BioTrade2020plus

Supporting a Sustainable European Bioenergy Trade Strategy

Intelligent Energy Europe
IEE/13/577/SI2.675534

Assessment of sustainable lignocellulosic biomass export potentials from Ukraine to the European Union

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The BioTrade2020plus Project

Objectives

The main aim of BioTrade2020plus is to provide guidelines for the development of a **European Bioenergy Trade Strategy for 2020 and beyond** ensuring that imported biomass feedstock is sustainably sourced and used in an efficient way, while avoiding distortion of other (non-energy) markets. This will be accomplished by analyzing the potentials (technical, economical and sustainable) and assessing key sustainability risks of current and future lignocellulosic biomass and bioenergy carriers. Focus will be placed on wood chips, pellets, torrefied biomass and pyrolysis oil from current and potential future major sourcing regions of the world (Canada, US, Russia, Ukraine, Latin America, Asia and Sub-Saharan Africa).

BioTrade2020plus will thus provide support to the use of stable, sustainable, competitively priced and resource-efficient flows of imported biomass feedstock to the EU – a necessary pre-requisite for the development of the bio-based economy in Europe.

In order to achieve this objective close cooperation will be ensured with current international initiatives such as IEA Bioenergy Task 40 on "Sustainable International Bioenergy Trade - Securing Supply and Demand" and European projects such as Biomass Policies, S2BIOM, Biomass Trade Centers, DIA-CORE, and PELLCERT.

Activities

The following main activities are implemented in the framework of the BioTrade2020plus project:

- Assessment of **sustainable potentials of lignocellulosic biomass** in the main sourcing regions outside the EU
- Definition and application of sustainability criteria and indicators
- Analysis of the **main economic and market issues of biomass/bioenergy imports** to the EU from the target regions
- Development of a dedicated and **user friendly web-based GIS-tool** on lignocellulosic biomass resources from target regions
- **Information to European industries** to identify, quantify and mobilize sustainable lignocellulosic biomass resources from export regions
- **Policy advice on long-term strategies** to include sustainable biomass imports in European bioenergy markets
- **Involvement of stakeholders** through consultations and dedicated workshops

More information is available at the BioTrade2020plus website: **www.biotrade2020plus.eu**

About this document

This report is a progress update of one of the six case studies to be developed under WP3 of the BioTrade2020+ project

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List of abbreviations

Acronyms

BAU	Business As Usual
EU	European Union
GHG	Greenhouse Gas
GDP	Gross Domestic Product
Wp2	work package 2
Wp3	work package 3
RPR	Residue to Product Ratio
EC	European Commission
EU RED	European Union Renewable Energy Directive

Units

MJ	Megajoules (10^6 Joules)
GJ	Gigajoules (10^9 Joules)
TJ	Terajoules (10^{12} Joules)
PJ	Petajoules (10^{15} Joules)
EJ	Exajoules (10^{18} Joules)
Mha	million hectares
ha	hectare
km	kilometre
kg	kilogram
t	tonne
tdm	tonne dry matter
toe	tonne oil equivalent
kt	kilotonne
Mt	Megatonne
KWh	kilowatt-hour
TWh	terawatt-hour
LHV	Lower Heating Value
L	litre
m^3	cubic meter
MW	Megawatt (10^6 Joules/second)
yr	year

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1. Introduction

The main objective of WP 3 is to analyse the main economic and market issues concerning biomass/bioenergy imports to the EU from each of the six selected sourcing regions. Main elements are the analysis of current and future production and consumption volumes of biomass , identification of on-going and possible future trade routes and delivered costs, and potential risks of competition with other industries (both local and not) utilizing the investigated feedstocks per region.

In this work package, methodology to determine a net sustainable export potential of biomass and related cost and GHG supply curves will be applied and tested to six different country case studies: Brazil, Colombia, Kenya, Indonesia, Ukraine and the USA. For these six case studies, various potentials (technical, sustainable, market etc.) will be determined.

The aim of this progress report is to highlight the status of the data collection and analysis until June 2015. In section 2, a summary of the methodology is presented. In section 3, the general case study description is presented (based on Deliverable 2.1). In section 4, a summary of the data collected and thus far and an overview of preliminary results are presented. Finally, in section 5, a short outlook on the further work and completion of the case study is given.

2. Methodology

The methodology chosen for the selection of the regions followed the overall general methodology (See the general report on methodology). The methodology is divided in three main areas: the selection of the regions, the considerations for the sustainable surplus potential in each region according to selected feedstock and the overall background information of the regions.

The focus regions include Brazil, Colombia, Kenya, Indonesia, Ukraine and the USA. The lignocellulosic feedstock that will be considered are those which can produce different carriers such as wood chips, pellets, torrefied biomass and pyrolysis oil.

The technical potential was calculated according to the availability of the selected feedstock and the residue production ratio identified in the literature as well as already calculated ratios and residues available.

The overall methodology is illustrated in **Error! Reference source not found.** according to the general methodology the selection of case studies and their assessment include the technological, and market potential. sustainable potential (see report on methodology).j

The background information for the selected countries helped to identify the regions in each country that were more promising for the availability of the feedstock but also that included some of the technological facilities (including transportation and other logistics). The information provided from the Advisory Board (AB) and Work Package 2 (D2.1) also contributed to better select the particular regions. **Error! Reference source not found.** shows the methodology and information followed in this report.

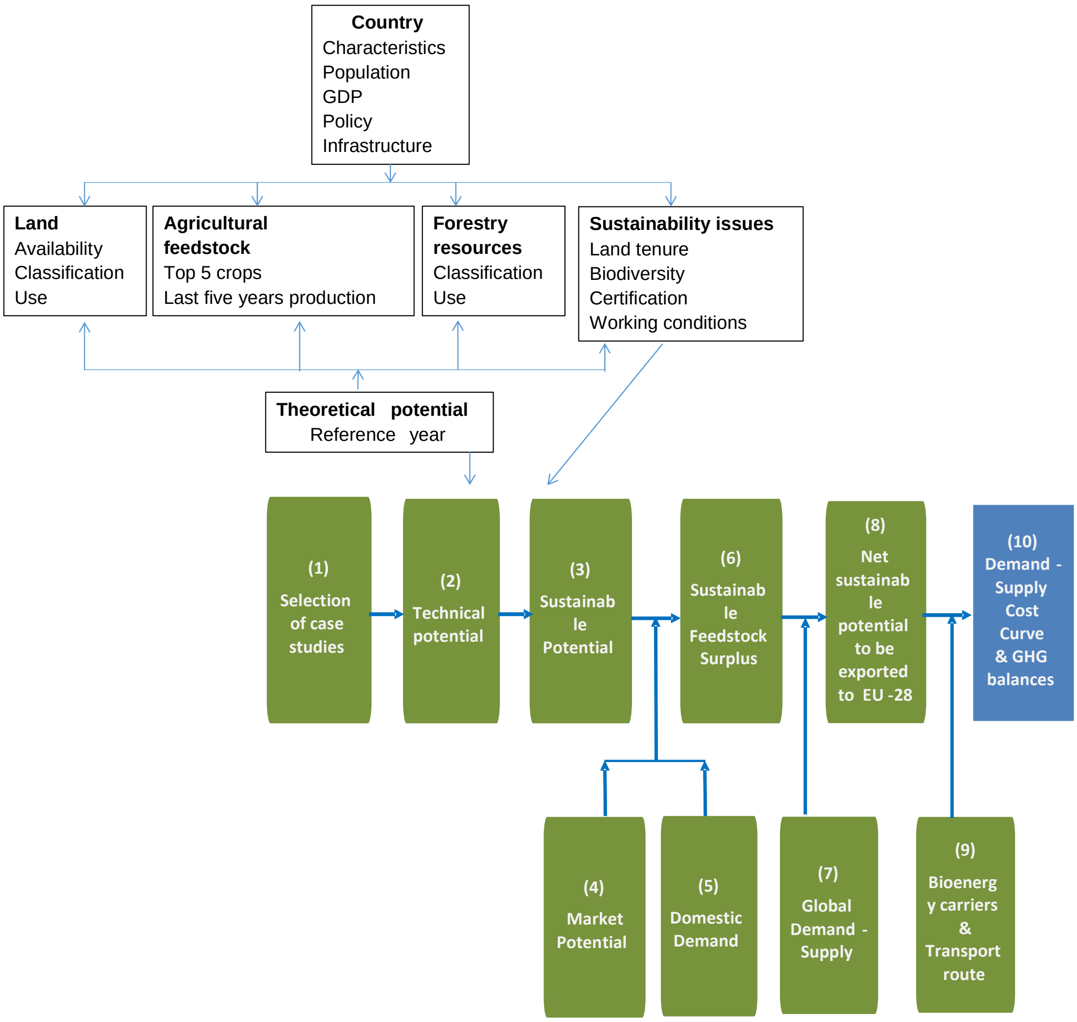

Figure 1 - Methodology for selected countries and regions

The following section presents the information collected for the selected countries and regions. This was based in literature review, partners' previous work in the selected countries and information provided by the Advisory Board members.
The detailed information and technical, sustainability and market potentials along with scenarios, is included in the specific case studies as the information needed requires more detail and in some cases field work provided mainly by students working in the regions.
Additional socio-economic issues such as the willingness to harvest and the management of the forests, in terms of the use of the resources (e.g. recreational, conservation, market) are not discussed in this report but are considered in the specific case studies.

The summary of the countries and feedstock potential presented in this report is shown in **Error! Reference source not found.**.

Table 1 - Summary of countries and feedstock potential

Country	Feedstock				
	Forest residues	Agricultural residues	Forest plantations	Biomass crops	New forest plantations

Brazil		√		√	√
Colombia		√		√	
Kenya		√	√	√	
Indonesia		√			
United States	√		√		√
Ukraine	√	√		√	

3. General case study description: Ukraine

3.1 General country overview

3.1.1 Population and economy

The total population of Ukraine in 2014 was 44,291,413. It has a GDP of $337.4 billion, which calculates to $7,400 GDP per capita, distributed as follows (CIA, 2015).:

agriculture: 9.9%

industry: 29.6%

services: 60.5%

Figure 2 - Map of Ukraine (CIA, 2015)

The main agricultural products of Ukraine are grain, sugar beets, sunflower seeds, vegetables; beef, milk, while the industry sector focus is on coal, electric power, ferrous and nonferrous metals, machinery and transport equipment, chemicals, food processing (CIA, 2015). The main ten agricultural commodities in Ukraine can be seen in the below figure.

Table 2 - Top ten agricultural commodities in Ukraine (FAOstat, 2015)

	Commodity	Quantity (kton)
1	Potatoes	23250
2	Maize	20961
3	Sugar beet	18439
4	Wheat	15763
5	Milk, whole fresh cow	11260
6	Sunflower seed	8387
7	Barley	6936
8	Soybeans	2410
9	Tomatoes	2274
10	Cabbages and other brassicas	1922

3.1.2 Land use

According to FAOstat (2015), the land use of Ukraine (total 60.35 million ha) is mostly arable land (56.1%), forest (16.5%), permanent meadows and pastures (13.6%), permanent crops (1.5%) and other land (12.2%). The temporary crops land has increased in recent years due to the growth of cereals.

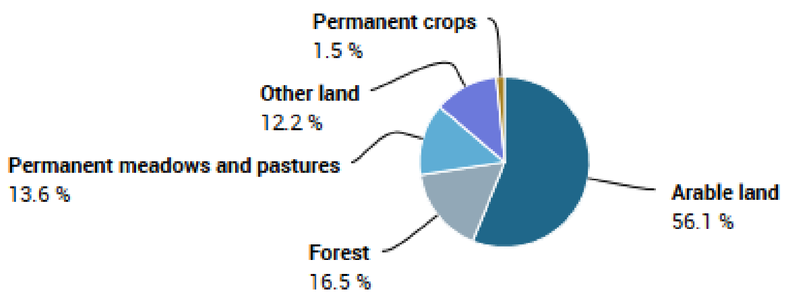

Figure 3 - Land use in Ukraine (FAOstat, 2015)

3.1.3 Energy Sector

The energy mix in Ukraine is dominated by natural gas (40%) and coal (31%). Nuclear also contributes a significant share of 17% (figure 4). The small share of renewable energy was until 2005 largely made up of hydropower. Since 2005 the share of primary solid biofuels has been increasing, and in 2010 was larger than the share of hydro powered energy (figure 5).

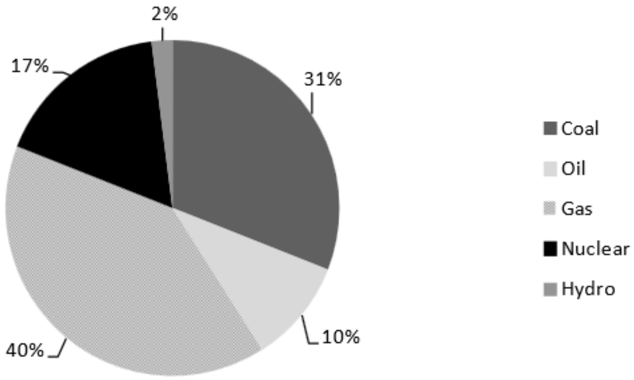

Figure 4 - Primary energy use in Ukraine (IEA, 2012)

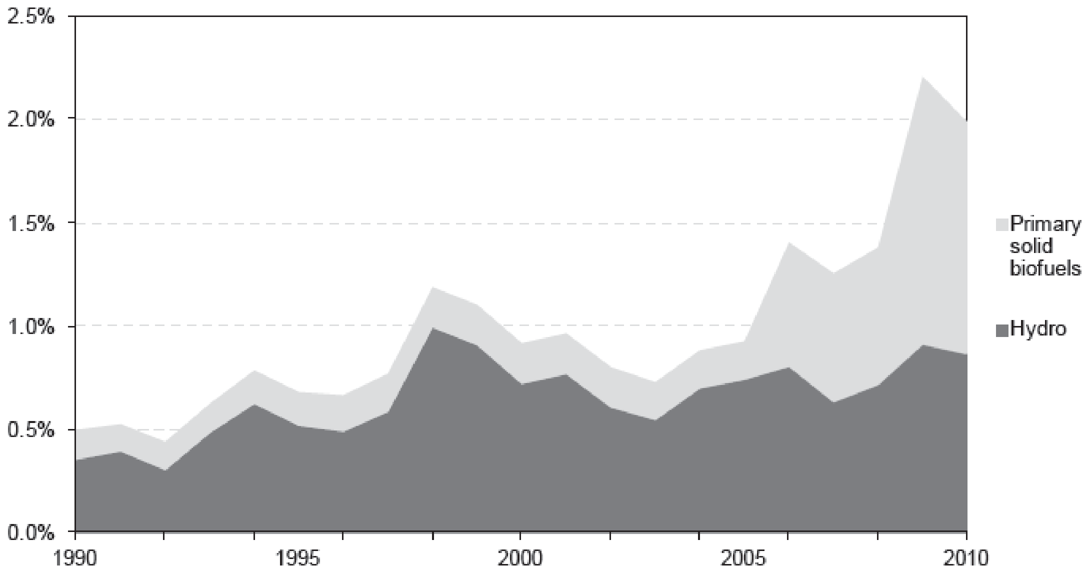

Figure 5 - Primary renewable energy use in Ukraine (IEA, 2012)

Renewable energy, primarily biomass and waste, is used for heat production in private households and public buildings in rural areas, as well as for heating and processes in the wood products industry. Estimates are that the total heat production from renewable energy sources does not exceed 1 million gigacalories (Gcal) , whereas in 2011 the total thermal heat supplied by district heating companies was 147 million Gcal (IEA, 2012).

3.2 Bioenergy and biomass

A wide range of estimates of the potential of agricultural and forest residues have been reported in previous studies, an overview is given in Table 4. Previous studies have applied different methodologies, and calculated different types of potential. Furthermore, they differ slightly in the types of feedstocks and residues included. For instance Lakyda et al. (2010) include primary agricultural residues as well as some secondary residues (sugar beet bagasse, rice husks, sunflower husks) and manure in the potential of agricultural residues. By contrast, this study only includes primary agricultural residues.

Furthermore, the type of potential calculated in the studies differs, most studies calculate the theoretical and technical potentials, some studies also focus on the economic potential or on a surplus potential by taking into account limitations to residue use such as sustainability constraints.

