}C (Demydov pers.comm. 2009). This straw is not used elsewhere: very small amounts of it are ploughed back to the soil and a lot of it is burnt in the field (Demydov pers.comm. 2009). There is almost no animal farming in the region (Demydov pers.comm. 2009; Galata 2009).

The company uses its own tractors and machines for agricultural purposes but rents a bailer from a neighbour organisation (Demydov pers.comm. 2009). According to the calculations by OJSC "Lebedyn Seed Plant", handling of one tonne of straw costs about UAH 200[61], and the most expensive step is baling due to the baling service order and strings purchase (Demydov pers.comm. 2009). All ash from straw combustion is spread on the fields (Demydov pers.comm. 2009).

The installation of a straw-fired boiler at OJSC "Lebedyn Seed Plant" has not created any additional jobs. They had a reverse effect instead since for the operation of the former gas-fired boilers more employees were required (Demydov pers.comm. 2009). Boiler operators load 2-3 bales to the burner per day, and tend to combine this work with other activities (Demydov pers.comm. 2009).

The boiler is very simple in operation, and no additional skills are required to run it (Demydov pers.comm. 2009). The managers are satisfied its work. The leading energy specialist at the company notes that gas boiler operation was more sophisticated both from the bureaucratic point (e.g. problems with inspection authorities) and in the sense of its exploitation and fire safety (Demydov pers.comm. 2009). The only problem indicated is linked to the evenness of the

[60] UAH 240 000 = EUR 32 000 (EUR 1 = UAH 7.52 as of January 2008)

[61] UAH 200 = EUR 16.6 (EUR 1 = 12.08 as of 4 December 2009)

combustion process, which sometimes leads to uncombusted leftovers (Demydov pers.comm. 2009).

The main reason to install a straw-fired boiler at the plant was to substitute the existing gas-fired boilers and get rid of dependence on expensive and bureaucratic natural gas based heating system (Demydov pers.comm. 2009). In addition to the fuel switch, the area with heating requirements was also reduced (Demydov pers.comm. 2009).

OJSC "Lebedyn Seed Plant" also owns two grain dryers of 1.4 and 1.6 MW, which are fired with natural gas. The company uses about 600-800 m^3 of natural gas per day to run them and spends about UAH 250 000[62] per season. According to the leading energy specialist, they would be interested to substitute natural gas with straw and crop residues but so far they have not heard about Ukrainian producers of grain dryers of this scale (Demydov pers.comm. 2009).

Lebedyn case is presented in the form of an agro-biomass framework in Table 6-3.

[62] UAH 250 000 = EUR 20 700 (EUR 1 = 12.08 as of 4 December 2009)

3. Polkovnyche village, Stavyshche region, Kyiv province

Polkovnyche village is located in the south of Kyiv province. In 2007 the trading company "ROPA Ukraine" installed a 600 kW straw-fired boiler RAU-2-600 in the village to heat their premises including a manufacturing centre, a working room, a storage room and an office. Altogether 3 000 m^2 are heated with the straw-fired boiler (Orlovskyi pers.comm. 2010).

"ROPA Ukraine" was funded in 2003 and is a daughter company of German plant ROPA, which produces combine-harvesters and beetroot loaders. They are also an official trading organisation of such companies as ROPA, Horsch, Bergmann, and Reichhardt (Prom.ua 2010). "ROPA Ukraine" owns a daughter agricultural enterprise, which operates on 800 ha of land rented from private users in the village of Polkovnyche. The enterprise specialises in beetroot production and also grows wheat and rapeseed (Orlovskyi pers.comm. 2010).

An idea to install a straw-fired boiler came to the director of the enterprise after he had seen UTEM boilers at the agricultural exhibition in Kyiv (Orlovskyi pers.comm. 2010). In 2007 the first disputes over natural gas supply started, and the company needed a source to heat its premises. According to the director, they could have connected to the natural gas grid but too many permits were required and the procedure tuned out to be highly bureaucratic. That is why they decided to start the heating of their premises with straw (Orlovskyi pers.comm. 2010).

The boiler is owned by "ROPA Ukraine" and was manufactured by UTEM, who supplied the boiler and its parts to the enterprise. UTEM installed the boiler and connected the stack within two days (Orlovskyi pers.comm. 2010). "ROPA Ukraine" received the necessary drawings from UTEM and constructed the foundation using their own building equipment. There were no difficulties with the boiler installation and no permits were required (Orlovskyi pers.comm. 2010). Local authorities did not demonstrate any interest in this activity (Orlovskyi pers.comm. 2010). The cost of the boiler was EUR 30 000, and its payback is 2-3 years. "ROPA Ukraine" paid the total cost from its own funds. First instalment was made as advance payment, and the rest of the cost was covered after the boiler had been installed (Orlovskyi pers.comm. 2010).

The boiler is fired with wheat straw produced by the daughter agricultural enterprise of "ROPA Ukraine" (Orlovskyi pers.comm. 2010). The boiler requirement is fulfilled with straw harvested from 100 ha of land and constitutes 800 cylindrical bales of 280-300 kg each per heating season (Orlovskyi pers.comm. 2010). In cold weather two bales are loaded 4 times per day (Orlovskyi pers.comm. 2010). Currently the boiler is operating only at 60% of its capacity.

"ROPA Ukraine" uses its own equipment to harvest, bale and transport straw. The company bought a new bailer two years ago, which they use to both bale their straw and some straw from the neighbouring farms (Orlovskyi pers.comm. 2010). All straw is stored on the field in bales that are put separately and not joined in clusters. There is also a small field close to the boiler, which is used as a technical yard and a straw storage (Orlovskyi pers.comm. 2010). Ash from straw combustion is collected and spread on the fields.

The installation of a straw-fired boiler at "ROPA Ukraine" is not reported to have created any additional jobs (Orlovskyi pers.comm. 2010). One of the company's employees is operating the boiler part time and gets salary surplus for his work (Orlovskyi pers.comm. 2010). According to the director of the company, no additional skills are required to operate the boiler: the operator should be able to load the boiler, start the burning process and clean the ash (Orlovskyi pers.comm. 2010).

Boiler owners are satisfied with its work and payback. In future they plan to develop their enterprise and construct new buildings and premises. Then the boiler will be used at its full capacity and satisfy heat requirements of the enterprise. According to the director of "ROPA Ukraine", Polkovnyche village is fully gasified, and there are no needs to supply district DH to the houses. That is why the company is rather interested in the use of the boiler for its own purposes (Orlovskyi pers.comm. 2010).

Polkovnyche case is presented in the form of an agro-biomass framework in Table 6-4.

4. Dyagova village, Mena region, Chernihiv province

The village of Dyagova is located in Mena region, Chernihiv province, Northern Ukraine. Farm enterprise "Butenko" is the biggest farm in Dyagova, and was established on previously collectivised lands, which are located in three villages nearby. The enterprise occupies 2000 ha, most of which is rented by the manager from private individual owners (Butenko pers.comm. 2009). Grain crops are grown on 1500 ha, corn - on 150-200 ha, and the rest of the land is covered with potatoes, buckwheat, millet, and other crops. Agricultural production on "Butenko" farm is certified as organic by the international NGO on organic farming certification "BioLan Ukrayina" (Butenko pers.comm. 2009). In addition, 200 milk cows are owned by the farmer (Butenko pers.comm. 2009).

Dyagova is gasified; the gasification project was funded by the manager of "Butenko" farm and cost UAH 600 000[63] (Butenko pers.comm. 2009). The office building of "Butenko" farm enterprise, a kindergarten and a few other municipal buildings are supplied with heat from a gas-fired boiler house (Butenko pers.comm. 2009). The rest of the houses have private heating systems. Most of them use old-fashioned ways of heating (ovens) while about 10% of houses have individual water pumps, toilets and bathrooms, hot water and individual gas fired heaters (Butenko pers.comm. 2009).

"Butenko" farm requires heat to run its grain dryers and hot water to wash machines, milk cans, cattle, etc (Butenko pers.comm. 2009). According to the farm manager, currently there is no need to heat premises on his farm and no requirement from private users as there is no DH system in place (Butenko pers.comm. 2009). Overall he would be interested to install a straw-fired boiler on his farm since a lot of crop residues are produced (Butenko pers.comm. 2009).

The manager has installed a biomass-fired heat generator to run his two grain dryers. The heat generator was produced by the company "NVT-Technology" located in the city of Chernihiv (Toropets pers.comm. 2009). The capacity of the generator varies from 100 to 250 kW depending on the fuel type, and it can use all types of bulky biomass mixtures including crop residues, husk, straw, wood chips, saw dust, etc. (Butenko pers.comm. 2009; Toropets pers.comm. 2009). The heat generator cost of UAH 56 000[2] was paid from the farmer's private funds (Butenko pers.comm. 2009).

The grain dryer at the agricultural enterprise "Butenko" can dry 6-10 tonnes of grain per hour (Fig. VII-1). It works in two different regimes: one for seed production and another one for food/feed production (Butenko pers.comm. 2009). Currently two heat generators are connected to the grain dryer on the farm: an old one fired with diesel oil and a new biomass-fired heat generator (Butenko pers.comm. 2009). The son of the farm manager operates the grain dryer. According to the operator, about 108 tonnes of wheat with the moisture content of 4%, and up to 40 tones of maize corn with moisture content of 34-36% can be dried every day. From 300 to 500 litres of diesel oil is substituted per day (or up to 50 tonnes per year) (Butenko pers.comm. 2009). The maximum available moisture level for the biomass-fired heat generator is 60% (Butenko pers.comm. 2009; Toropets pers.comm. 2009). In addition to hot air supply for the grain dryers, some heat is used to warm up two tonnes of water that is used on the farm for various purposes (Butenko pers.comm. 2009).

A mixture of different biomass fuels is used in the biomass-fired heat generator including forestry residues from a forest plot on the farm and up to 300 tonnes of straw produced on the farm, which has been wasted before in the digestion pit (Butenko pers.comm. 2009). Overall up to 3000 tonnes of straw can be produced by the agricultural enterprise "Butenko" (Butenko pers.comm. 2009). It is used for the farm's own needs (i.e. cattle bedding and fodder, in the heat generator for the grain dryers) and for sale (e. g., in 2007 500 tonnes of straw was sold to mushroom growing enterprise "Ukrshampinyon") (Butenko pers.comm. 2009). The farm manager considers straw burning in the field to be a bad idea from ecological point of view. He thinks that ploughing of straw back to the soil is an acceptable and environmentally favourable solution, for which rye straw has the best properties (Butenko pers.comm. 2009).

[1] UAH 600 000 = EUR 55 500 (1 EUR = UAH 10.82 as for 1 January 2008)

[2] UAH 56 000 = EUR 5200 (EUR 1 = UAH 10.82 as for 1 January 2008)

Figure VII-1. Grain dryer in the village of Dyagova, Chernihiv province, Ukraine

The manager of "Butenko" enterprise owns four combine harvesters, three tractors (i.e. those of Ukrainian and Belarusian production, and a new tractor made by New Holland), a millet planter Grimmer, a straw bailer from Bobruysk, Belarus, an on-site wood chopper, two grain dryers, a 100-250 kW heat generator from "NVT-Technology", etc (Butenko pers.comm. 2009).

In future the manager of the farm is interested to expand bioenergy use and start up biogas production on his farm. Annually they produce about 5 000 tonnes of cow manure on the farm, and currently only some of this manure is used as a natural fertiliser. The main share of manure is left in a dedicated open air collector. The manager would like to construct a small biogas co-generation plant working on animal manure and crop residues from the farm, and is ready to invest up to EUR 170 000 in this installation (Butenko pers.comm. 2009).

Dyagova case is presented in the form of an agro-biomass framework in Table 6-5.

5. Olgopil village, Chechelnyk region, Vinnytsya province

The village of Olgopil is located in Chechelnyk region, Vinnytsya province, central Ukraine, about 180 km from the city of Vinnytsya, and has a population of 3900 inhabitants (Who-is-Who.com.ua 2006). In 1997 the collective farm "Ukraine" was reorganised in agricultural LLC "Olgopil", which was created by joint investments from private funds of Olgopil citizens (Who-is-Who.com.ua 2006).

The village is not gasified, and people use traditional fuels to heat their houses. There is no DH network in the village (Tkachynskyi pers.comm. 2009). A 300 kW straw-fired boiler RAU-2-331 was installed in December 2008 and is used for the heating of a local secondary school. The project was implemented under the framework of the State Programme for Energy Saving Technologies in Vinnytsya province, and was funded from state budget (Tkachynskyi pers.comm. 2009).

The boiler is in the communal property. It was manufactured by UTEM, who supplied the boiler and its parts, installed it and trained the operators to manage the boiler. Local company also participated in the construction works. It took several days to install the boiler (Tkachynskyi pers.comm. 2009). No environmental permits were required for the boiler installation and no external inspections were made (Tkachynskyi pers.comm. 2009).

The cost of the boiler was UAH 360 000[1]. The budget of Vinnytsya province provided UAH 530 000[2] for all the procedures. The straw-fired boiler substituted the existing coal-fired boiler-house, which used to supply heat to the local school. No data is available on the payback period of this boiler, however, a straw-fired boiler is considered to be more beneficial for local budget than a coal-fired since the funds circulates within a local budget (Tkachynskyi pers.comm. 2009).