When comparing the different studies it becomes clear that there is a considerable range of potentials, for instance the theoretical in Lakyda et. al (2010) is almost a factor of two higher than the potential calculated in Raslavicius (2011). The methodologies followed and the assumptions made are not explained in detail in all of these reviewed studies, making it difficult to compare the studies and use any of the results.

Still this comparison does show that the potential of bioenergy in Ukraine could be considerable. The total primary energy supply in Ukraine was about 130 Mtoe in 2010, which converts to 5443 PJ. Biofuels clearly have the potential to supply more energy than the approximately 1% that can be seen in figure 5.

Table 3 - Agricultural residues potential in Ukraine

		Agricultural residues (PJ)	Forest residues (PJ)	Energy crops
Lakyda et al. (2010)	Theoretical	1135	312	
	Technical	415	89	
Tebodin (2013)	Unclear	564	69	
Raslavicius (2011)	Theoretical	628		427
	Technical	375	28.3	363
	Economical	227		363
Gelethuka (2015)	Theoretical	915	60	204
	Surplus	337	58	184

Ukraine already produces bioenergy products from wood such as sawdust briquettes, pellets, fuel wood chips, charcoal and firewood. According to Tebodin (2013), in 2011 a total of 740 thousand tons of solid fuels were produced, of which h620 thousand tons of pellets and 120 thousand tons of briquettes. An estimated 80-85% of the solid biofuels produced are exported to the EU, to be used for electricity and heat production (Tebodin, 2013).

3.3 Sustainability issues

3.3.1 Land tenure

The Oakland Institute in 2014 reported that over 1.6 million hectares (ha) of land in Ukraine are now under the control of foreign-based corporations. Further research has allowed for the identification of additional foreign investments. Some estimates now bring the total of Ukrainian farmland controlled by foreign companies to over 2.2 million ha (Oakland Institute, 2015).

In general, Ukraine's land reform has been a lengthy process and has posed major obstacles for the rural population. To date, agricultural policies have provided hardly any state support for small and medium farmers , and the government seems to lack much of an understanding of how to foster rural development. Demyanenko (2008: 8-9) asserts that while policies exist on paper, they are not implemented.

Currently, although private smallholders still dominate many foreign companies are taking over the land the same as oligarchs (Plank, 2013).

3.3.2 Food security

In 2008 Ukraine was declared by the UN as the solution for world food production due to the large production of cereals which amounts to about $$ million/year. FAO statistics (2015) shows a relative stable food supply per capita until 2011 (Table 6)

Table 4 – Food supply per capita in Ukraine (FAOstat, 2015)

	Quantity (kcal/capita/day)			
	1996	**2001**	**2006**	**2011**
Food Supply	2799	3013	3244	3142

Nevertheless, the conflict in eastern Ukraine following the annexation of Crimea changed the situation. Although there have been casualties, the main problem is the massive displacement of the population, currently estimated at around 1 million people. This has contributed to economic decline, resulting in rising inflation, currently at 25%, and significant difficulties in resupply of markets. This has led to food shortages, particularly in eastern Ukraine

3.3.3 Working conditions

According to a report by Lopatin et al. (2011), 350,000 people were employed by the forest sector and 260,000 of them worked in the private sector in 2006. The estimated total employment contribution, which also includes indirect positions, was about 500,000. The State Committee of Forestry owns forests, and they conduct 80% of the harvesting with their employees. The rest (0-10%) is done by contractors which are hired by the Committee (Lopatin et al, 2011).

Working hours

Ukraine has not ratified the ILO Hours of Work (Industry) Convention 1919 (No. 1). However, the country has enacted legislation in which working time is regulated at a statutory duration of 40 hours per week. The agricultural sector is however one of a few sectors in which the majority of people working more than 48 hours per week were employed (FAO, 2011)**.**

Child labour

A 1999 study showed that 3.8 percent of underage children (aged five to seventeen) were engaged in economic activities. Again, the agricultural sector is one of the sectors in which the worst forms of child labour prevail. Although in 2000 the Worst Forms of Child Labour Convention, 1999 (No. 182) was ratified, underage individuals are still allowed to perform certain types of work under specific conditions. Other concerns are the negative consequences of children being left at home with insufficient care as a result of parents departing abroad for work purposes and the public education system suffering from lack of funds (FAO, 2011).

Security of work

The labour market has deteriorated significantly since the second half of 2008. Unemployment rates are increasing, as well as time-related underemployment. As a result of the closure of large agricultural farms, combined with the lack of other jobs in rural areas, many workers have turned to subsistence farming. The labour market in Ukraine is highly flexible but also provides a low level of worker protection as a result of weak control and supervision of labour legislation (FAO, 2011).

Gender equality

Although Ukraine has undertaken steps to establish a legal and institutional framework to promote gender equality and tackle discrimination, the implementation of legislation as well as the development of policies is lagging behind. Between 2000 and 2004 the gender pay gap increased considerably and exceeded 30% (FAO, 2011).

Occupational safety and health

Non-fatal injury rates have been decreasing in Ukraine, while fatal occupational injuries only decreased gradually. This reduction may be the result of a shift from employment in high risk sectors to the services sector. In 2009 8.5 deaths per 100,000 workers were registered. Most injuries are the result of organizational issues in the workplace, some 77% (FAO, 2011).

Social security system

The social security system in Ukraine covers the nine main branches that are listed in the ILO Social Security Convention, 1952 (No. 102). Ukraine has taken major steps in shifting to a unified and coherent social benefit framework, with a 25.4% of total budged expenditure spent on social protection in 2009 (FAO, 2011).

The table below shows the ILO conventions that Ukraine has signed, specifically related to the bioenergy/biomass sector.

Table 5 - ILO conventions ratified by the USA

No.	ILO Convention	Ratified	In force
29	Convention concerning Forced or Compulsory Labour	1969	√
87	Convention concerning Freedom of Association and Protection of the Right to Organise	1976	√
98	Convention concerning the Application of the Principles of the Right to Organise and to Bargain Collectively	1976	√
100	Convention concerning Equal Remuneration of Men and Women Workers for Work of Equal Value	1963	√
105	Convention concerning the Abolition of Forced Labour	1963	√
111	Convention concerning Discrimination in Respect of Employment and Occupation	1969	√
138	Convention concerning Minimum Age for Admission to	2001	√

	Employment)		
182	Convention concerning the Prohibition and Immediate Action for the Elimination of the Worst Forms of Child Labour	2005	√

3.3.4 Certification

Several ecolabels are implemented in Ukraine. Among those related to forestry are:

- Forest Stewardship Certification (FSC) for both chain of custody and forest management
- Programme for the Endorsement of Forest Certification (PEFC) schemes

There is a national certification system as well.

3.3.5 Biodiversity

Ukraine occupies only 6% of the region in Europe but possesses 35% of its biodiversity. This is due to its favorable location, with a lot of migration routes and natural zones occurring in the country. The biota comprises over 70 thousand species, including many rare, relict and endemic species. According to the Convention on Biological Diversity (2015), the main pressures on biodiversity are due to fragmentation of landscapes, the development of infrastructure and urbanization, pollution, over-exploitation of bioresources, destruction of certain types of landscapes as a result of agricultural activities and the introduction of alien biological species (CBD, 2015).

3.4 Policy

Ukraine's energy legislative framework relative to renewable energy with influence on biomass includes:

- Energy Savings (No. 74/94-BP) 1994
- Alternative Fuels No.1391-XIV) 2000, amended (No.1391-VI) 2009
- Alternative Energy Sources (No. 555-IV) 2003;
- Combined Heat and Power Production and Use of Waste Energy Potential (No.2509-IV) 2005;
- Heat Supply (No.2633-IV) 2005;
- Energy Saving Promotion (No.760-V) 2007;
- Green Tariff (No. 601-VI) 2009;
- Power Industry Promotion of Alternative Energy Use (No.1220-VI) 2009
- Promotion of Biological Fuels Production and Use (No.1391-VI) 2009.

According to FAO (n.d.), the Land Code adopted in 2001 shows three types of property in Ukraine: state, communal and private. Land plots up to 5 ha from the agricultural and farming lands may be transferred to the private property. On forestry other Laws apply:

- Land Code of Ukraine (adopted by the Parliament, 2001)
- State Programme "Forests of Ukraine 2002-2015" (Government resolution №581 on 29.04.2002).

- President's Decree aimed to reform forestry of Ukraine (2004)

3.5 Agriculture

3.5.1 Agricultural history

Agriculture has traditionally been a very important sector of the Ukrainian economy, the area produced 5.2% of the world's barley and 2.3% of the global output of wheat in 2012 (FAO, n.d.). This production is the result of a high availability of agricultural land which is very fertile due to rich soils and an advantageous climate. The importance of the agricultural sector in Ukraine is also reflected by the fact that in 2010 46% of the total domestically extracted material in Ukraine was biomass (Schaffartzik, Plank, & Brad, 2014).

After the Second World War, productivity was low compared to Western European countries, partly as a result of the abundance of agricultural land as well as human labour (de Wit, Londo, & Faaij, 2011). During the 1980s yields started to grow as a result of increased mechanization, state subsidization of the agricultural sector and increased fertilizer use. The total production also increased further due to an expansion of agricultural land cultivated (de Wit et al., 2011). After the dissolution of the Soviet Union, yields in Ukraine fell sharply after three decades of steady growth. The transition of a centrally planned economy to a market economy, accompanied by abolishment of subsidies, lack of financial resources, lack of adequate policies to support the transition, reallocation of agricultural land and a turbulent economic and political environment resulted in a sharp decline in productivity as well as a decline in utilized agricultural area (de Wit et al., 2011; Schaffartzik et al., 2014).

3.5.2 Current state of agriculture

Now, the agricultural sector in Ukraine, like in other ex-Soviet republics, is characterized by a combination of large-scale commercial farms and a large number of family farms that were founded after the Soviet Union dissolution (FAO, n.d.). The policy support for agriculture, is still very unstable and is based on short term needs instead of long-term priority setting. For instance, between 1997 and 2010 the annual monetary value of transfers from taxpayers to the agricultural sector arising from policy measures varied between 0.3% and 11.3% as a share in total gross farm receipts (FAO, n.d.). During the end of the 1990s and the beginning of the 2000s, productivity levels started to recover. The progression along the transition to a market economy provided improved investment climates and stronger competition. This resulted in improvements within existing farms, as well as good opportunities for the entrance of new, more productive farms. This period also saw a vast increase in investments in the services sector in the former Soviet Union regions. This labour shedding increased labour productivity in the agriculture and manufacturing sectors (The World Bank, 2008). Recent years have been characterized by some years of strong increase in gross production, such as 2008, 2011 and 2013 and some years that showed declining production, such as 2007, 2009, 2010 and 2012. According to the FAO (Kobuta et al., 2012) the variation in production, after exclusion of the weather condition factor, is evidence of the fact that recovery is not consistent.

Especially the gross crop production has increased over the last two decades, with 2011 being the first year in which gross crop production surpassed the level of 1990. However compared to highly industrialized countries, agriculture in Ukraine is still lagging behind. For instance fertilizer input increased from 13 kg/ha in 2000 to 79 k/ha in 2013 but is still low compared to the UK, the Netherlands, Germany or France (>150 kg/ha) (Schaffartzik et al., 2014; State Statistics Service of Ukraine, 2014). Machinery use in Ukraine reaches an average of 9 tractors per 1000 ha, whereas this is 41 in Germany, 49 in Spain and 107 in Poland (FAOSTAT, 2015; Schaffartzik et al., 2014).

3.5.3 Outlook

With the crop production in Ukraine being back at the previously highest levels right before the fall of the Soviet Union, while the potential to grow to Western European agricultural standards remains, the question is where the agricultural sector in Ukraine is headed next. The fluctuating historic trends make it difficult to project the outlook for Ukraine. De Wit et al. (2011) state that a scenario in which yields in Ukraine catch-up with the levels of Western Europe could be envisioned. At the same time this article also acknowledges the barriers to achieving this.
To account for the different future trajectories, resulting from differences in political, institutional and technical changes realized, two scenarios are proposed in this report in analogy with the Van der Hilst et al. (2014) study.

The growth in agricultural productivity in Ukraine has varied greatly over the last few years. From 2010 to 2013, the latest available data, the business as usual productivity growth was larger than in the period until 2010, on which the Van der Hilst et al. (2014) scenario is based. However, the Ukrainian Revolution of February 2014 and the ongoing political unrest will probably have a significant effect on the agricultural production. Statistics show that the agricultural production yields have been anything but stable in the past decades, it seems unlikely that stable growth will happen in the near future, understanding that the future investments in the agricultural sector in Ukraine and the actual productivity improvements are very uncertain. Taking into account all of the above arguments, it was decided to follow the assumptions made by Van der Hilst et al. (2014).

4. Methodological application into the Ukraine case study

The general Biotrade2020+ methodology (see figure 1) was adapted to suit the Ukraine case study. These changes mostly affect the calculation of the technical potential. It was considered unfeasible to include detailed calculations of potentials of which it is known beforehand that it is based on residues that are not practically available. For instance stubbles are not harvested at the moment and presumably will not be harvested in the near future. Therefore some market considerations, such as the mobilization of certain types of residues were taken into account before the calculation of the technical potential.

Another deviation from the general methodology is the calculation of the market potential. Instead of calculating the limitations of mobilizing biomass and establishing markets, this was combined by calculating the potential to pelletize biomass, based on actual pellet plant capacity and growth rates modelled after the business as usual growth in Ukraine in the BAU scenario and modelled after the historical US growth rates in the HE scenario. The available pelletization capacity was recognized as a major limitation from the beginning of the analysis. Mobilization of biomass and a market for lignocellulosic biomass carriers are factors already included in the attractiveness of investing in new pellet plants.

A third adaptation is the fact that costs are assumed to remain constant over time. Because of a lack of reliable data it was very difficult to make cost estimations. Furthermore, the difficult political and economic situation in Ukraine makes the future extremely uncertain. For this reason it was considered not feasible to make statements about the development of certain cost components.

In order to analyse the potential of residues and energy crops that will be available for export to the EU several other characteristics need to be taken into account. The market potential mainly depends on the future implementation of technologies in Ukraine, as well as the state of the infrastructure in the country. For instance the production of pellets is limited to the availability of pellet producers, as well as the accessibility of these factories (dependent on the existing road and rail infrastructure).

The developments in Ukraine are summarized in two different scenarios. These give an idea about the potential future agricultural production and demand for agricultural products. The business as usual scenario is based on a continuation of current and historic trends, whereas the High Export scenario envisions more progressive improvements. This latter scenario represents the implementation of agricultural and institutional reforms, resulting in a convergence with levels of Western European countries by 2050. The main characteristics of the two scenarios are based on the work of Van der Hilst et al. (2014) in order to guarantee a consistent scenario approach between the different components of this research.

4.1 Technical potential

The technical potential is generally defined as the potential that can be obtained by full implementation of an already demonstrated technology or practice while taking into account practical constraints such as topographic limitations and land-use constraints (Intergovernmental Panel on Climate Change, 2011). In this report the technical potential is defined as the lignocellulosic biomass potential that is available under current and future technological possibilities, taking into account spatial restrictions due to competition with other land uses (food, feed and fibre production).

In this research three different types of feedstocks are included: Dedicated energy crops, primary agricultural residues and primary and secondary forestry residues. The amount of residues per produced feedstock is calculated using the Residue to Product Ratio method, using values from literature. The Residue to Product Ratio (RPR) gives the ratio between the production of residues to main agricultural products. Overviews of RPR values given in literature show that there is a considerable difference between various studies (Koopmans & Koppejan, 1998; Scarlat et al. 2010). One reason for the differences can be that RPR depend on local variables such as soil type and climate. Therefore, RPRs were used, these were taken from literature sources, where possible specifically determined for the Ukraine. The RPRs in this report give an estimation of the total amount (in kilotonnes) of residue that can be harvested, stubbles and roots are not included. Furthermore, the RPR is given in kilotonnes left on the field straight after harvest, so before drying.

4.1.1 Selection of studied regions

The Ukraine is a major producer of grain and oilseeds, located in the top ten of countries of production of wheat, coarse grain, corn, barley and oilseeds (United States Department of Agriculture, 2015). The country has traditionally relied upon the export of agricultural products, and is the leading exporter of sunflower oil as well as barley (respective market shares of 14.1% and 23.5%)(FAO, n.d.). Within the Ukraine there are some regional differences when it comes to the production of agricultural products and forestry residues. Agricultural production is mainly taking place in the central part of Ukraine. However the regional differences are not that large, except for the western regions and the Autonomous Republic of Crimea. The technical potential of primary agricultural residues lies in the range of 200 – 683 ktoe per region. The distribution of wood biomass is somewhat more centered, around the Northern and Western regions, with Zhytomyr, Kiev, Rivne and Lviv being the regions with the most technical potential (Oliynyk et al., 2015).

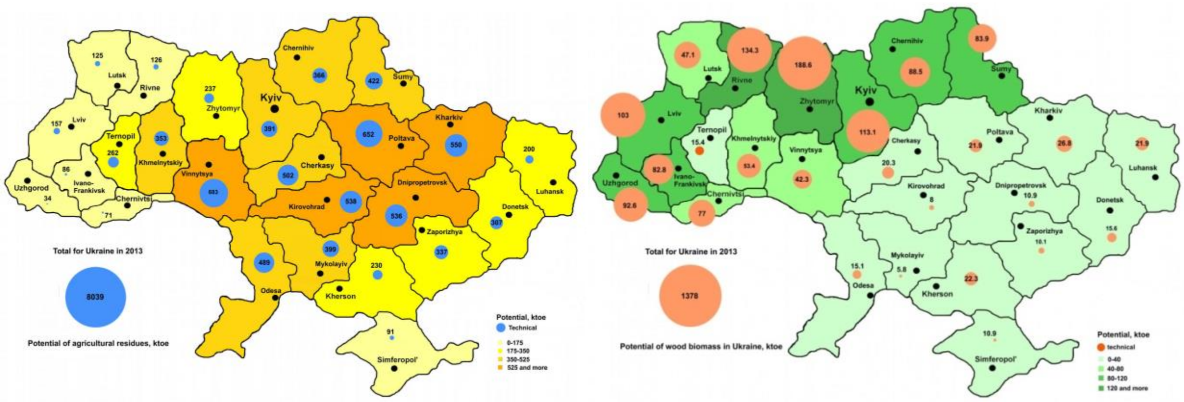

Figure 6 – Distribution of the technical potential of primary agricultural residues in Ukraine (left) and wood biomass (right), ktoe (2013) (Oliynyk et al., 2015)

All regions in Ukraine will be included in this analysis, in order to calculate the potential for the entire country. In-field data gathering was aimed at the regions with the largest potential, based on agricultural production volumes and the distribution of wood biomass. Anecdotal information from stakeholders about aspects such as local sustainability constraints will be assumed to apply to all the regions in the country in the absence of other evidence. The selection of crops will depend on the potential of those crops as well as data availability. Those crops with the largest potential, based on agricultural production and preliminary data about sustainability constraints and local use, will be selected for further analysis.

4.1.2 Land Availability

The potential for energy crops in Ukraine depends on the land used for agricultural production. This is analysed in previous research of Van der Hilst et al. (2014). This research is based on a PCRaster Land Use model (PLUC) which is described in Verstegen et al. (2012). The methods and data requirements are described in Van der Hilst et al. (2012). The model analyses five-year intervals for a Business As Usual and a Progressive scenario, using the above described assumptions.

In the PLUC model, Land-use is modeled for each year by modeling the total demand and by allocating this to detailed spatial locations until the demand is met, while taking account specific suitability factors (e.g. population density, distance to railroad). Some areas are considered not suitable for conversion to agricultural land and therefore excluded, such as existing forest areas, areas with steep slopes or conservation areas. The outcome of the PLUC model is the land availability for energy crops, namely switch grass and wheat, towards 2030, based on potential Land Use Change (LUC) developments, on a detailed spatial level (1 km^2) (van der Hilst et al., 2012; Verstegen et al., 2012).

The study of Van der Hilst et al. (2014) applies a Business as Usual scenario, representing a continuation of historic trends, as well as a Progressive Scenario, representing the implementation of agricultural and institutional reforms. The Progressive Scenario will result in the above mentioned convergence of yield levels with Western European Countries by 2050. The main characteristics of the two scenarios as used in this research, are given in Table 8 (van der Hilst et al., 2014).

In this study switchgrass is selected as typical feedstock for second generation biofuel. For modeling the total production it is assumed that an abandoned area will be taken into use for the production of the crops in the same year it is abandoned. The yield of switchgrass production is assumed to be based on state-of-the art agricultural practices so that high yields can be realized from the moment the land is taken into use. The maximum yield is based on the studies of De Wit (2010) and Fischer et al. (2010a; 2010b) in which yields are varied based on the suitability of the land. The maximum obtainable potential for switchgrass production is 21.4 odt/ha. The energy content of raw biomass is based on Boehmel et al. (2008) and is 18.4 GJ/odt.

Table 6 – Characteristics used in BAU and High Export scenario's (van der Hilst et al., 2014)

Characteristic	**BAU - 2030**	**High Export - 2030**

Population	40.5 Mpeople	
Diet	3300 kcal/cap	
Self Sufficiency Rate	1.29 (additional production is available for export)	
Technology adoption	Little improvement in accessibility of inputs and machinery.	High adoption inputs and machinery; meets West European practices.
Agricultural productivity	No development in yields and cropping intensity.	High increase in crop yields (3.8% p.a.) and cropping intensity (1.2% p.a.) resulting in a CI of 1 in 2030.
Livestock sector	Increase in livestock numbers and modest increase in productivity. Due to modest shift from small to large production farms. 1.9% annual growth	Increase in livestock numbers (same as BAU), shift towards high productive farms, full mechanization and the use of high quality fodder. Similar practices and productivity in livestock sector as in Western Europe by 2030. 3.3% annual growth (meets 1990 level in 2030)
Bioenergy implementation	No significant commercial bioenergy production.	Abandoned agricultural land is used for bioethanol crops.

4.1.3 Agricultural production

The agricultural practices in Ukraine are highly dispersed, whereas some farms adopt Western European practices and realize high yields, other farms operate in a far less efficient manner. It is considered unrealistic to assume that all the agricultural land in Ukraine is farmed using best available technologies. Through the two different future scenarios a range of technically realistic possibilities is explored.

Since the start of the problems in Ukraine, population decline has gone faster than expected. Consumption patterns might as well develop in a different direction than foreseen. Furthermore trade to Russia, Ukraine's foremost trading partner, could be significantly affected by export bans. Data form the State Statistics Service in Ukraine shows that both imports and exports of goods and services has declined in 2014 (State Statistics Service of Ukraine, 2015). Taking this into account the assumption is made that the demand for agricultural production remains constant over time in both scenarios.

The data about agricultural production is taken from the State Statistics Service Ukraine (State Statistics Service of Ukraine, 2014) and data from the latest available year is used, which is 2013. A comparison of available statistical data, of the years 2013, 2012 and 2011, shows that the differences between these years is less than 5%, therefore the conclusion was made that there are no outliers in 2013. Agricultural trends in Ukraine do not point at yield improvements. For instance, although the yield of wheat improved between 2000 and 2005, it declined again from 2005 to 2010. In recent years yields varied strongly from year to year. Furthermore, the very recent issues in Ukraine with respect to political and economic crises contribute to the conclusion that agricultural yield improvements are not to be expected. Therefore, in the Business As Usual scenario, yields and cropping intensity are kept constant, resulting in a technical potential equal to the potential in 2015.

4.1.4 Collection efficiency

It is not feasible to collect 100% of the above-ground agricultural residues. Part of the residues fall on the ground during collection and bailing, furthermore collecting all residues would not be cost efficient. In this research it is assumed that a maximum of 70% of the above ground biomass will be collected for use, for all the different residues (Cardoso et al., 2013; Glassner et al. 1998). Therefore the technical potential will consist of 70% of the above ground agricultural residues.

4.1.5 Energy content biomass

The energy content of raw biomass is taken from literature. Lower heating values are used since this is considered to more accurately represent the cogeneration systems used in practice. Since it is not certain that all boilers in which the biomass might be used are able to utilise the condensation heat of water by cooling the flue gasses, the LHV was used in this research. Thereby this research followed the approach used by the European Environmental Agency (European Environmental Agency (EEA), 2007) and the Biomass Energy Europe project (as used by (Lakyda et al., 2010) and described in the Methods Handbook of Vis & Van den Berg (2010). Lower heating values from literature may differ, depending on the method used to measure the values. Therefore multiple values will be used and compared, and an average will be used.

It is important to note that the heating value is influenced by the moisture content. The higher the moisture content, the lower the heating value. Not only does the moisture provide no energy, it costs energy to evaporate the moisture in the feedstock. To calculate the heating value of the biomass, it is therefore essential to know the moisture content of the residues. This research follows the most recent estimations of the situation in Ukraine by SEC Biomass (Geletukha & Zheliezna, 2014).

4.2 Estimation of the Sustainable Biomass Residue Potential

Sustainable sourcing of lignocellulosic biomass is considered a precondition for imported biomass to the EU, therefore several sustainability aspects are taken into consideration. Within the BIotrade2020+ project several sustainability criteria are identified to be considered for bioenergy production, this is assessed in Deliverable 2.4. The principle behind the criteria is the notion that there should be a uniform set of criteria applied to all non-food biomass feedstocks. Differences however exist between minimum requirements and advanced requirements, as well as basic and advanced levels of ambition. Table 9 shows the list of basic requirements that are applied in all the case studies. It must be noted that these requirements are closely aligned with the requirements of the RED (European Union, 2013).

Table 7 - Basic sustainability requirements applied in Biotrade2020+ case studies

Criterion	**Indicator**
Biodiversity	Conservation areas and land with significant biodiversity values
Climate	Life cycle GHG emissions incl. direct LUC
Employment and labor conditions	Human and Labor Rights
	Occupational safety and health for workers

Biodiversity

The issue of biodiversity is taken into account by excluding biodiverse areas from the expansion of energy crops. The expansion of energy crops is also excluded in existing forest areas and conservation areas as explained earlier in this report.

Climate

The GHG emissions of biomass pellet production across the supply chain, from agricultural production and harvesting to pellet production and transport are calculated. This calculation is made on Oblast level, resulting in a GHG supply curve calculated based on regional export potentials. These values are compared to average GHG emissions values of FT-diesel and electricity generation in order to compare the emissions of biomass pellets compared to alternative fossil based energy production.

4.2.1 Soil quality

In this research another sustainability focus point is maintaining soil organic carbon (SOC) levels. Maintaining the structure and texture of the soil, as well as the nutrient level, is not only crucial in ensuring long term agricultural productivity but also plays an important role in biodiversity and greenhouse gas balance. When looking at primary biomass production, several of the sustainable criteria's are affected by the amount of agricultural or forest residues that are left on the field. Agricultural residues can improve or maintain soil quality by returning to the soil the nutrients that were removed during the growth phase. A second function of residues on the field is to maintain soil structure. If soil structure is damaged, and the soil is left without protection in the form of crop residues, the soil is easily eroded away by wind or rain. This removes the fertile top layer of the soil and therefore reduces the soil quality and agricultural productivity. Considering this, soil quality is included as additional criterion in this case study.

Table 8 - Additional sustainability requirement applied in the Ukraine case study

Criterion	Indicator
Soil Quality	Soil Organic Carbon, soil structure

Estimates in literature about the percentage of residues that should be left in the field to prevent depletion of organic matter of the soil and erosion vary widely. For example, Ericsson & Nilsson (2006) assume 75% of the residues should remain on the field to ensure long-term productivity. Hoogwijk et al. (2003) examined the approaches used for assessing biomass potential and also concluded that about 25% of the residues could be recovered while maintaining SOC levels. Some researchers believe all residues should remain on the field. For example, Lal (2008) argues that residues must never be removed from croplands because leaving residues does not only prevent soil erosion, but it also contributes positively to water conservation and soil biodiversity. Other studies about the sustainable removal rate of straw state that in no tillage systems 76% - 82% of the residues is available when taking into account constraints (Glassner et al., 1998; Scarlat et al., 2010). Wilhelm et al. however conclude that some of the conflicting conclusions in literature stem from differences in factors such as SOC levels, soil characteristics, climate and management practices. These researchers also state that experimentally measuring changes in SOC levels is difficult.

The extent to which some of these sustainability constraints might hinder agricultural production depends partially on natural characteristics, such as soil type, slope, climate, biodiversity etc. On the other hand, local land management practices, such as tillage, water management, agricultural practices, fertilizer use etc., also impact the extent to which these limitations must be applied (Batidzirai et al. 2012). Because most of these sustainability constraints have to be applied to a very small local scale, and depend to a large extent on local land management and agricultural practices, modelling the effect on agricultural production at the country level is difficult. It is therefore recognized that modelling the sustainable potential based on certain aggregated characteristics will result in an approximation. This should in no way form the basis for local agricultural practices; instead field or farm specific tools could be used to assess the local potential for maximum residue removal.

4.2.1 Sustainable removal rate agricultural residues

To determine the sustainable potential of primary agricultural residues, the sustainable removal rate was defined. This is the percentage of the technical potential that can be taken of the field while ensuring that some of the abovementioned sustainability criteria are met, such as soil quality.

In this research the amount of residues that need to be left on the field to maintain SOC levels is modelled by using the Rothamsted Carbon (RothC) Model (Coleman et al., 1997). The RothC model is designed to model the effect of soil type, soil moisture, temperature and plant cover on the turnover of organic carbon in soil. This model was developed based on experimental field measurements on

sites in Europe, the USA and Australia (Coleman et al., 1997). Over the course of time the model was improved based on further field simulations and extended to cover different regions and soil types (Farina et al., 2013; Jenkinson & Coleman, 2008).
The RothC model depends on input, which is taken from the MITERRA-EUROPE model. This is an integrated model based on the models CAPRI and RAINS. The model is designed to assess the effects of ammonia and nitrate measures on the emissions to the atmosphere and leaching to ground water and surface water. The database used in this model is on NUTS 2 level and includes data which is also relevant for this research, such as land use, crop types, soil type and topography (Velthof et al., 2007). Although the MITERRA model is designed to work on EU level, most of the data for Ukraine is also available through this database. Data on Soil Organic Carbon, which was not yet available, was retrieved from the European Soil Database (ESDB). For data on yield and harvested area the State Statistics Service of Ukraine (2014) database was used.

In this method, the soil organic carbon balance was determined for the situation in which all straw was removed from the field as well as the situation in which no straw was removed. Based on the outcomes, it was determined how much percent of the straw could be removed from the field to have a soil organic carbon balance of zero. In some oblasts the soil organic carbon balance was negative, even when no straw was removed. In these cases the sustainable straw removal rate is determined to be zero. The calculations were performed based on production statistics of Wheat, Rye, Barley, Maize, Rapeseed and Sunflower. It is assumed that the outcome of this analysis applies to all the different crops.

The technical potential, as calculated by using the RPR values, excludes the part of the residues that cannot be removed cost effectively such as stubbles. As previously stated, it is assumed that 70% of the residues are harvested, leaving 30% on the field as a result of technical constraints. The sustainable recovery factors are however modelled based on the theoretical case of 100% straw removal. In order to avoid a double count of the residues left on the field, the sustainable recovery factor is increased with 30%, to a maximum of 100% of the technical potential. This does not apply for the Oblasts in which the sustainable removal rate is 0% since these regions are considered entirely unsuitable for sustainable removal of residues.

4.2.2 Sustainable removal rate biomass crops
A study by Gelten (2010) showed that soil organic content increases as a result of high intensity wheat and switchgrass production with fertilizer application. Van der Hilst et al. (2014) conclude that the conversion of cropland to switchgrass would result in a strong increase in SOC and below ground biomass. This is also true for a conversion from poorly managed pastures to well-managed switchgrass (van der Hilst et al., 2014). Furthermore Smeets & Faaij (2010) conclude that soil depletion can be avoided by application of fertilizers. Taking the above into account it is assumed that the conversion of agricultural land to well-managed cultivated land for energy crops will result in an increase or balanced SOC and below ground biomass. Therefore, the sustainable potential of switchgrass is considered to be 100% of the technical potential.

4.2.3 Sustainable removal rate forestry residues
The European Environmental Agency (EEA) (2009) set a maximum extraction rate of forest biomass, based on the theoretical potential, considering:

- Conservation and protection of biodiversity
- Sustaining site productivity/ site fertility
- Soil protection/ soil erosion
- Water protection
- Forest management and fire protection measures
- Nitrogen deposition and fertilization

The parameters taken into account include soil fertility, slope and compaction of the soil and base saturation. In this research only soil fertility is considered, based on the type of soil. Soil fertility is considered the most important criteria, in analogy with the sustainable criteria for agricultural residue extraction. Furthermore, data about soil type is readily available.
Different types of soil are classified into four different suitability classes, for each a maximum level of residue extraction is given, as can be seen in table 9 (EEA, 2009).