The boiler is fired mainly with wheat and barley straw supplied as 150 kg bales. Its fuel requirement is 300-360 tonnes of straw per year (Tkachynskyi pers.comm. 2009). In 2008-2009

[1] UAH 360 000 = EUR 39 000 (UAH 1 = EUR 9.32 as for December 2008)

[2] UAH 530 000 = EUR 57 000 (UAH 1 = EUR 9.32 as for December 2008)

about 0.5 tonne of straw was used daily with outdoor temperature at 0-+10°C (Tkachynskyi pers.comm. 2009). In 2009 local authorities managed to harvest and bale only 100 tonnes of straw, which should suffice only for the half of the heating season (Tkachynskyi pers.comm. 2009). There is a discussion about burning wood too as there are 20 000 ha of forest in the region and a lot of forestry residues (Tkachynskyi pers.comm. 2009).

All straw for the boiler is supplied from the LLC “Olgopil” on a contract basis (Tkachynskyi pers.comm. 2009). The company manages up to 6000 ha of land in the region and owns modern agricultural equipment and machines including bailers (Tkachynskyi pers.comm. 2009; Who-is-Who.com.ua 2006). They bale straw and then give it back to the farmers in return for land rent. In addition, local administration of education contributed with UAH 35 000[1] for straw handling and storage, which is located at the premises of a sanitary-epidemiological inspection outside the village (Tkachynskyi pers.comm. 2009). Not much ash produced from straw combustion, hence, the problem of its utilisation is not considered to be crucial (Tkachynskyi pers.comm. 2009). Some village citizens pick up the ash for soil fertilisation (Tkachynskyi pers.comm. 2009).

The installation of a straw-fired boiler at Olgopil secondary school has not created any additional jobs. All people who used to work at the coal-fired boiler-house have moved to the straw-fired installation (Tkachynskyi pers.comm. 2009). In case there is a need to guard an outside straw storage, at least 3 people should be hired according to the labour legislation (Tkachynskyi pers.comm. 2009).

The boiler is very simple in operation (Tkachynskyi pers.comm. 2009). The main difficulties for the boiler installation were linked to the preparation of all needed documents to obtain expert conclusions for construction permit and funding. It took about three months to prepare the required documentation (Tkachynskyi pers.comm. 2009). It was also important to carry out the construction and design control. A challenge in 2008 was to get baled straw acceptable for

[1] UAH 35 000 = EUR 3800 (UAH 1 = EUR 9.32 as for December 2008)

combustion in the boiler within three weeks as it had not been prepared in advance (Tkachynskyi pers.comm. 2009).

Currently the most urgent problems are linked to the organisation of straw delivery and associated costs (Tkachynskyi pers.comm. 2009). So far the straw reserves stored close to the school are used. However, in the future local authorities will need to hire people to organise straw delivery, and search for possible sources of funding (Tkachynskyi pers.comm. 2009). The first deputy head of Chechelnyk regional administration considers that the best idea for straw management is to create a cooperative of 3-5 straw-fired boilers in neighbouring districts or villages, and have one company owning all needed machinery and organising straw handling (Tkachynskyi pers.comm. 2009).

Olgopil case is presented in the form of an agro-biomass framework in Table 6-6.

6. Stavy village, Kagarlyk region, Kyiv province

Coal and wood have been traditional sources of heat supply in most houses in the village of Stavy, Kagarlyk region, Kyiv province (Oliynyk pers.comm. 2010). A 350 kW straw-fired boiler was installed in 2008 to heat the local school and kindergarten, which had been fired with a coal boiler-house before (Oliynyk pers.comm. 2010). This project is carried out with grant support from the U.S. Civilian Research and Development Foundation (CRDF) (Geletukha & Globenko 2009). According to the project tasks, Scientific Engineering Centre (SEC) Biomass develops, produces and installs three straw-fired boilers (i.e. 100, 250 and 350 kW), and later passes them over to be owned and exploited by the users (Oliynyk pers.comm. 2010).

SEC Biomass is the chief executing organisation while project partners include Kagarlyk regional administration, village council and Stavy secondary school (Geletukha & Globenko 2009). All materials, equipment and services will be transferred into the property of Stavy secondary school for free (Geletukha & Globenko 2009). New owners should let SEC Biomass carry out its exploitation tests, organise demonstration site visits and control that the boiler is used in accordance with its purpose (Geletukha & Globenko 2009; Oliynyk pers.comm. 2010; Geletukha *et al.* 2007). The contract between the parties is valid for three years. Until it expires school authorities are forbidden to sell, let or pledge any of the equipment or use it not in the accordance with project goals (Geletukha & Globenko 2009).

In August 2007 a five-year contract was signed between SEC Biomass, Kagarlyk regional administration, Stavy village council and Stavy secondary school. The secondary school was obliged to obtain all necessary permits before the project implementation as well as to carry out all building works including the construction of the school straw storage (Geletukha *et al.* 2007). Kagarlyk regional administration, Stavy village council and local secondary school are responsible to supply the boiler with straw fuel. The school in turn should sign contracts with agricultural producers in the region while Kagarlyk regional administration should develop a funding scheme for the school to enable fuel purchase (Geletukha *et al.* 2007). Kagarlyk regional administration should ensure a reasonable straw price establishment by the producers (Geletukha *et al.* 2007).

Since SEC Biomass lacks technical resources for the boiler construction and transportation, they are only responsible for its development and exploitation tests (Oliynyk pers.comm. 2010). The boiler manufacture was carried out at OJSC AK "SATER" by its branch company "Sahenergoservis" (SEC Biomass 2009). SEC Biomass made an agreement with the local construction company on the boiler installation. They helped to deliver the boiler, prepared the site for it and constructed its foundation, installed heat exchangers, prepared heat distribution pathways, and connected the stack (Oliynyk pers.comm. 2010).

According to SEC Biomass consultant, it is beneficial to hire local construction companies since they have established connections with local authorities and inspections and are experienced in obtaining building permits (Oliynyk pers.comm. 2010). There are a number of permits required, not least due to the fact that local school is funded from the state regional budget (Oliynyk pers.comm. 2010). These include a permit for land acquisition, a building permit, an environmental permit, a fire safety permit, and a permit from sanitary-epidemiological inspection. The project also needs to be negotiated and agreed upon with local authorities (Oliynyk pers.comm. 2010).

The total cost of the boiler installation including construction and assembling work is calculated at UAH 346 000[1] (Geletukha & Globenko 2009). The boiler cost is UAH 230 000[2]. SEC Biomass estimates the boiler's payback at 2-3 years (SEC Biomass 2009).

The boiler is not functioning at its full capacity yet, however, SEC Biomass experts tested it in real conditions. They tried burning dry wheat straw in small (12 kg) cylindrical bales by rolling them into the burner. If the boiler operates at its full load, 84 kg of straw are required per hour (or about 300 tonnes per season) (Oliynyk pers.comm. 2010). It is possible to use other biomass in the boiler (e. g. SEC Biomass tried burning logs with high moisture content). Experts have also monitored air emissions per cycle, estimated boiler capacity and efficiency (Oliynyk pers.comm. 2010).

[1] UAH 346 000 = EUR 46 000 (EUR 1 = UAH 7.52 as for January 2008)

[2] UAH 230 000 = EUR 30 000 (EUR 1 = UAH 7.52 as for January 2008)

Eventually SEC Biomass constructed a straw storage near the boiler-house on their own (Oliynyk pers.comm. 2010). They developed a one-time contract on straw purchase with the agricultural enterprise "Plyuty", which is located in the neighbour village and produces grain crops (Oliynyk pers.comm. 2010). The contract regulates straw characteristics including bale size, moisture content and colour (Geletukha & Plyuta 2008). Straw is accepted with the bale size of ∅1.3 m x 0.4 m for cylindrical bales and 0.7 m x 0.5 m x 0.4 m for rectangular bales, moisture content below 15% and in yellow or gray colour. Straw price is set at UAH 250[1] per tonne, which includes bale delivery by "Plyuty" to the boiler, the boiler loading and unloading. The total fuel cost per season is specified at UAH 8500[2] (Geletukha & Plyuta 2008).

In 2008 SEC Biomass bought five tonnes of straw from "Plyuty" for the boiler tests. The contract is flexible and does not oblige SEC Biomass purchase the precise amount of straw. In case more straw is required, the necessary adjustments can be made (Oliynyk pers.comm. 2010). SEC Biomass recommended Kagarlyk regional administration to conclude a long-term contract on straw delivery with the agricultural enterprise "Plyuty" (Oliynyk pers.comm. 2010). According to SEC Biomass consultant, the enterprise is good to work with as the manager is responsible for the whole straw supply chain, and neither local authorities nor the school administration need to organise straw logistics (Oliynyk pers.comm. 2010). The director of the agricultural enterprise "Plyuty" is interested to try straw-to-energy business as he owns machinery that is not used constantly and manages people who are not employed on a yearly basis (Oliynyk pers.comm. 2010).

In particular, the farm manager has a tractor and a lorry, and could supply about ten bales at a time, which is enough for 1-2 days of the boiler operation and which could be stored in the barn near the boiler (Oliynyk pers.comm. 2010). The only issue that could have impact on the farmer's interest to deliver straw is linked to the fact that the school is funded from the state

[1] UAH 250 = EUR 22.77 (EUR 1 = UAH 10.98 as for 22 December 2008)

[2] UAH 8500 = EUR 774 (EUR 1 = UAH 10.98 as for 22 December 2008)

budget and thus the revenue for straw purchase is paid only at the end of the year (Oliynyk pers.comm. 2010).

Currently the director of "Plyuty" does not own a bailer and orders baling from other companies in the region. However, he is negotiating the purchase of a second-hand bailer (Oliynyk pers.comm. 2010). Up to two day fuel requirement can be stored near the school. The major part of straw is stored in the field or in covered storages (Oliynyk pers.comm. 2010). SEC Biomass experts recognize that the ash from straw combustion should be returned to the soil; however, they have not arranged this yet (Oliynyk pers.comm. 2010).

According to SEC Biomass consultant, the fact that straw is sourced locally is important as it implies that people will be employed locally (Oliynyk pers.comm. 2010). Local companies (e. g., agricultural enterprises, construction companies) could add value to their activities. In addition, the funds stay and circulate within the local budget (Oliynyk pers.comm. 2010). Operators of the existing coal-fired boiler could either combine their job with or switch to the operation of a straw-fired boiler. In addition, local seasonal jobs will be created including employment in straw harvesting, baling, storage and delivery (Oliynyk pers.comm. 2010).

Boiler operators should be educated how to start up and stop the boiler, and on the activities in case of emergency. This training requires up to two weeks (Oliynyk pers.comm. 2010).

The developers are satisfied with the overall work of the boiler. They, however, strive to increase its efficiency from current 83% (Oliynyk pers.comm. 2010; SEC Biomass 2009).

The major problem identified but the developers is related to the efficient organization of a straw-supply chain and assignation of responsibilities. SEC Biomass expected the school director to take care of straw purchase and delivery, however, he was not interested in this (Oliynyk pers.comm. 2010). The school director was satisfied with the existing coal supply scheme, which has been functioning for many years, while the new fuel and boiler introduction required a range of additional arrangements (e.g. teaching of boiler operators, arranging the straw supply, etc.), which are not among school priorities (Oliynyk pers.comm. 2010).

Local authorities also tried to find a straw supplier for the boiler-house. A company located in 20 km from the school baled straw for them, however, it was not responsible for straw delivery. The organization of straw delivery by local authorities failed. Eventually people in the village collected straw bales from the company for their needs (Oliynyk pers.comm. 2010).

Stavy case is presented in the form of an agro-biomass framework in Table 6-7.

7. Vyshnyuvate village, Rozivka region, Zaporizzhya province

Heat to the secondary school in the village of Vyshnyuvate, Rozivka region, Zaporizzhya province, is supplied from a coal-fired boiler-house with two boilers КВУ5-М. Normally only one boiler operates while the other one is in reserve. About 800 kg of coal are used per day during 180 day heating season. Coal is stored at Zachativka station, Donetsk province, and is delivered by the company Donetskoblpalyvo to the school boiler-house weekly (Belay 2009b).

There are several farm enterprises and two agricultural production cooperatives - "Rosiya" and "Rozagroprodukt" - in Vyshnyuvate. These cooperatives specialise in growing grain crops (e. g., wheat, barley, millet, oats, etc.), corn and sunflower. They bale some of their straw and use it for their own needs. However, the main share of their straw is left on the field and burnt there. For example, agricultural cooperative "Rosiya" leaves from 80 to 90% (i. e. 2500-3900 tonnes) of its straw in the field every year (Belay 2009b). Local private farmers have the same practice (Belay 2009b).

Currently the secondary school in Vyshnyuvate is being renovated from the funds supplied by the enterprise "Rosiya". The authors of the project suggest that one of the school's coal-fired boilers is replaced with a straw-fired one (Belay 2009b). In this case the school could use either coal or straw for heating. The main reason to start the project in 2006 was the lack of efficient heat supply in the village school, where the temperature in the classrooms was not maintained at sufficient level in winters (Belay pers.comm. 2009).