Table 9 – suitability classes, from (European Environment Agency, 2009)

	Highly suitable	**Moderately suitable**	**Marginally suitable**	**Unsuitable**
Level of residue extraction	75%	50%	15%	0%
Soil types	Cambisol Chernozem Podzoluvisol Kastanozem Rendzina Gleysol Phaeozem Fluvisol Greyzem Andosol Vertisol	Podzol	Histosol Ferralsol Planosol	Ranker Arenosol Lithosol Xerosol Solonchak Regosol Acrisol Solonetz Marsh

The soil type of the soil in Ukraine are taken from the European Soil Database (European Commission, 2013). Using ArcGis, these soil types are translated into a map of the soil suitability, as can be seen below in figure 9.
Next to the soil suitability, one other specific aspect is taken into account. According to the European Environment Agency specifically Cambisol soils are reclassified as moderately suitable instead of highly suitable based on low base saturation (saturation of cations such as calcium, magnesium, sodium and potassium) (EEA, 2009). To be on the conservative side, in this analysis all the Cambisol soil is reclassified as moderately suitable. The overall sustainable resource extraction rate for each Oblast is calculated by considering the number of grid cells of each suitability type in each Oblast.

Figure 7 – Soil Suitability Ukraine for forest residue removal, based on (European Commission, 2013; European Environment Agency, 2009)

The methodology for forest residues differs from the general methodology in the sense that the sustainability criteria are applied to the theoretical potential instead of the technical potential. This is because the EEA methodology, which is considered most suitable for this research, is based on theoretical resource extraction rates. It is considered that part of the sustainable potential as calculated using this method might not be technically extractable. Therefore the sustainable potential is defined as the lower number of the technical potential as calculated by Lakyda et al. (2010) and the sustainable potential, thereby taking as much as possible both limitations into account.

4.2.4 Scenarios

Proper management of agricultural areas can result in an increased sustainable removal rate. As mentioned earlier, the application of synthetic or organic fertilizer could compensate for the removal of sustainable residues. The amount of fertilizer applied in Ukraine is lower than in Western European countries; however this has been increasing steadily over the last decade. Business as Usual growth of fertilizer use will result in levels equal to Western Europe from 2030 (FAO, 2012; State Statistics Service of Ukraine, 2014). Field research has shown that fertilizer application, in combining with favourable management practices, could result in significantly increased carbon contents in top soils (Campbell et al. 1991; Geisseler & Scow, 2014). Storage of carbon from applied fertilizers works best if fertilizers are applied in sufficient yet balanced quantities. Also the higher the organic matter content of the soil, the more effective fertilizer will be (Bot & Benites, 2005). Knowing this, it is assumed that in a perfectly managed agricultural system, 100% of the residues can be removed. However, this presumably only applies to the Oblasts with non-zero removal rates, since the soil type of the Oblasts from which no residues could be harvested is not suitable for residue removal.

It is assumed that in the High Export scenario all of the agricultural companies are applying good management practices in 2030, thereby fully replacing residue removal with other types of fertilizer input. It is assumed that the residue removal rate will increase linearly until this maximum.

Field research in Ukraine has shown that agricultural practices are highly dispersed. Modern agricultural enterprises, often managed by farmers from Western European countries adopt best available technologies; small scale local farmers on the other hand still use sub-optimal practices. In the Business as Usual scenario the sustainable removal rate will presumably be unchanged.

4.3 Sustainable surplus

4.3.1 Local demand

Considering the lack of reliable statistical data of uses of residues, anecdotal information will be used to determine the domestic demand, this is the same for all type of feedstocks. For the calculation of the Business as Usual potential it is assumed that the domestic demand is the higher end of the range of anecdotal information. In the High Export scenario this is assumed to be the mean value. Because detailed verifiable data about domestic demand is missing, and no trends can be identified, the demand is modelled to stay constant until 2030 in both scenarios.

The domestic demand is modelled per Oblast, the assumption is made that residues for local use are not traded across regions. This entails that in some Oblasts the domestic demand will be higher than the sustainable availability. It is assumed that in this case the domestic demand takes up all of the residues, but no additional residues from other Oblasts. It is considered realistic that the local demand of residues in Oblasts is limited by the actual availability of residues locally. The use of residues is attractive since residues are readily available for minimal cost. Trade of residues across larger distances would eliminate these benefits. Therefore, instead of assuming that residues are traded across Oblasts, the assumption is made that alternative uses of residues are limited by the local availability.

The local demand of wheat residues is estimated by four experts in Ukraine, estimates can be found in table 10.

Table 10 - domestic demand of agricultural residues

	Fodder	Bedding	Burned on field	Left on field	Heat (used at farm)	Heat (used in region)	Production of pellets	Other (mushrooms)
[A]	5%	5%	15%	50%	10%	4%	50%	0%
[B]	27%	35%	0%	34%	1%	2%	0%	1%
[C]	0%	30%	45%	25%	0%	0%	0%	0%
[D]	4%	6%	5%	84.4%	0.1%	0.2%	0.2%	0.1

As can be seen, the estimations vary quite a bit. Also, part of this local demand is considered available for use as additional lignocellulosic biomass for pellet production. For instance, the part of the residues left on the field can be used, as long as sustainable limitations are taken into account. The part that is burned on the field is also available for use. Production of pellets for domestic uses is also excluded, since the total production of pellets in Ukraine is already subtracted from the total potential. Finally bedding is also not included as a limiting factor. The reason for this is that bedding is return to the fields after use in for instance chicken farms. Because this is returned, it fulfills the sustainability requirements of providing nutrients to the soil. To prevent from double counting the residues that are not available for pellet production, bedding is not included in the local demand.

Table 11 – Share of non-available residues because of domestic demand limitation

	Share
[A]	19%
[B]	31%
[C]	0%
[D]	4.4%

The total domestic demand that limits the sustainable surplus ranges from 0% to a maximum of 31%. It is impossible to say which one of these estimations is the most reliable. Instead, this uncertainty is included in the different scenarios. In the Business As Usual scenario, a cautious approach is adopted and the assumption is made that the highest end of the range, 31% is not available. On the other hand, in the High Export scenario the assumption is made that in 2020 and 2030 the domestic demand lies in the middle of the range, namely 15.5% is not available for pellet production.

4.4 Export Potential

4.4.1 Market potential

Most forms of biomass can be characterized by low energy densities; the relatively high moisture content further reduces the heating value of biomass feedstocks. Furthermore most biomass is highly heterogeneous and therefore poorly suited for direct use as fuel. These drawbacks of biomass compared to fossil fuels apply particularly to agricultural crops and to a lesser extent to forest biomass. The low energy density of raw biomass limits the marketability. In order to cost effectively transport biomass over larger distances, the energy density must be improved. Another factor that impacts the storage and transport of biomass is the presence of natural pathogens in biomass, this makes storing raw biomass a health risk. Other risks exist, such as self-heating and dust explosions, pre-treatment can help minimize or solve these risks.

Pre-treatment of biomass helps to improve the energy content, homogenize the feedstocks and reduce above mentioned risks. Pre-treatment includes several processes, such as drying, size reduction through milling, grinding and pulverization and subsequent treatment methods including torrefraction, pyrolysis and pelletization.

Drying of the feedstocks decreases the moisture content and therefore increases the energy density. Natural drying, for instance by leaving biomass on the field, is often sufficient for agricultural biomass, whereas woody biomass often requires additional forced drying in industrial dryers (Haarlemmer, 2015).

Milling is applied to obtain particles of equal size, in the order of a few millimeters. Different applications require different particle sizes and thus require different grinding and milling steps.

Pelletization increases the density of the biomass feedstocks. After grinding, drying and milling of the feedstock, mechanical pressure is applied to compress the biomass (Mani et al.,2006). Frictional forces resulting from the high pressure lead to a rise in temperature which causes the lignin and resins in the biomass to soften and act as binding agents (Zafar, 2014).

4.4.2 Pellet plants

In this research, for the current scenario only pelletization of biomass will be considered as pre-treatment technology. This is because the other technologies have not matured yet and are still in a state of development. Pelletization is currently mainly applied for woody residues, agricultural residues are mostly just dried and baled and used locally. It is however possibly to use pelletization technology also on agricultural residues or on mixtures of agricultural and forestry residues (Nuneset al., 2014).

The capacity in existing pellet plants is considered a limiting factor for the transport of pre-treated biomass to the EU. The current potential is calculated based on capacity in existing plants. Data about the total installed capacity is not available; instead the most recent data about pellet production in the Ukraine is used as a proxy. Business as Usual increase of pellet plant production, based on the years 2008 - 2012 will be assumed in the BAU scenario. In the High Export scenario the capacity is assumed to increase at a higher rate. This higher rate is determined by comparing the situation in Ukraine to that in the South-East of the US. The pellet market in this region is the most developed in the world and has experienced an impressive increase in the last decade (Southern Environmental Law Center, 2015). Mimicking this growth rate is considered realistic considering it is based on actual realized growth rates, but optimistic considering the more favorable conditions in the US compared to Ukraine. In order to compare the two countries, the current capacity is compared. The capacity in Ukraine is almost similar to the capacity in the US in 2009. After 2009, capacity grew steadily until heaving reached a four-fold increase in seven years (included capacity that will be operational in 2016) (see figure 10). The growth rate of US pellet plants is used to mimic pellet plant growth in Ukraine between 2015 and 2022. After 2022, the growth rate is considered to be somewhat lower, compared to the growth rate in the US between 2013 and 2016. Since this is the most recent data available, it is assumed that the more or less linear growth of the last three years will continue.

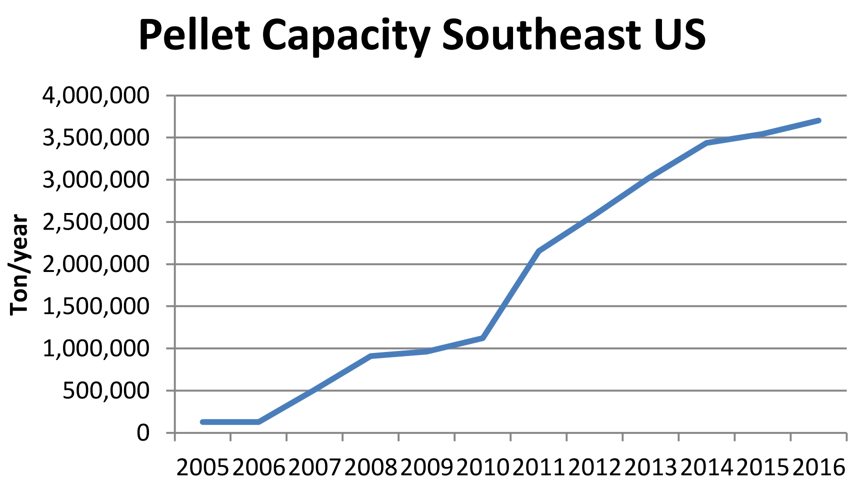

Figure 8 – Pellet plant capacity Southeast US

The assumption is made that additional pellet plants will be installed in the geometric centre of those regions with sufficient supply. The installed capacity of existing pellet mills in the US varies between 13000 ton/year and 750000 ton/year, as can be seen in figure 11. A large number of pellet mills have capacities between 75000 and 150000 tons (29%) and 440000 and 550000 tons (37%). In this research it is assumed that smaller sized pellet mills will be placed with a capacity of 50000 tons. It is assumed that pellet mills will be installed according to potential, thereby being placed first in the Oblast with the highest potential and only in those Oblasts with a potential greater than 50000 tons of pellets per year.

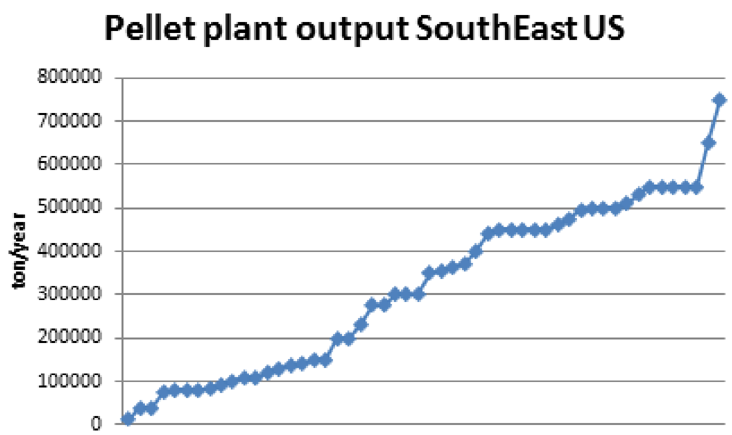

Figure 9 – Pellet plant output Southeast US

It is outside the scope of this research to allocate the different feedstock potentials to pellet mills. Instead it is assumed that the capacity will first be filled by agricultural residues. Supply of dedicated energy crops is only used if the capacity exceeds the sustainable supply of agricultural residues.

4.5 Cost Supply curve

4.5.1 Costs

By taking into account the sustainability restrictions and subtracting the domestic demand of lignocellulosic biomass, the net available export potential is calculated, the next step is calculating the cost of exporting these pellets to the EU.

To assess whether the imported biomass pellets from Ukraine could compete with alternative energy carriers in the EU, the various costs in the supply chain were calculated. Costs can be divided in feedstock costs, transport costs, handling costs and pre-treatment costs. All these costs contribute to the market price of biomass residue energy carriers, for example wood pellets. Costs and the market price determine, among others, whether consumers in the EU are willing to import biomass residues and/or their derivatives and whether producers are willing to export them. Data on costs are derived from databases, literature and from interviews with local experts.

To estimate the cost of lignocellulosic pellet production the following cost components are included:

$$C_D = C_P + C_{Pt} + C_{Tdf} + C_{Tdp} + C_{Ti} + C_H$$

Where:

C_D = Total production cost of biomass residues

C_P = Cost of production of feedstock

C_{Tdf} = Cost of domestic transport from field to pre-treatment facility

C_{Tdp} = Cost of domestic transport from pre-treatment facility to export location

C_{Ti} = Cost of international transport from facilities to the EU

C_{Pt} = Cost of pre-treatment

C_H = Cost of handling

Handling cost include cost components such as loading and unloading of pellets, storage of pellets, harbour fees etc. These costs will be aggregated into one total cost for the handling of pellets.

In order to be able to compare the cost over the different case studies, the cost calculations are harmonized. Pre-treatment cost estimations are taken from Ehrig et al. (n.d.). This study assesses economics and price risks in pellet supply chains including pelletization and transport from Western Canada, Western Australia and Northwest Russia to the European market (Ehrig et al., n.d.). Cost assumptions are taken from market data, meaning costs are requested from bioenergy traders and experts, and costs are considered from an end-user perspective and are therefore suitable to use in this project. Costs are calculated for two different scales, a medium-scale pellet production plant of 40,000 ton/year and a large-scale pellet plant producing 120,000 ton/year. Another option that is added based on the work of Ehrig et al. (n.d.) is pellet production with the use of part of the biomass feedstock for heat production to deliver the required heat for drying purposes.

In addition to the cost components from Ehrig et al. (n.d.), cost of consumables are included based on Pirraglia et al. (Pirraglia et al., 2010). This study explicitly includes the cost of parts and replacements, as well as marketing and sales fees. These components seem to be overlooked often, and are added to the cost calculation in this study for the sake of completeness.

Whereas the cost of pellet production are harmonized over the different case studies, some cost factors are adapted to represent country specific cost, such as labor cost or cost of electricity. Certain feedstock characteristics, such as moisture content and calorific value are also adapted where necessary to represent differences between feedstocks. The input values used to calculate the cost of biomass pellet supply to the EU are given in Appendix D.

4.5.3 Cost of delivering feedstock to pellet mills

The total production cost of biomass residues can often be set at 0, since the cost are allocated to the main agricultural product. However the collection of residues does require the collection from the field, baling and storage at facilities. Furthermore residues must be transported to pelletizers, often by relatively expensive road transport.