School boiler-house fuel demand is about 150 tonnes of coal per heating season, or 242 tonnes of straw (Belay 2009b). Excess straw from just "Rosiya" cooperative can potentially supply up to 13 yearly straw requirements for the school heating. In addition, the enterprise owns all necessary equipment to bale straw and space for its storage (Belay 2009b). Also the abandoned building of the school shooting gallery could be used for straw storage (Belay 2009b).

If the project is carried out, "Rosiya" could get additional source of income from straw sales and create employment in the region (Belay 2009b). Also coal substitution with straw could contribute to improved environmental quality in the village. The authors of the project have estimated that fuel switch in the school boiler-house would reduce GHG emissions by 325 tonnes per year (Belay 2009b). However, today local authorities do not put environmental problems in rural areas among their priorities (Belay 2009b).

In February 2008 the project gained the first prize in the National round of the International competition of youth projects on energy saving "Energy and the Environment" (Belay pers.comm. 2009). The authors of the project also received support in the form of a cost-benefit analysis of the project, which was carried out by SEC Biomass experts on a voluntary basis (Chaplygin & Oleynik 2008). Three scenarios were considered including:

- the Baseline Scenario (i.e. continuation of the current situation);
- Scenario 1 (i.e. installation of a 150 kW straw-fired boiler to supply heat to the local school);
- Scenario 2 (i.e. installation of a 300 kW straw-fired boiler to both heat the school and sell 50% of excess heat to local municipality).

Scenario 1 was considered unprofitable at the coal price of UAH 350[1] per tonne and straw price of UAH 120[2] per tonne, and its payback was estimated to be longer than 10 years. Although Scenario 1 could bring a number of co-benefits as compared to the Baseline one (e. g., reduction of dependence on exogenous coal and contribution to local economy), it was concluded to be economically feasible only at coal price of UAH 800-1000[3] per tonne. Scenario 2 was concluded to be economically profitable, and its discounted payback period was estimated at about four years (Chaplygin & Oleynik 2008). Scenario 2 was recommended for the realisation.

In 2008 the price for coal was UAH 380[4] per tonne, and the annual spendings on fuel were UAH 47 875[5] (Belay 2009b). In August 2009 the price for straw in Vyshnyuvate was UAH 169[1]

[1] UAH 350 = EUR 47 (1 EUR = 7.52 UAH as for 1 January 2008)

[2] UAH 120 = EUR 16 (1 EUR = 7.52 UAH as for 1 January 2008)

[3] UAH 800-1000 = EUR 106-133 (1 EUR = 7.52 UAH as for 1 January 2008)

[4] UAH 380 = EUR 38 (EUR 1 = UAH 9.97 as for 15 December 2008)

[5] UAH 47875 = EUR 4800 (EUR 1 = UAH 9.97 as for 15 December 2008)

per tonne including baling (UAH 60[2] per tonne) and delivery (UAH 10[3] per tonne) (Belay 2009b). Annual spendings on straw would be UAH 40 656[4], which would bring savings up to UAH 7219[5]. In case the straw market is created in the village, the price for straw is expected to decrease, which in turn would increase annual savings on fuel (Belay 2009b).

After an offer from SEC Biomass to install a demonstration boiler in Vyshnyuvate the manager of the project sent a letter on organisational support for the boiler installation to Rozivka regional administration. According to the project manager, the administration and its head opposed the idea (Belay pers.comm. 2009). The manager had been trying to pursue the idea for about a year, organised meetings with governmental officials, called their hot lines, etc (Belay pers.commю 2009). Eventually SEC Biomass chose another location for its pilot project and installed the boiler in the village of Stavy (see case study 6 in Annex VII for details) (Belay pers.comm. 2009; Oliynyk pers.comm. 2009). The manager of the project in Vyshnyuvate after three months of unsuccessful attempts to take the local authority representatives to Zlatoustivka, where a 600 kW straw-fired boiler had been installed in 2005 and had been functioning (see case study 8 in Annex VII for details), finally managed to do so by driving them in his own car (Belay pers.comm. 2009).

The following year in order to implement the project the requirement for local budget was to cover UAH 40 000[6] from UAH 160 000[7] of the boiler price. The manager of the project had been seeking for different funding opportunities including an inquiry to the Ukrainian National Agency of Environmental Investments but did not achieve any positive results (Belay pers.comm. 2009). After the negative experience with the lack of support from local authorities,

[1] UAH 169 = EUR 15.6 (EUR 1 = UAH 9.97 as for 15 December 2008)

[2] UAH 60 = EUR 5.5 (EUR 1 = UAH 9.97 as for 15 December 2008)

[3] UAH 10 = EUR 0.9 (EUR 1 = UAH 9.97 as for 15 December 2008)

[4] UAH 40656 = EUR 3757 (EUR 1 = UAH 9.97 as for 15 December 2008)

[5] UAH 7219 = EUR 667 (EUR 1 = UAH 9.97 as for 15 December 2008)

[6] UAH 40 000 = EUR 3700 (EUR 1 = UAH 10.81 as for 1 August 2009)

[7] UAH 160 000 = EUR 14 800 (EUR 1 = UAH 10.81 as for 1 August 2009)

the manager referred to the head of the regional administration but all his inquiries were rejected again (Belay 2009b).

Later the project manager turned to the Ministry of Housing and Communal Services and the first vice prime-minister of Ukraine. They showed some interest in the project but explained the major problem in the absence of transparent vertical governmental influence (from top to bottom), and thus the Ministry was not able to influence local governors in their decisions (Belay pers.comm. 2009). After no positive outcome, the project leaders applied to the Foundation headed by the First Lady and got her support and encouragement (Belay pers.comm. 2009). In the meanwhile local authorities in Vyshnyuvate purchased coal in summer of 2009 while normally this is done in autumn. This, according to the project manager, was done deliberately to have an excuse against straw purchase (Belay pers.comm. 2009).

Vyshnyuvate project implementation is still in progress. Project authors established agreements with local agricultural producers on the future supply of straw as well as with the investors interested in the project implementation (Belay 2009b). However, according to the project manager, any interest or assistance in the project implementation from the side of local authorities is missing (Belay 2009b). So far the project leaders have not been granted the building permit for the construction of a straw-fired boiler (Belay pers.comm. 2009).

The main reasons from local and regional authorities against the project refer to the lack of access to funds and technology (in particular, straw baling systems), and to storage places (Belay pers.comm. 2009). The project manager considers these reasons "absolutely unjustified" since the main straw producers in the region have German bailers and space for straw storage, and he had already agreed on straw supply conditions with them (Belay pers.comm. 2009). As for funding constraints, there exists a share in the local budget of UAH 10 million[1], which could be spent on the project implementation (Belay pers.comm. 2009). In addition, there is a boiler construction scientific-producing enterprise LLC "Chysta Energiya" in Zaporizzhya province, which is ready to cover 50% of the boiler cost (Belay pers.comm. 2009).

[1] UAH 10 million = EUR 924 000 (EUR 1 = UAH 10.81 as for 1 August 2009)

The project leaders identify several factors as preconditions for the project success. These include significant straw potential in the region, the fact that the village of Vyshnyuvate is not gasified and also has densely located municipal buildings, which could be jointly heated from the school boiler-house (Belay pers.comm. 2009). Overall there are nine secondary schools in Rozivka region, two of which are heated with electricity and seven - with coal (Belay 2009b). The project authors see the potential to substitute coal with locally sourced straw in all seven schools (Belay 2009b).

The authors of the project also plan to create an energy service company ESCO (G. Belay & V. Belay 2009a), the main goal of which would be the establishment of ten 600 kW UTEM straw-fired boilers in Rozivka region to supply heat to village schools and other municipal buildings that are currently fired with coal. In the first stage the company will be responsible for straw-boiler purchase, installation, operation and maintenance, and straw supply including its purchase and storage (G. Belay & V. Belay 2009a). In particular, they plan to establish three 600 kW straw-fired boilers in the regional centre Rozivka to supply heat to a local school, kindergarten, hospital and other buildings in the vicinity (G. Belay & V. Belay 2009a). In the second stage it is planned to start the maintenance of all central heat distribution installations in the region by ESCO. In the third stage the project authors plan to introduce straw briquette and pellet production lines in order to supply private houses with locally sourced fuels (G. Belay & V. Belay 2009b). Project budget is estimated at UAH 10 million[1]. The project implementation is expected to reduce annual fuel spendings in the region by about UAH 1.5 million[2] through coal substitution with locally sourced straw (G. Belay & V. Belay 2009b). In addition, 30 new jobs will be created and GHG emissions will be reduced by 14 000 tonnes per heating season (G. Belay & V. Belay 2009b).

The main barriers for the project implementation as identified by the project manager are linked to personal economic interests pursued by the local governmental officials and embedded

[1] UAH 10 million = EUR 840 000 (EUR 1 = UAH 11.9 as for 15 October 2009)

[2] UAH 1.5 million = EUR 126 000 (EUR 1 = UAH 11.9 as for 15 October 2009)

lobbies (Belay pers.comm. 2009). Except for that straw-to-energy business has good prospects to create competitive markets for the established coal sector, there are no incentives to cut down fixed local state budgets (Belay pers.comm. 2009).

Vyshnyuvate case is presented in the form of an agro-biomass framework in Table 6-8.

8. Zlatoustivka village, Volnovakha region, Donetsk province

The village of Zlatoustivka is located in Volnovakha region, Donetsk province, Eastern Ukraine, and has a population of about 1900 inhabitants. LLC "Rossiya", which used to be a collective farm in Soviet times, is the biggest agricultural enterprise in the region (Volnovakhskiy gorodskoy portal 2010). The enterprise is located on 10 000 ha of land, which is rented from private users in the village (Yerkhov pers.comm. 2010). LLC "Rossiya" specialises in seed production and animal breeding. 30% of the land is covered with grasses for animal fodder (i.e. perennial and silage grasses), 25-30% - with sunflower, and the rest – with grain crops (wheat and barley) (Yerkhov pers.comm. 2010). They also have 1500 heads of milk cows (3000 heads of cattle altogether) (Yerkhov pers.comm. 2010).

Zlatoustivka is not gasified. Village citizens mostly use coal and sometimes wood to heat their houses. There had been a central boiler-house working on coal, and LLC "Rossiya" used to operate it and provide DH to municipal buildings. In 2005 they installed a 600 kW straw-fired boiler RAU-2-600 (Fig. VII-2) and substituted the fuel for heat supply (Yerkhov pers.comm. 2010).

Figure VII-2. 600 kW straw-fired boiler RAU-2-600, Zlatoustivka, Donetsk province, Ukraine (Photo: courtesy of V. Belay)

The boiler is owned by LLC "Rossiya" and was manufactured by UTEM. It supplies DH to several community buildings in the village including several two-, four- and five-storied houses, a kindergarten, an office, a hotel, and a building of the village council. Overall 10 000 m^2 are heated with the straw-fired boiler (Yerkhov pers.comm. 2010).

An idea to install a straw-fired boiler came from the director of LLC "Rossiya", who aimed to eliminate the use of coal, which was expensive and polluting, and had been exploring alternatives (Yerkhov pers.comm. 2010). Initial idea was to purchase a straw-fired boiler in Denmark but later the director learned about the UTEM production line and decided to buy it from national manufacturers (Yerkhov pers.comm. 2010).

The boiler in Zlatoustivka was the fifth straw-fired boiler that UTEM had sold in Ukraine (Yerkhov pers.comm. 2010). UTEM supplied the boiler and its parts, installed it within two days and trained the operators to manage it. LLC "Rossiya" had to prepare the foundation, which took about two weeks (Yerkhov pers.comm. 2010). No environmental or other permits are required for the operation of the installation, and there were no difficulties with obtaining necessary documents for the boiler installation (Yerkhov pers.comm. 2010).

The cost of the boiler was EUR 57 000 and was paid from the funds of the agricultural enterprise. First instalment was made in advance while the remaining cost was paid after the boiler had been installed (Yerkhov pers.comm. 2010). The boiler paid back within one heating season (Yerkhov pers.comm. 2010). In 2008 the cost of 1 Gcal from straw production was UAH 53[1], which was three times cheaper than that from coal and five times cheaper than that from natural gas. Savings achieved in the first heating season amounted UAH 250 000[2] (V. Belay 2009b).

The boiler in Zlatoustivka uses about 800 tonnes of straw per year. 12 rectangular bales (120 cm x 80 cm x different length), and two round bales (Ø150 cm x 120 cm) are loaded with a front loader (Fig. VII-3) and burnt every day (Yerkhov pers.comm. 2010). The load in frosty

[1] UAH 53 = EUR 5.3 (1 EUR = UAH 9.97 as for 15 December 2008)

[2] UAH 250 000 = EUR 41 000 (1 EUR = UAH 6.1 as for 1 April 2006)

weather is four times per day but can be increased up to six times (V. Belay 2009b). No other fuels except for wheat straw are used although the owners also tried burning sunflower residues (Yerkhov pers.comm. 2010).