The costs include the cost for transport from fields to pellet mills. This could however vary with the size of oblasts. When assuming that oblasts are circular shaped and calculating the average distance to the centre based on the area of oblasts, this distance varies between 33.5 and 68 km. It is assumed that this small difference in transport kilometres does not result in large differences between the Oblasts, therefore the same prace for transport of feedstocks to the pellet plants is assumed.

4.5.4 Cost of delivering feedstock from pellet mills to the EU

Cost of transport of biomass from the Oblasts in Ukraine to the EU is calculated by using the BIT-UU model (Hoefnagels et.al., 2014). The BIT-UU model is a GIS-based biomass transport model with an intermodal network structure of road, rail, inland waterways, short sea shipping in Europe and ocean shipping. The model combines linear optimization of the allocation between supply and demand nodes with global input data on cost for transport of solid biomass. The BIT-UU model can optimize supply chains for least cost or GHG emissions. In this case, results from a cost-optimization are used as transport costs.

Cost of transport to three different EU countries is calculated: Austria, Italy and the Netherlands. These countries serve as examples of countries that can be reached via either the North Sea or the Mediterranean Sea, as well as a landlocked country. The cheapest option from each Oblast is then selected and used in the Cost Supply Curve calculation.

5. Results

5.1 Net sustainable volumes of feedstocks – BAU Scenario, current situation, 2020 and 2030

5.1.1 Agricultural feedstocks

The potential of agricultural residues in Ukraine has been mapped based on literature research about the agricultural production in Ukraine and the Resource to Product Ratio (RPR)(Geletukha & Zheliezna, 2014; State Statistics Service of Ukraine, 2014). The total technical potential of agricultural production is 865 PJ and as a result of scenario assumptions remains constant over time. When considering the amount of residues generated, as can be seen in figure 13, the central part of Ukraine offers the largest potential. The agricultural potential is divided in 43% maize residues, 24% wheat residues, 22% sunflower residues, with the remainder being barley and rapeseed residues.

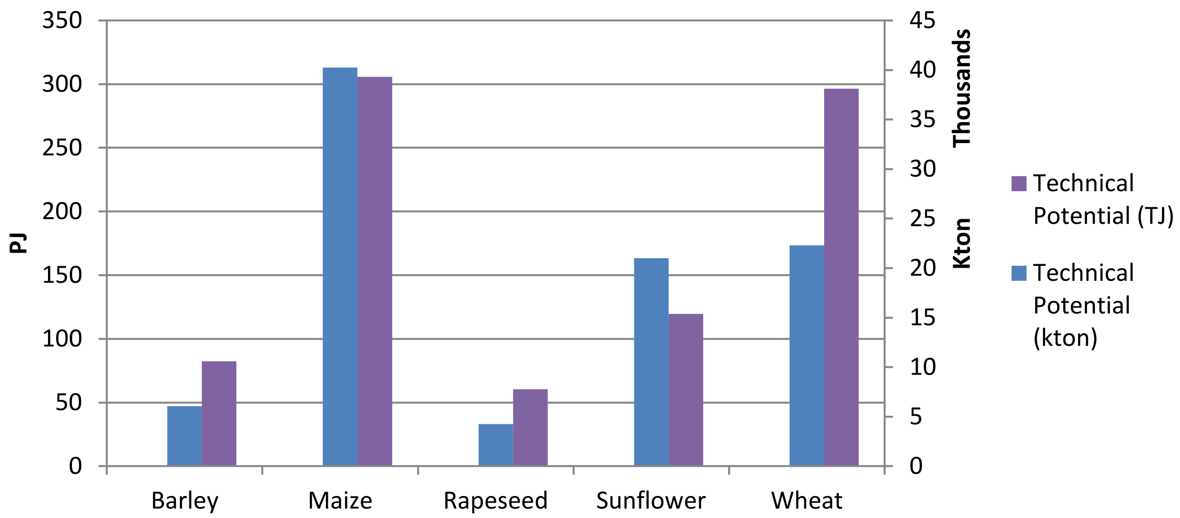

Figure 10 – Agricultural residues 2013, divided over five largest feedstocks (State Statistics Service of Ukraine, 2014)

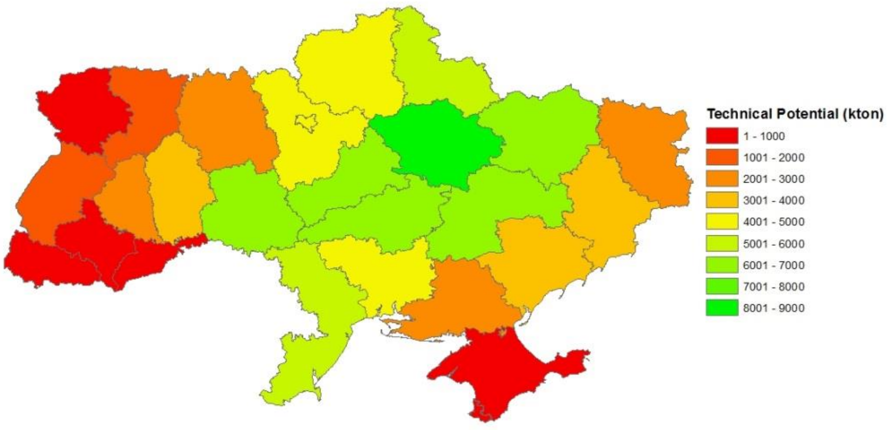

Figure 11 – Technical potential of agricultural residues - geographical map

When taking into account the sustainability constraints, the potential decreases by 25% on average, to 641 PJ. The differences between regions are large, the potential is 100% in some Oblasts and 0% in others, a complete list of sustainability potential per feedstock per Oblast can be found in Appendix B.

When taking into account the share of the sustainable potential not available due to local demand, the potential is lowered by 17%. The sustainable surplus is 533 PJ in 2015, remaining unchanged over time in the Business As Usual scenario.

By far the biggest constraint is the lack of pellet mill capacity. According to business as usual growth curves, capacity will increase to slightly more than 2 million pellets in 2030, or 54 PJ taking into account the energy content of the different feedstocks that make up the pellet mixture in Ukraine. The export potential increases from 17.5 PJ in 2015 to 34 PJ in 2030 in the BAU scenario.

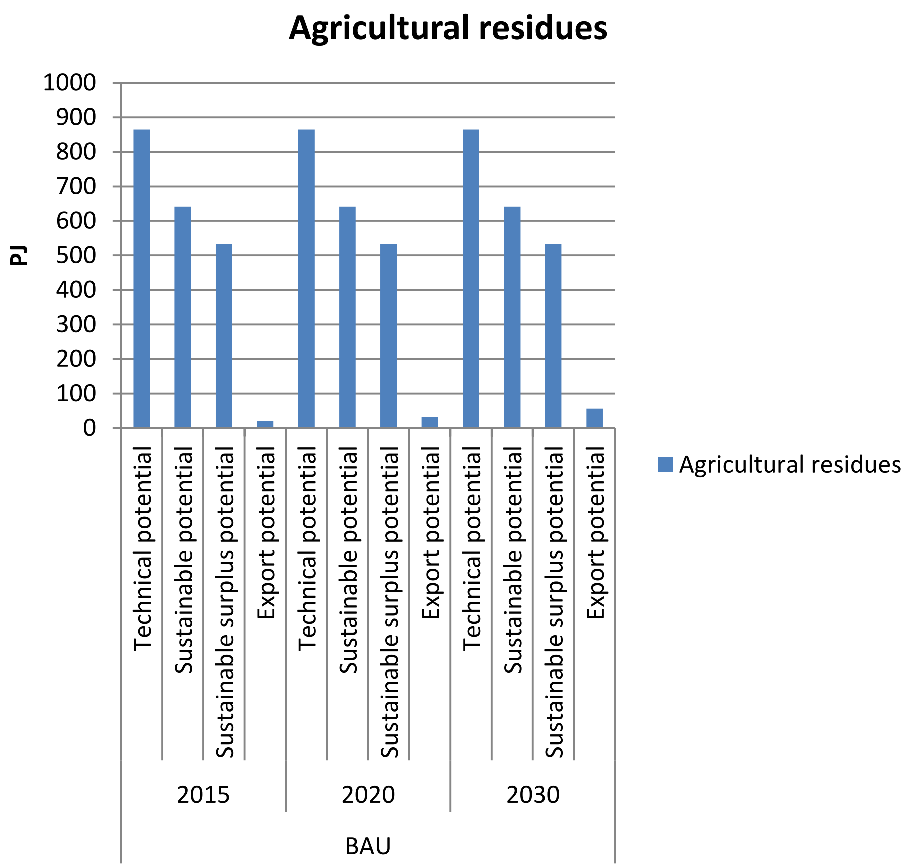

Figure 12 – Potential agricultural residues Business as Usual scenario

5.1.2 Energy crops

Land availability

The outcome of the study of Van der Hilst et al. (2014) is the spatially explicit land use from 2010 up to 2030 in five year time intervals (figure 15). In both scenarios the land used as dedicated cropland and pasture land increase at the expense of mosaic cropland-pasture land. In the BAU scenario cropland mainly expands in those areas that are already popular and suitable for agricultural

production. Expansion of agricultural land happens at the expense of mainly grassland and shrubland, but sometimes also at the expense of forest patches that are already surrounded by agricultural land and that are located in areas very suitable for agricultural production.
In the BAU scenario all currently available land for agriculture is needed to meet the future food and feed production demand. In the Progressive scenario land does become available since agricultural production is rapidly concentrating on highly suitable land due to high productivity increases. Agricultural land which is less suitable for production is abandoned first; this is mostly marshy mosaic forest. Since there is a trend towards more dedicated land use in the progressive scenario, mixed cropland-pasture areas are abandoned more rapidly than dedicated pasture and cropland areas.

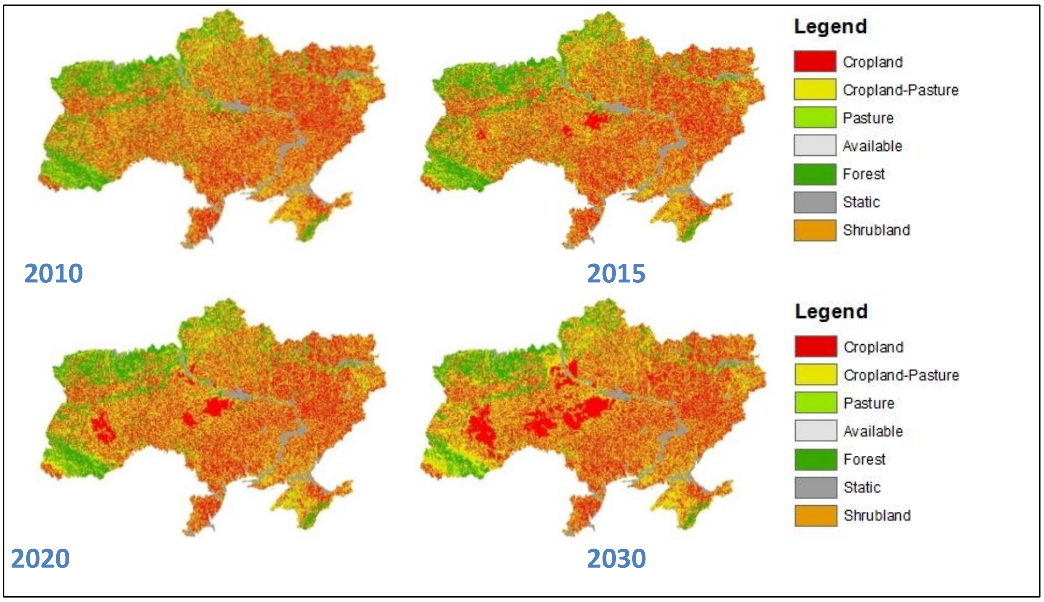

Figure 13 – Land Use Ukraine – Business as Usual (van der Hilst et al., 2014)

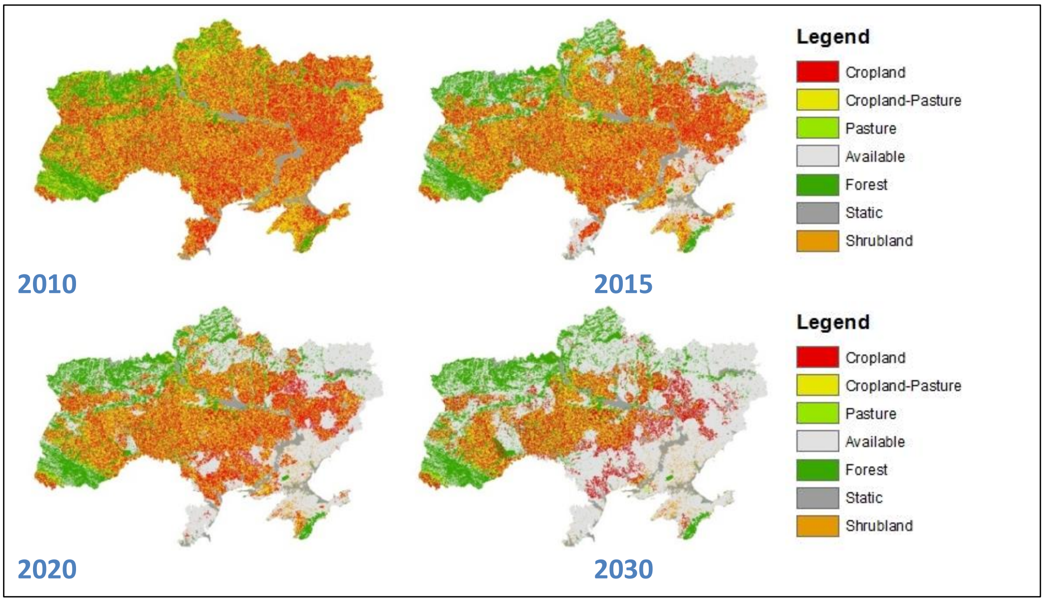

Figure 14 – Land Use Ukraine – Progressive (van der Hilst et al., 2014)

As can be seen in these figures, the available land is mostly located along the edges of the country. The Oblasts in the south and east of the country offer the greatest potential for dedicated bioenergy crop production. It must be mentioned that this is a direct result of the modelling choices.
The reality could of course deviate from the assumption that the least suitable land will become available for bioenergy production.

In the Business As Usual scenario the potential for dedicated energy crops is very small. This is because the available land for agricultural production is needed in its entirety for the production of agricultural crops to meet the demand for food.

Figure 15 - Theoretical potential dedicated energy crops 2030 – Business As Usual (TJ)

The potential for agricultural products is just 2.3 PJ in all the different scenarios. Just as is the case with forestry products, it is assumed that there is no export production since all the available pellet mill capacity is already used.

5.1.3 Forestry residues

The potential for forestry residues is much less than agricultural residues. As can be seen in figure 18, the Oblasts with the largest potentials are Zhytomyr, Zakarpattya, Lviv, Kyiv and Chernihiv, together making up 46% of the potential. The potential of primary residues makes up 58% of the total, with secondary residues accounting for the other 42%. The total technical potential of forestry residues is 39 PJ per year, considerably less than the potential of agricultural feedstocks.

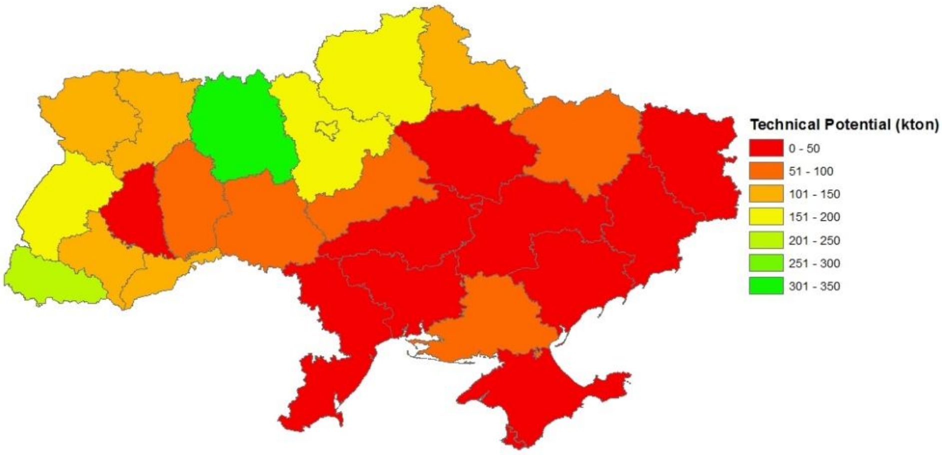

Figure 16 – technical potential of forestry residues – geographical map

Since the soils in Ukraine are generally classified as highly suitable, the sustainable potential is close to 75% of the theoretical potential, and almost 92% of the technical potential, limiting the potential to 36 PJ.

Currently forestry feedstocks are not collected from Ukrainian forests. This means that on the one hand there is no local demand to limit the sustainable potential. The sustainable surplus is therefore equal to the sustainable potential. On the other hand this does mean that there is no market potential and export potential as well in the current Business As Usual scenario. Since the pellet mill capacity as projected cannot meet the supply of agricultural residues, it is assumed that there is no incentive to start collecting forestry residues; therefore the export potential is 0 PJ.

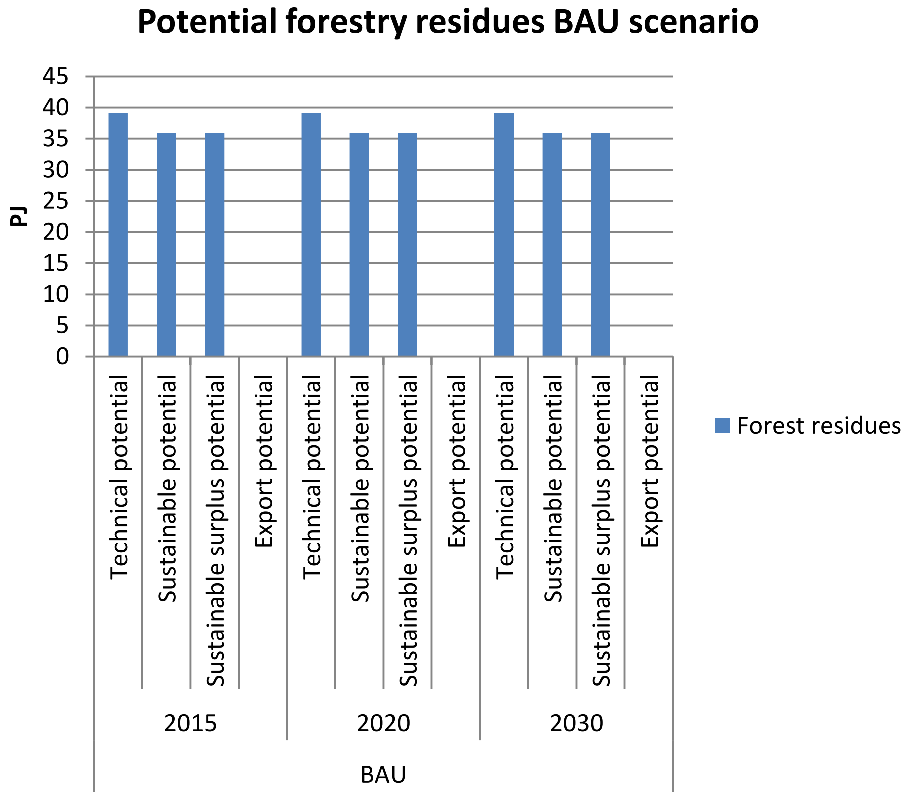

Figure 17 - Potential forestry residues Business as Usual scenario

5.1.4 Total potential of lignocellulosic biomass

The total technical potential of lignocellulosic biomass exceeds 900 PJ and consists almost completely of agricultural residues. Sustainability constraints limit about 25% of the technical potential and domestic demand another 16%. By far the biggest limiting factor is the pellet mill capacity. This limits the potential to only 17.5 PJ in 2015, increasing towards 34 PJ in 2030.

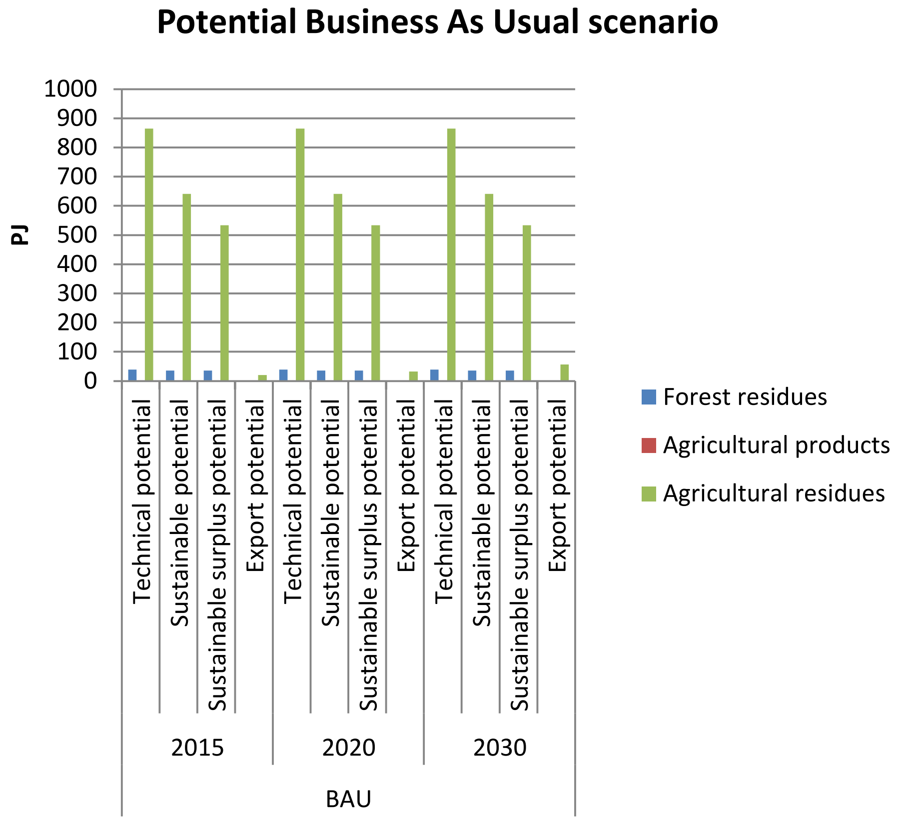

Figure 18 - Total potential Business as Usual scenario

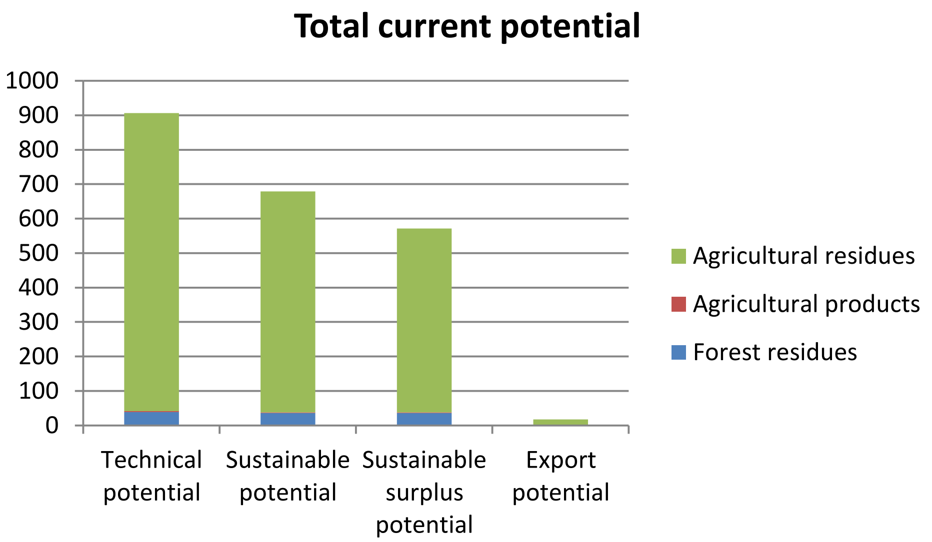

Figure 19 - Total current potential

5.2 Net sustainable volumes of feedstocks – High Export scenario, current situation, 2020 and 2030

5.2.1 Agricultural feedstocks

The technical potential in the High Export scenario remains the same, as a result of the assumption that agricultural output remains constant. The sustainable potential does increase somewhat since the use of fertilizers is increasing and therefore more residues can be taken from the field, as can be seen in Appendix B. The surplus potential is therefore also larger since the fraction used locally remains the same. The export potential increases from 17.5 PJ in 2015 to 203 PJ in 2030. This is because of the sharp increase in pellet production capacity.

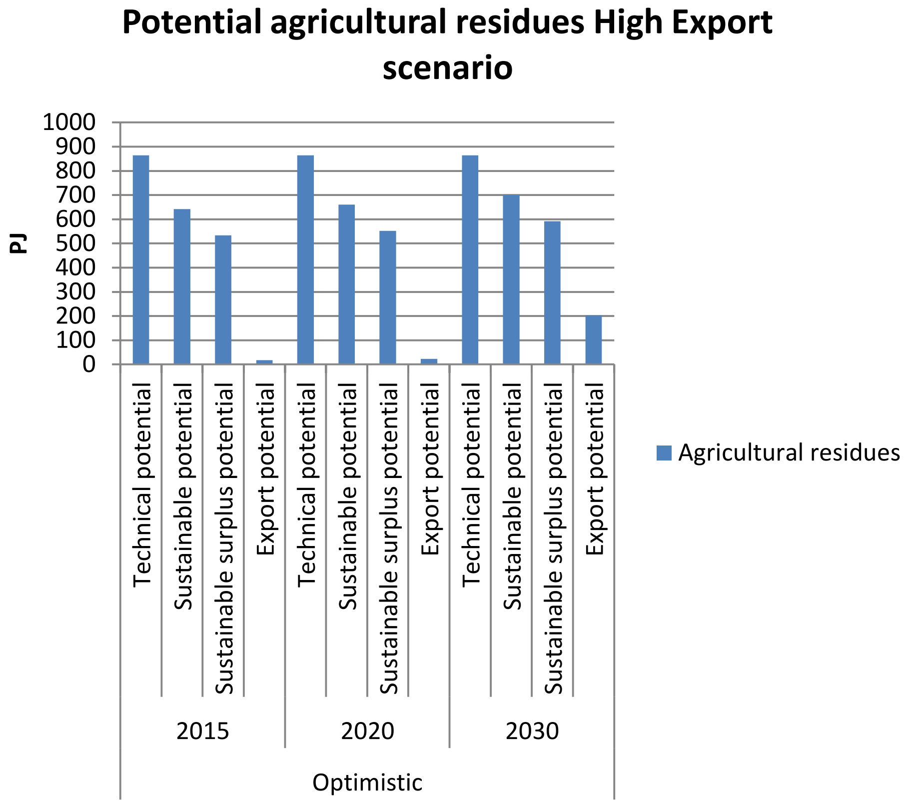

Figure 20 - Potential agricultural residues High Export scenario

5.2.2 Biomass crops

The potential in the Progressive scenario in 2030 is much larger, over 7000 PJ in total. This potential is concentrated in the southern and eastern parts of Ukraine, although some regions in the northern and western part also hold great potentials. Considering the optimistic assumptions underlying this analysis (immediate use of abandoned land, state of the art yield), this progressive potential can be considered the upper boundary of what is theoretically feasible to produce in Ukraine. Considering the fact that the pellet capacity mill is still completely being fed with agricultural residues, the potential for dedicated crops will not result in any export potential.

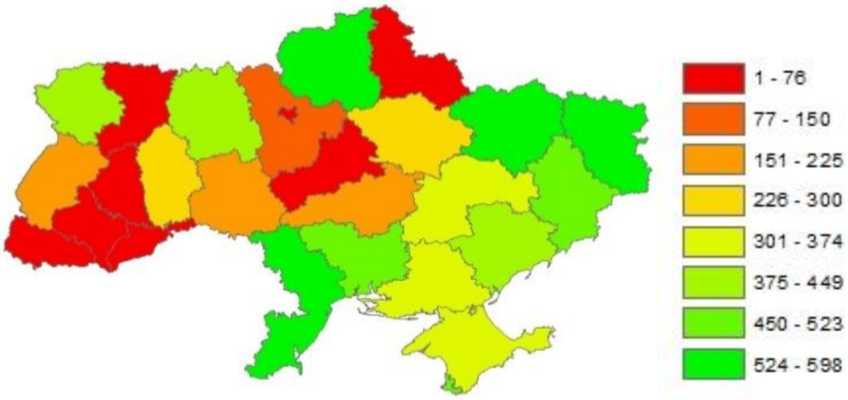

Figure 21 - Theoretical potential dedicated energy crops 2030 – Progressive (PJ)

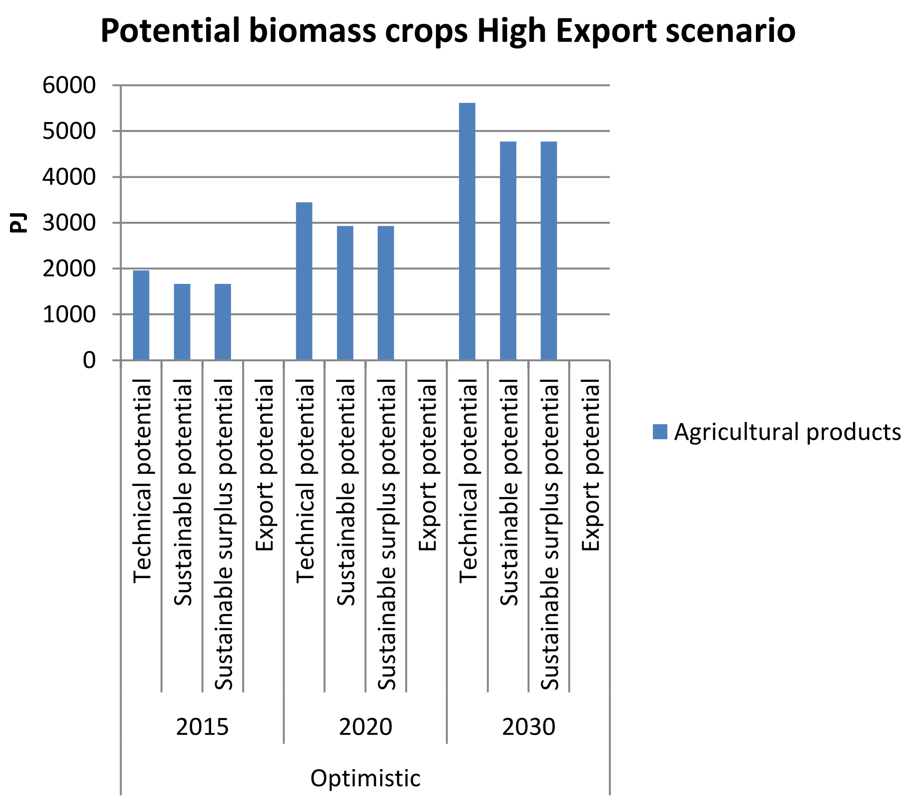

Figure 22 - Potential biomass crops High Export scenario

5.2.3 Forestry residues

Since data about the development of forestry residues is lacking, this potential will remain the same in both scenarios. Since the pellet mill capacity is used for the production of pellets from agricultural residues, the export potential of forestry residues is 0 PJ.

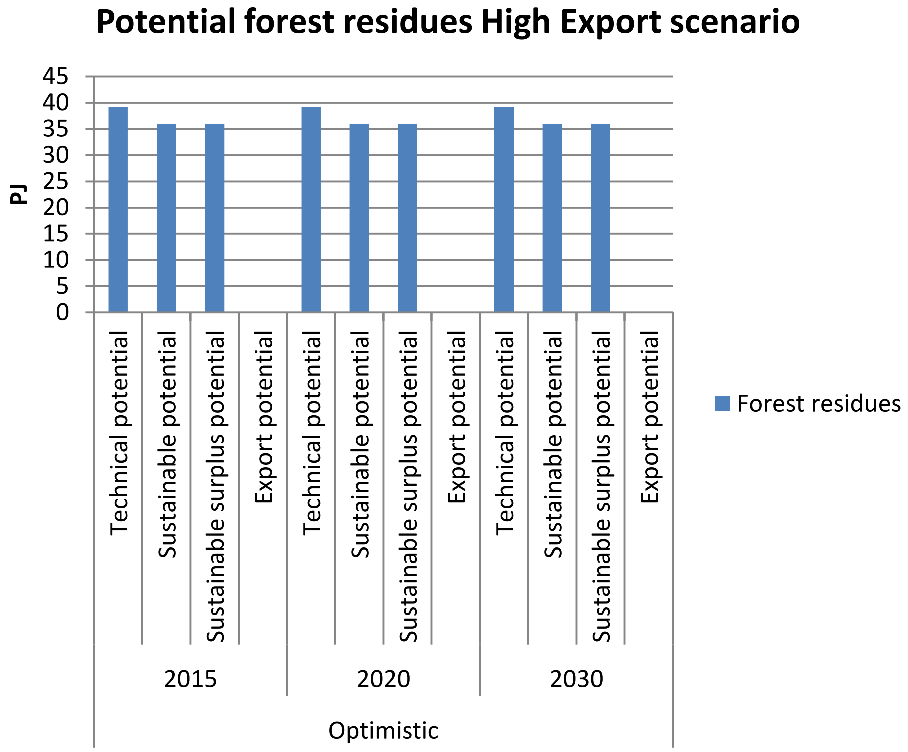

Figure 23 - Potential forestry residues High Export scenario

5.2.4 Total potential of lignocellulosic biomass

The total potential of export of pellets from lignocellulosic biomass from Ukraine is 203 PJ in 2030 in the High Export scenario. This is mainly determined by the pellet mill capacity. If capacity would not be an issue, the potential would be 30 times higher.