Figure VII-3. Boiler loading in Zlatoustivka, Donetsk province, Ukraine

(Photo: courtesy of V. Belay)

All straw is produced on the farm of LLC "Rossiya". The enterprise bales about 3000 tonnes of straw per year, which is used for various purposes (e. g., bedding, fodder, sold to mushroom industries, etc.) (Yerkhov pers.comm. 2010). Straw that is left in the field is ploughed back. According to the director of the company, ideally all straw should be ploughed back into the soil (Yerkhov pers.comm. 2010).

LLC "Rossiya" owns four bailers and two loaders as they need to harvest about 3000-4000 of straw every year, which needs to be done fast (Yerkhov pers.comm. 2010). Straw is stored in a few storages, most of which are covered. There is also a storage near the boiler with straw reserves sufficient for five days of the boiler operation (Yerkhov pers.comm. 2010). The ash from the combustion is either spread on the fields or mixed with animal manure in the manure storage on the company's farm (Yerkhov pers.comm. 2010).

No additional jobs were created with the boiler installation - vice versa the number of people employed went down. There were 40 people employed at a coal-fired boiler-house while now only four operators work at the straw-fired installation (Yerkhov pers.comm. 2010). The boiler is reported to be very easy in operation, and no additional training of personnel is required. The only parameter to be set is the water temperature that is desired at the end (normally about 70ºC) (Yerkhov pers.comm. 2010).

The only problem linked to the boiler operation occurred due to a human factor. Farmers have not taken accounted for periodical droughts and have not secured straw reserves for fuelling purposes. That is why straw had to be delivered from 150 km distances, which lead to unjustified expenses (Khoba 2008).

Overall the owners of the boiler and local citizens are satisfied with its work (Khoba 2008; Yerkhov pers.comm. 2010; V. Belay 2009b). The question of straw residue utilisation is solved (Khoba 2008). Heat consumers are no longer reliant on exogenous coal, and the air quality in the village has improved. Boiler operators also admit cleaner working conditions (Khoba 2008).

In future the director of LLC "Rossiya" does not plan to expand DH in the village. However, on his farm he is interested to substitute the use of fuel oil in the grain dryers with a mixture of diesel fuel, straw and sunflower residues and husk (Yerkhov pers.comm. 2010). The capacity of the grain dryer is 50 tonnes per hour. Currently an engineer from Dnipropetrovsk is developing a heat generator for the farm, and the farmer plans to install it by June 2010. The grain-dryer cost is UAH 450 000[1], and is expected to pay back in 1-1.5 years (Yerkhov pers.comm. 2010).

Zlatoustivka case is presented in the form of an agro-biomass framework in Table 6-9.

[1] UAH 450 000 = EUR 40 000 (EUR 1 = UAH 11.27 as for 22 January 2010)

9. Drozdy village, Bila Tserkva region, Kyiv province

Agricultural enterprise "DiM" is located in the village of Drozdy, Bila Tserkva region, Kyiv province, and specialises in grain growing and bread production. It is a limited liability company (LLC) with a bread production company being a legal entity and agricultural enterprise "DiM" being as a physical party (Lytvyn pers.com. 2009). The ownership of its shares is divided 50/50 between these two companies. They also specialise in cattle and pig breeding, and are now expanding animal livestock to 10 000 heads (Lytvyn pers.com. 2009).

The enterprise grows crops on 3250 ha of land, which is rented from private farmers in two neighbouring villages - Drozdy and Mazepyntsi. The areas of main crops grown on the farm are given in Table VII-1.

Table VII-1. Main crops grown by agricultural enterprise "DiM"

Crop	***Area, ha***
Winter wheat	1050-1100
Buckwheat	560
Corn	450
Barley	300
Grasses for fodder	Some
Total	**3250**

Source: Lytvyn pers.comm. 2009

Every year about 4000 tonnes of straw from various crops are produced on the farm. Straw is used for agricultural purposes (i.e. bedding and fodder) and for energy production in two boilers, which are installed on the farm (Lytvyn pers.com. 2009). A 980 kW straw-fired boiler provides DH to local buildings in the village while a 150 kW one heats the pig breeding facility.

It is wheat straw that is mainly used for energy (Lytvyn pers.com. 2009). Corn residues and buckwheat straw is cut and ploughed back to the soil. Barley straw has high protein content and thus is mainly used as animal fodder (Lytvyn pers.com. 2009). Residues from soy and pea production have good burning properties and can be used for energy production (Lytvyn pers.comm. 2009). They tried to burn buckwheat straw in a big boiler but the ash from combustion is composed of very fine particles, which stick to the pipes and create explosion risks (Lytvyn pers.com. 2009).

LLC "DiM" sells its straw for animal bedding and fodder, for compost and to mushroom growing enterprises in Kyiv on a contract basis. Current straw price in Ukraine is UAH 250-300[1] per tonne (Lytvyn pers.comm. 2009; Oliynyk pers.comm. 2010). No straw is sold for energy.

Straw is combusted for heat production in two boilers on the farm, both of which are owned by the enterprise "DiM". A 980 kW boiler RAU-2-1210, which is mainly analysed here, was manufactured by Danish company Passat Energi A/S (Lytvyn pers.com. 2009). It was installed in 2000 with financial support of Danish Environmental Agency (Miljø and Energi), and under the coordination of Danish Energy Agency (Energistyrelsen). Danish Technological Institute (DTI) acted as a partner and SEC Biomass - as a sub-contractor to this project (Lytvyn pers.comm. 2009; SEC Biomass 2006). Straw bailing technology was introduced together with the boiler installation (SEC Biomass 2006).

The boiler has efficiency of 81%. It burns rectangular bales with a maximum size of 120 cm x 120 cm x 240 cm and cylindrical bales with a diameter of 160 cm or 180 cm (SEC Biomass 2006; Lytvyn pers.comm. 2009). In the heating season (i.e. from 15 October till 15 April) about 4-5 tonnes of straw are burnt daily (Lytvyn pers.comm. 2009). The boiler's maximum straw consumption is 1100 tones per year (SEC Biomass 2006). The boiler has a hot water accumulator, which is located on the top of the combustion chamber (Fig. VII-4). The door of a combustion chamber is filled with water, which transmits heat through the pipes located above the chamber (Lytvyn pers.com. 2009).

Figure VII-4. 980 kW straw-fired boiler RAU-2-1210 in Drozdy village, Kyiv province, Ukraine

[1] UAH 250-300 = EUR 21.2-25.5 (EUR 1 = UAH 11.77 as for 8 October 2009)

The boiler supplies DH to a community centre, a three-storied secondary school, a two-storied kindergarten, sauna, a three-storied administrative building and four two-storied houses, which are connected to the central heat distribution network (Zhovmir *et al.* 2007; Lytvyn pers.comm. 2009). The total heated volume is 27 800 m^3 (Lytvyn pers.com. 2009).