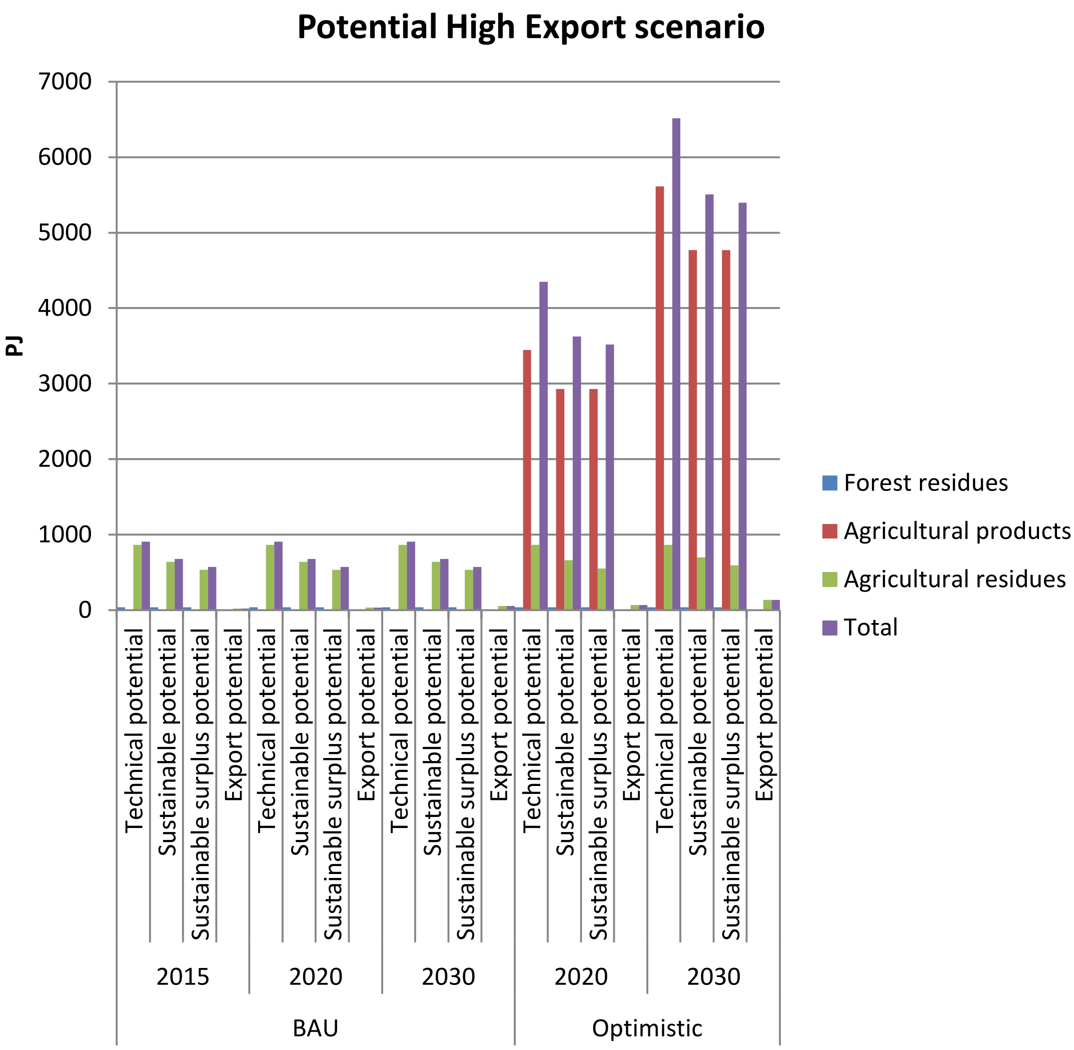

Figure 24 - Total potential High Export scenario

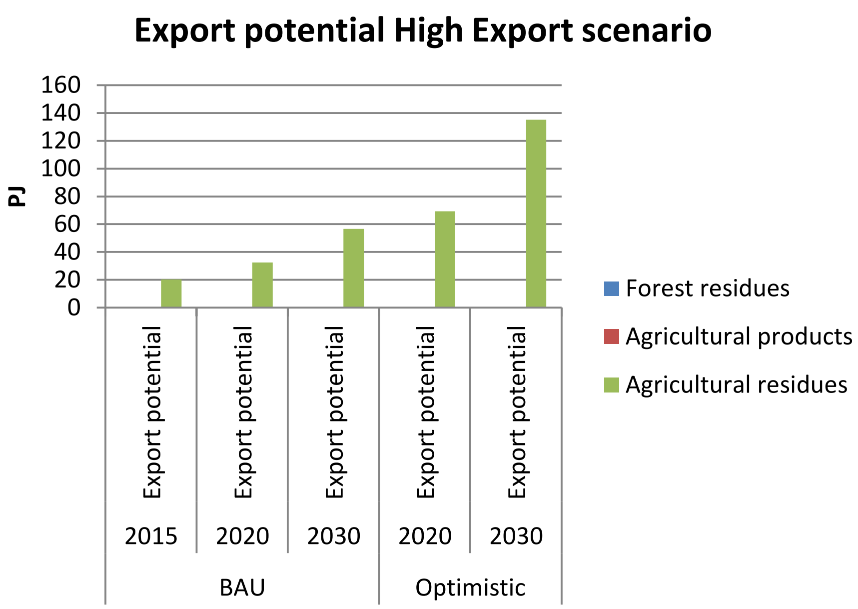

Figure 25 - Export potential High Export scenario

6. Discussion

6.1 Biomass Cost-Supply Curves

The net export potential in the current situation is 20 PJ, as discussed earlier. Figure 28 shows the cost-supply curves of the current situation, using the most up to data information about cost components possible. The cheapest pellets could be available for €6.6/GJ delivered to a European country, the most expensive residues are available for €9.6/GJ. In some Oblasts cost would be close to €12.0/GJ, however in these Oblasts there is no potential for lignocellulosic biomass export. For all the different Oblasts, the cost of energy crops are the lowest, followed by agricultural residues (2% more expensive) and forest residues (22% more expensive).
The cost of transport are calculated to three different countries, Austria, Italy and the Netherlands. For each Oblast the cheapest option is selected, since the assumption is made that market mechanisms favour the country with the lowest import cost requirements. When looking at transport cost, the cost are, on average, lowest to the Netherlands (2.1 €/GJ), followed by Italy (3.4 €/GJ) and Austria (3.9 €/GJ), however, this order differs for some Oblasts. The range of transport costs from the different Oblasts is much larger, transport from Volyn to the Netherlands only costs 0.46 €/GJ, whereas transport from Cherkasy to Austria would cost 5.39 €/GJ according to the calculations.

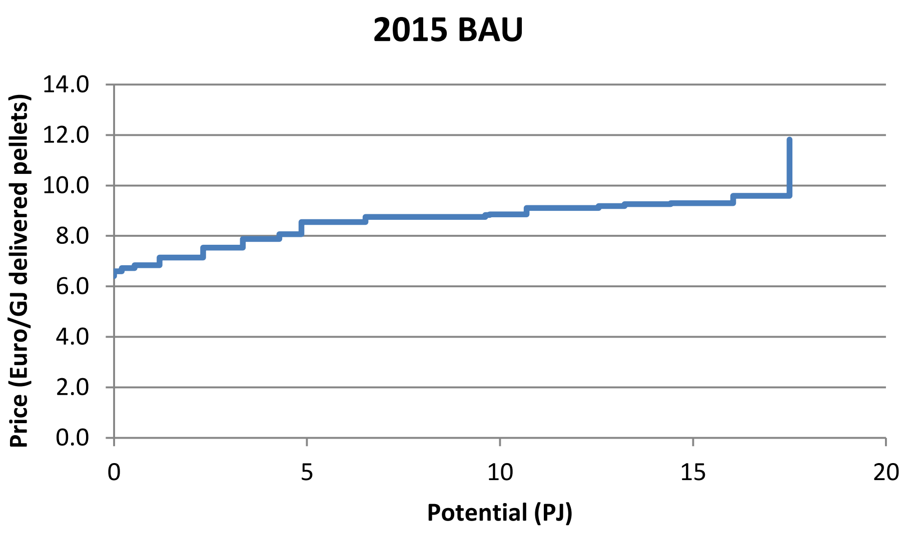

Figure 26 - Cost Supply Curve BAU – Current situation

As explained earlier, the costs per feedstock are assumed to remain constant in the different scenarios. The only change between the curves therefore is the total potential of biomass availability. As can be seen in the below figures, in which the axis is fixed, the potential in the 2030 High Export scenario is considerably larger than in the other scenario's.

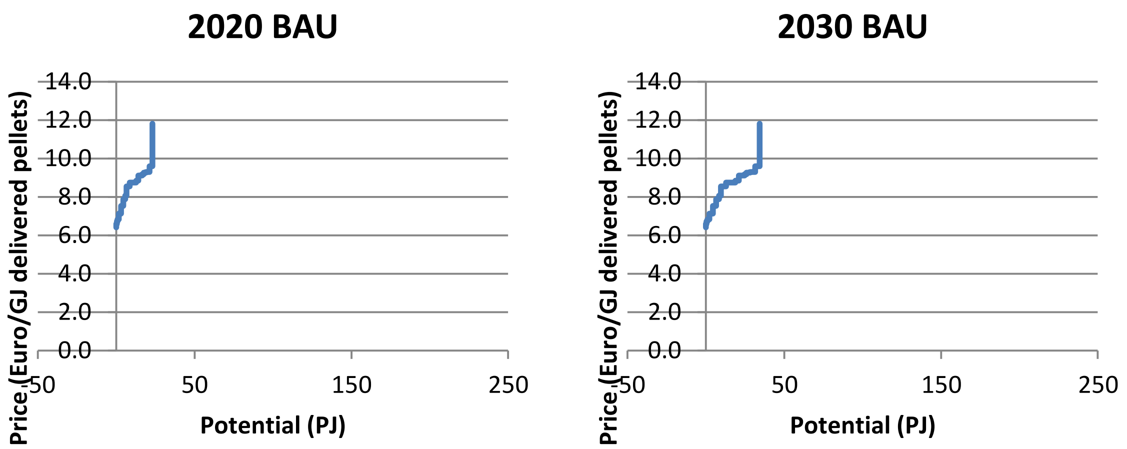

Figure 27 - Cost Supply Curve BAU – 2020 & 2030

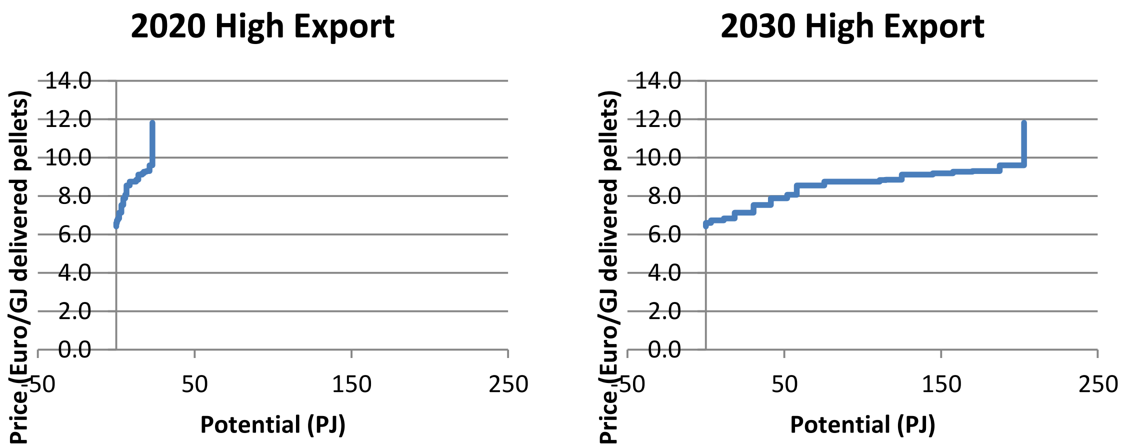

Figure 28 – Cost Supply Curve HE – 2020 & 2030

Comparing these price estimates to spot prices of biomass imported into Europe shows that the entire potential from Ukraine, if available for the calculated prices, would be able to compete with currently imported biomass. A cif ARA spot price of 179.32 $/ton translates to 10.1 €/GJ, which is higher than the available potential in 2030 from the Ukraine would cost.

The entire net export potential from Ukraine is made up of agricultural residues. As explained above, forestry residues are assumed to be more expensive. If forestry residues would be available, these would range from €8.5/GJ to €11.8/GJ, which means that only part of this potential could be cost effectively imported.

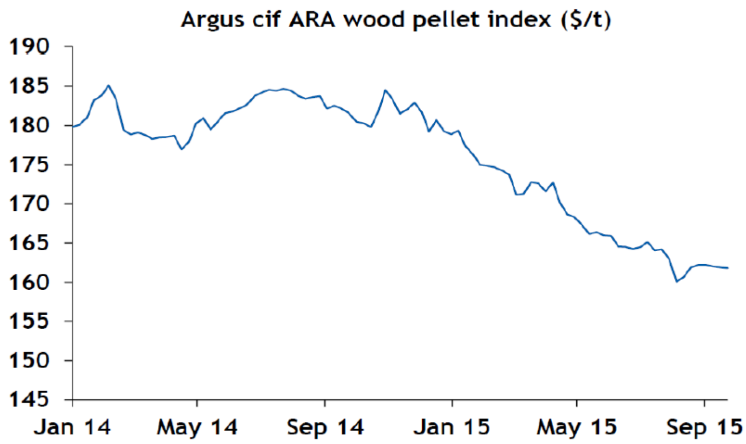

Figure 29 - Spot prices of imported wood pellets into Europe (Dell, 2015)

6.2 GHG emission savings

One of the sustainability criteria important for residue use for pellet production is the total (direct) greenhouse gas emissions across the supply chain. Greenhouse gas emissions are calculated based on the same characteristics of the pellet production cost. GHG emissions of transport are, just as the cost, taken from the BIT-UU model.
In this case the GHG emissions are given for the three different import countries that are analysed. This in order to avoid underestimating the GHG emissions. Other mechanisms except cost will most likely also influence the export of pellets to a certain country. Therefore it is important to take into account the GHG emissions of pellet export to the different countries.

The below figure 34 shows the GHG supply Curve for Ukraine in the 2020 BAU scenario. The GHG emissions per Oblast and type of feedstock do not differ between the different scenarios, what does differ is the total potential of residues.