Specific energy requirements of the agricultural enterprise "DiM" are comprised by heating needs of pig and cattle breeding facilities, where the temperature should be maintained at 25°C (Lytvyn pers.com. 2009). In 2006 the enterprise installed a smaller 150 kW straw-fired boiler, which was manufactured by UTEM. This boiler delivers heat to two pig breeding facilities on the farm and burns 1.5-2 tonnes of bailed straw per day.

Straw fuel for the boilers is collected from the fields located in two neighbouring villages - Drozdy and Mazepyntsi. All equipment and machines are owned by the LLC "DiM". They include bailers New Holland and Krone, which have been used within the last 10 years, several tractors, loaders Karpatets and Ranger and other machines (Lytvyn pers.com. 2009). Bailers produce both round and rectangular bales of 320 kg each. Straw is stored in the field in an open storage (Fig. VII-5). A straw barn is located in front of the boiler-house. It has a capacity to store straw reserves for 10-12 days of the boiler operation (Lytvyn pers.com. 2009). The ash from straw combustion is collected every second day to maintain shifts of workers. Ash is mixed with animal manure in storage and returned to the field as a fertiliser.

Baling is the most expensive step in the straw value chain (e. g. yearly baling rope requirement cost UAH 23 000[1]) (Lytvyn pers.com. 2009). Other main expenses are linked to the use of diesel oil to run harvesting and baling machinery.

According to the deputy director of "DiM" enterprise, the main driving factor to start energy production from straw on the farm was economic. In 2000 the price for natural gas has grown, and they started looking for alternative fuel to supply DH in the village of Drozdy (Lytvyn pers.com. 2009). The initial idea was to burn husk and residues from buckwheat production, and to generate heat. This idea was suggested by the bread production company,

[1] UAH 23 000 = EUR 1960 (EUR 1 = UAH 11.74 as for 17 September 2009)

which had already had a similar installation at their enterprise (Lytvyn pers.com. 2009). However, the DH system on natural gas existed in the village of Drozdy, and too many changes needed to be done in the case of switch to crop residue burning so the managers looked for other alternatives.

Figure VII-5. Field straw storage at agricultural enterprise LLC "DiM", Drozdy village, Kyiv province, Ukraine

Initially the manager of the farm was interested to construct a biogas plant on the farm, and was seeking for advice and technical support from the Institute of Engineering Thermophysics in Kyiv (Lytvyn pers.com. 2009). He was put in touch with the director of SEC Biomass, who suggested that agricultural enterprise "DiM" should apply for a tender called by Danish partners to host a pilot straw-fired installation in Ukraine. The enterprise won this tender. According to the deputy director of "DiM" enterprise, their success was linked to the fact that they had large volumes with heating needs (i.e. 33 000 m^3) with buildings located along 900 m of the village road (Lytvyn pers.com. 2009).

It is also important to mention that the tradition of straw and firewood burning in conventional ovens existed in the past in the rural areas in Ukraine and was an ordinary way of supplying heat to private houses (Lytvyn pers.com. 2009). Drozdy has been gasified since 1985. Most of the houses have now installed private natural gas heaters (Lytvyn pers.com. 2009).

According to the manager of the farm, the installation of a straw-fired boiler did not require significant changes in the existing system. In 2000 there was a gas-fired boiler-house and a DH system in place in Drozdy so the boiler was the only element to be replaced. A straw-fired boiler substituted six gas-fired ones, which burned 1055-1560 m^3 of natural gas per day (Lytvyn pers.com. 2009). Gas substitution with locally produced straw eliminated the problem of fuel dependence (Lytvyn pers.com. 2009). In the new boiler-house they have also replaced 15 kW pumps with 5.5 kW ones and in this way reduced electricity consumption by the installation (Lytvyn pers.com. 2009).

The boiler substitution led to natural gas savings of about 280 000 m^3 per season (Lytvyn pers.comm. 2009). During all years of the boiler operation 2.5 million m^3 of natural gas and 325 000 kW of electrical energy were saved. The investment cost was about USD 100 000[1], and the payback period was estimated to be 4.7 years (Lytvyn pers.comm. 2009; SEC Biomass 2006). The project revealed to be quite profitable. It resulted in cost savings from fuel substitution of about UAH 1.5 million[2] (Lytvyn pers.com. 2009).

The boiler installation helped to optimise the work load during the winter season. Three technicians and three tractor drivers, who work on the field in summer and used to be unemployed in winter, are now involved in the boiler operation (Lytvyn pers.com. 2009). The boiler operation requires three employees working in shifts. They also change activities to have similar distribution of responsibilities (e. g., while one person collects straw in the field, another one is responsible for straw combustion, and the third one is responsible for ash removal) (Lytvyn pers.com. 2009).

The managers of LLC “DiM” were satisfied with the functioning of a big boiler and savings achieved (Lytvyn pers.com. 2009). This led to the installation of a smaller boiler, which has been operating without any problems (Lytvyn pers.com. 2009). The small boiler was constructed from the enterprise’s funds, and cost UAH 121 000[3]. Savings from the small boiler operations were not calculated as there was no benchmark to compare them with (Lytvyn pers.com. 2009).

[1] USD 100 000 = EUR 98 000 (EUR 1 = UAH 5.54 and 1 USD = UAH 5.42 as for 15 January 2000)

[2] UAH 1.5 million = EUR 127 400 (EUR 1 = UAH 11.77 as for 8 October 2009)

[3] UAH 121 000 = EUR 19 800 (EUR 1 = UAH 6.12 as for 15 January 2006)

Together with economic gainings from heat sales "DiM" enterprise has also had expenses linked to the boiler maintenance. The boiler flame tubes were worn out after five years of their exploitation and needed to be replaced (Lytvyn pers.com. 2009). UTEM plant reconstructed flame tubes according to the project instructions from Passat Energi, and "DiM" enterprise replaced them for UAH 240 000[1] (Lytvyn pers.com. 2009).

In terms of new skills and technical abilities, the boiler operation is quite easy and does not require highly qualified experts (Lytvyn pers.com. 2009). Operation instructions were provided by Danish partners in Ukrainian language and distributed among plant operators. Overall the managers are satisfied with the performance of both boilers (Lytvyn pers.com. 2009).

The case of Drozdy is presented in the form of an agro-biomass framework in Table 6-10.

[1] UAH 240 000 = EUR 34 200 (EUR 1 = UAH 7.02 as for 15 January 2005)