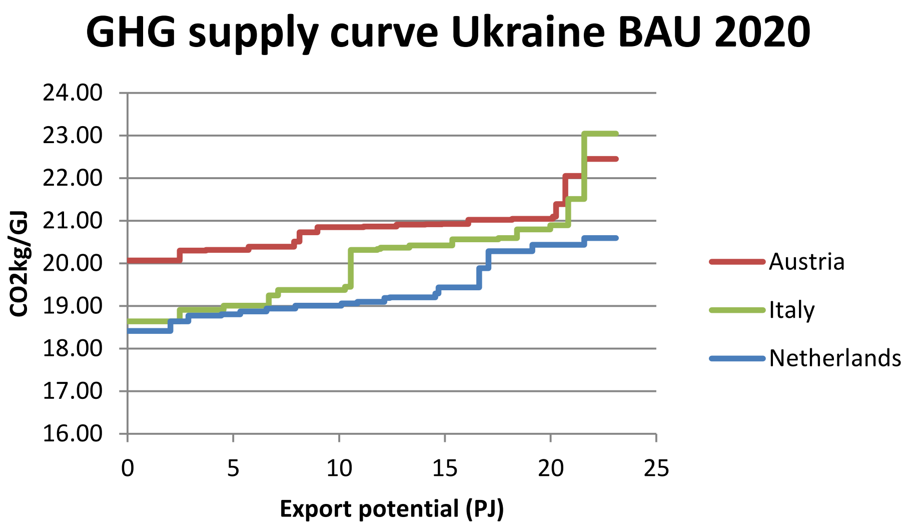

Figure 30 - Cost Supply Curve Business as Usual scenario (2020)

As can be seen in the below tables, the entire potential meets the EU criterion for liquid biofuels of 35% greenhouse gas savings of at least 35% in comparison to fossil fuels. This criterion will increase to 50% in 2017 and 60% in 2018, still the potential from Ukraine would meet these targets(European Commission, n.d.). The expectation is that the same criteria will be applied in the future for solid fuels.

The differences between the three countries are due to additional train, truck and inland waterway transport required to transport the pellets to Austria or Italy. The slight differences between the feedstocks are due to the different nutrient substitution requirements. The assumption is made that nitrogen, potassium and phosphorus that are withdrawn from the soils are replenished by applying fertilizers. Since the nutrient content of residues varies, the amount of fertilizer needed to replenish residue extraction also varies. Tables 12 to 14 show the exact GHG emisisons of pellet export of pellets produced from agricultural residues, as well as GHG emissions savings compared to the use of FT-diesel and electricity generation.

Table 12 - GHG emissions of pellet delivered from Brazil to Austria

Austria	**GHG emissions of pellet export(g CO2-eq/MJ)**	**GHG emission savings**	
		FT-diesel (NGCC)	**Electricity generation**
Sugarcane	20.94	84%	89%
Soybean	20.81	84%	89%
Corn	20.89	84%	89%
Rice	20.85	84%	89%
Forest	20.86	84%	89%

Table 13 - GHG emissions of pellet delivered from Brazil to Italy

Italy	**GHG emissions of pellet export (g CO2-eq/MJ)**	**GHG emission savings**	
		FT-diesel (NGCC)	**Electricity generation**
Sugarcane	20.06	85%	90%
Soybean	20.05	85%	90%
Corn	20.05	85%	90%
Rice	19.98	85%	90%
Forest	20.10	85%	90%

Table 14 - GHG emissions of pellet delivered from Brazil to the Netherlands

Netherlands	GHG emissions of pellet export (g CO2-eq/MJ)	GHG emission savings	
		FT-diesel (NGCC)	Electricity generation
Sugarcane	19.30	85%	90%
Soybean	19.40	85%	90%
Corn	19.26	85%	90%
Rice	19.36	85%	90%
Forest	19.27	85%	90%

6.3 Uncertainties

This study however found that the availability of pellet plants to convert residues into suitable bioenergy carriers for export is greatly limiting the potential. The current potential is reduced to only 22 PJ. When using a very optimistic growth rate, modelled assuming the growth of pellet capacity in the US, this potential might increase to 135 PJ in 2030. If Business As Usual capacity of pellet production is continued, the potential would be reduced to 61 PJ.
Better data about available pre-treatment capacity is needed to more accurately calculate production capacity of solid biofuels. Local experts mentioned that capacity in Ukraine is a lot larger than shown in reports, however this additional capacity is in the form of small scale installations using very old equipment designed for local use of pellets. The question is whether this capacity should be included or whether the conclusion can be made that this capacity would not meet standards for export.
Furthermore the development of pellet plant capacity is highly uncertain. A study into market developments in Ukraine, as well as drivers and barriers for installing pellet plants is recommended to better understand the possible development of the pellet market in Ukraine.

An issue that could further reduce the potential for export is the use of biomass domestically. Ukraine is currently heavily dependant on gas supply from Russia. The political conflict with this country could push Ukraine towards increased utilization of its own resources, including lignocellulosic biomass. In case that Ukraine is interested in lignocellulosic pellet for domestic uses, this development could mean that pellet plant capacity is built at increased rates, but also that less pellets are available for export to other countries.
An aspect which is not yet taken into account in this report is the potential to use agricultural residues for second generation ethanol production. Under certain circumstances, for instance vast increasing fuel prices, there could be sufficient incentive to invest in this technology in Ukraine. Use of residues for ethanol would mean that there is increased competition for the use of residues, therefore the potential for solid biofuels could be lowered.

Another aspect that is insufficiently covered in this case study is the mobilisation of residues. Forest residues are currently not included in the potential since these are in practice not mobilized and there seems to be little incentive to change this. However, if demand for residues greatly increases, for instance due to the abovementioned political situation or as a result of increased local demand, this could change. On the other hand, a share of the agricultural potential could be difficult to mobilise since the quality of the road network limits accessibility of certain areas. Especially during certain weather conditions, such as wet and cold weather, some dirt roads will become inaccessible.

Another insecurity is the issue of agricultural residue in pellet plants. Currently pellet plants are designed for the pre-treatment of woody residues, changing to agricultural residues could mean that pellet plants need to be redesigned. Whether this will happen and what kind of impact this would have on the cost needs to be investigated. The assumption is made in this report that pellet plant capacity will be used for agricultural residues, in reality this could be a mix of agricultural residues, forestry residues and potentially even energy crops. Whether there will be any investments in large scale energy crops in Ukraine also highly depends on the attractiveness of producing biofuels. More data is needed about scenario's that determine the competitiveness of specific types of biomass based energy carriers.

7. Conclusion

There is a large potential of agricultural and forestry residues in Ukraine available for use as bioenergy carrier. Ukraine is one of the largest producers of grain crops in the world, due to the fertile soils, favourable climate and large availability of agricultural land. At the moment residues are hardly utilized for energy generation, and therefore could be available for export. The use of agricultural and forestry residues for pellet production could offer a sustainable potential of 533 PJ.

This study however found that the availability of pellet plants to convert residues into suitable bioenergy carriers for export is greatly limiting the potential. The sustainable potential is reduced to only 18 PJ in the current scenario. This potential is entirely made up of agricultural residues since there is no potential for energy crops yet in the current scenario and forestry residues are not harvested at the moment. In the 2020 scenarios pellet export could increase to 32 PJ in the BAU scenario and 69 PJ in the HE scenario. There is no difference between the BAU and the HE potential since the assumption is made that pellet capacity will grow linearly in both scenarios until 2020. In the 2030 BAU scenario the export potential increases to 34 PJ, following the linear increase in capacity. In the HE scenario the assumption is made that pellet plant capacity will grow exponentially following the growth curves in the US, resulting in a potential of 203 PJ.

The cost of pellet production in Ukraine has not been investigated into great detail since reliable data about costs of the different components is missing. Instead the same pellet production cost factor is used for all of the case studies, with the implementation of cost specific factors such as cost of electricity, labour and local transport. Cost calculations using these values resulted in a range between €6.6/ GJ and €9.6/ GJ. Comparing this range with cif ARA spot prices shows that a very large part of the potential of the Ukraine is competitive under the lowest prices in the 2014 – 2015 range, and the whole of the potential is considerable cheaper than the highest prices in the range. This can be explained by the cheap labour and electricity in the Ukraine, as well as low transport prices as a result of the proximity to Europe.

This study has identified a large potential source of lignocellulosic biomass from the Ukraine. Mobilizing this source would contribute to socio-economic developments in Ukraine as well as strengthen the renewable energy sector both in Ukraine as well as in the EU. The lignocellulosic biomass from Ukraine could play an important role in meeting the EU renewable energy targets. On the other hand a developed bioenergy sector in the Ukraine could help the country meet its targets to be self sufficient in terms of energy supply.

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7. Appendix A

	Barley kton	Maize kton	Rapeseed kton	Sunflower kton	Wheat kton	Barley TJ	Maize TJ	Rapeseed TJ	Sunflower TJ	Wheat TJ
Autonomous Republic of Crimea	167	114	30	208	351	2271	866	429	1186	4668
Vinnytsya	378	3621	442	964	1521	5141	27520	6321	5495	20229
Volyn	74	227	138	3	476	1006	1725	1973	17	6331
Dnipropetrovsk	449	1710	291	2228	1769	6106	12996	4161	12700	23528
Donetsk	320	466	26	1479	1387	4352	3542	372	8430	18447
Zhytomyr	63	2037	116	198	327	857	15481	1659	1129	4349
Zakarpattya	9	244	3	18	115	122	1854	43	103	1530
Zaporizhya	316	226	129	1750	1481	4298	1718	1845	9975	19697
Ivano-Frankivsk	60	453	116	38	219	816	3443	1659	217	2913
Kyiv	206	2824	208	564	827	2802	21462	2974	3215	10999
Kirovohrad	363	2799	227	2335	1115	4937	21272	3246	13310	14830
Luhansk	105	449	3	1215	706	1428	3412	43	6926	9390
Lviv	107	511	277	35	588	1455	3884	3961	200	7820
Mykolayiv	603	954	175	1786	1208	8201	7250	2503	10180	16066
Odesa	873	1048	353	1477	1634	11873	7965	5048	8419	21732
Poltava	263	5306	87	1386	1151	3577	40326	1244	7900	15308
Rivne	115	669	116	8	344	1564	5084	1659	46	4575
Sumy	137	3136	126	796	865	1863	23834	1802	4537	11505
Ternopil	227	1568	281	57	693	3087	11917	4018	325	9217
Kharkiv	357	2086	57	2124	2027	4855	15854	815	12107	26959
Kherson	263	489	180	678	875	3577	3716	2574	3865	11638
Khmelnytskiy	250	2373	320	146	828	3400	18035	4576	832	11012
Cherkasy	238	3462	316	926	1063	3237	26311	4519	5278	14138
Chernivtsi	39	529	54	32	164	530	4020	772	182	2181
Chernihiv	67	2932	165	544	548	911	22283	2360	3101	7288
Sevastopol	1	0	0	0	0	14	0	0	0	0

Technical potential – based on agricultural production, RPR, LHV

	Sust rate	Barley kton	Maize kton	Rapeseed kton	Sunflower kton	Wheat kton	Barley TJ	Maize TJ	Rapeseed TJ	Sunflower TJ	Wheat TJ
Autonomous Republic of Crimea	0%	0	0	0	0	0	0	0	0	0	0
Vinnytsya	57%	215	2064	252	549	867	2930	15686	3603	3132	11531
Volyn	36%	27	82	50	1	171	362	621	710	6	2279
Dnipropetrovsk	94%	422	1607	274	2094	1663	5740	12216	3912	11938	22116
Donetsk	100%	320	466	26	1479	1387	4352	3542	372	8430	18447
Zhytomyr	82%	52	1670	95	162	268	703	12695	1360	925	3566
Zakarpattya	0%	0	0	0	0	0	0	0	0	0	0
Zaporizhya	0%	0	0	0	0	0	0	0	0	0	0
Ivano-Frankivsk	0%	0	0	0	0	0	0	0	0	0	0
Kyiv	83%	171	2344	173	468	686	2325	17814	2469	2668	9129
Kirovohrad	100%	363	2799	227	2335	1115	4937	21272	3246	13310	14830
Luhansk	100%	105	449	3	1215	706	1428	3412	43	6926	9390
Lviv	0%	0	0	0	0	0	0	0	0	0	0
Mykolayiv	26%	157	248	46	464	314	2132	1885	651	2647	4177
Odesa	0%	0	0	0	0	0	0	0	0	0	0
Poltava	100%	263	5306	87	1386	1151	3577	40326	1244	7900	15308
Rivne	2%	2	13	2	0	7	31	102	33	1	92
Sumy	100%	137	3136	126	796	865	1863	23834	1802	4537	11505
Ternopil	13%	30	204	37	7	90	401	1549	522	42	1198
Kharkiv	100%	357	2086	57	2124	2027	4855	15854	815	12107	26959
Kherson	0%	0	0	0	0	0	0	0	0	0	0
Khmelnytskiy	78%	195	1851	250	114	646	2652	14067	3569	649	8590
Cherkasy	100%	238	3462	316	926	1063	3237	26311	4519	5278	14138
Chernivtsi	0%	0	0	0	0	0	0	0	0	0	0
Chernihiv	66%	44	1935	109	359	362	601	14707	1557	2047	4810
Sevastopol	0%	0	0	0	0	0	0	0	0	0	0

Sustainable potential – based on sustainable removal rate

Appendix B

Oblast	Removal rate BAU	Removal rate HE
Autonomous Republic of Crimea	30	
Vinnytsya	87	
Volyn	66	
Dnipropetrovsk	100	
Donetsk	100	
Zhytomyr	100	
Zakarpattya	0	
Zaporizhya	0	
Ivano-Frankivsk	0	
Kyiv	100	
Kirovohrad	100	
Luhansk	100	
Lviv	0	
Mykolayiv	56	
Odesa	0	
Poltava	100	
Rivne	32	
Sumy	100	
Ternopil	43	
Kharkiv	100	
Kherson	0	
Khmelnytskiy	100	
Cherkasy	100	
Chernivtsi	0	
Chernihiv	96	
Sevastopol	0	

Sustainable potential of wheat residues per oblast.

Appendix C

Autonomous Republic of Crimea	64%
Vinnytsya	74%
Volyn	69%
Dnipropetrovsk	72%
Donetsk	74%
Zhytomyr	74%
Zakarpattya	56%
Zaporizhya	72%
Ivano-Frankivsk	64%
Kyiv	74%
Kirovohrad	75%
Luhansk	62%
Lviv	70%
Mykolayiv	74%
Odesa	74%
Poltava	75%
Rivne	70%
Sumy	75%
Ternopil	71%
Kharkiv	74%
Kherson	68%
Khmelnytskiy	75%
Cherkasy	75%
Chernivtsi	66%
Chernihiv	75%
Sevastopol	50%

Suitability rates for forest residue removal

BioTrade2020+
www.BioTrade2020plus.eu

Appendix D

	scale	medium	large	large - wood chips
Plant characteristics				
Size	kton/yr	40.000	120.000	120.000
Pellet production rate	t/h	5	15	15
Lifetime	yrs	17,5	17,5	17,5
CCR		0,12	0,12	0,12
Capital cost				
CAPEX	M€	3,74	9,18	11,29
operation & Maintenance cost	% percentage of total i	1%	1%	1%
Other cost	% percentage of total i	3%	3%	3%
Operational details				
Labour requirement	FTE	5,75	5,75	5,75
	h/yr	16790	16790	16790
Energy-e	kW	570	1617	1900
	MWh/yr	4556	12934	15200
	kWh/t pellets ar	114	108	127
Energy-h	kWh/tev.w.	1.200	1.000	1.000
Boiler efficiency		90%	90%	90%
Consumables	€ / t ad	9	9	9

Variables	**Feedstock characteristics**				
	Cal. value	MJ / kg ar (LHV)	10,80	10,80	10,80
	Moisture content (fresh)	wt.% (w.b.)	50%	50%	50%
	Moisture content (dry)	wt.% (w.b.)	8,5%	8,5%	8,5%
	Cal. Value after drying	MJ / kg ar (LHV)	16,00	16,00	16,00
Variables	**Plant characteristics**				
	Interest rate		0,10	0,10	0,10
	Operating hours	h	7000	7000	7000
Variables	**Input costs - land factors**	Ukraine			
	Electricity price	€ /MWh	14,49	14,49	14,49
	Labour	€ /h	1,81	1,81	1,81
	Transport cost (truck)	€ /km/t	0,04	0,04	0,04
	Transport cost (train)	€ /km/t	0,01	0,01	0,01
	Harbor cost	€ /t	0,37	0,37	0,37
	Profit	%	10%	10%	10%
Agricultural residues	Pre-processing cost	€ /t field site	12,08	12,08	12,08
	Transport to pellet plant	€ /t ar delivered	2,15	2,15	2,15
Forest residues	Pre-processing cost	€ /t field site	20,04	20,04	20,04
	Transport to pellet plant	€ /t ar delivered	4,30	4,30	4,30
Energy crops	Pre-processing cost	€ /t field site	12,08	12,08	12,08
	Transport to pellet plant	€ /t ar delivered	2,15	2,15	2,15