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Economics of energy processing of wastes of agricultural and food production

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled “Economics of energy processing of wastes of agricultural and food production” independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In 23.04.2019

Tornike Toradze

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Abstract

The aim of the thesis was to analyse the potential of underutilised agricultural biomass waste in the region of Imereti in Georgia and to assess economic impact of creating a biomass processing plant. Data on availability of biomass resources, costs of processing and prices were collected in the study region in September 2017. Data confirmed that there is sufficient number of agricultural residues in the region for initiating the production. Accounting method was selected for assessing the competitiveness of the briquettes from waste biomass. Based on heat value of the briquettes, cost per heat unit in Gigajoule (GJ) was calculated. For comparison and determination of cost efficiency, we generated costs of thermal energy from fossil sources (natural gas, electric energy and coal). Final step was comparison of the price of an estimated heating value of these briquettes to the price of thermal energy received from fossil sources. The analysis of cost efficiency showed that cost of thermal energy of briquettes produced from waste biomass can be competitive in comparison with cost of thermal energy of other energy sources on the market. In addition, couple simulations were done, that showed the most important factors affecting efficiency and competitiveness of production: first, distance between the source of waste biomass and the place of pressing of briquettes, second, number of the workers involved.

Key words: Biomass, Energy, Economics, Quantitative methods.

Table of Contents

List of tables

List of figures

List of the abbreviations used in the thesis

Association Peaceful and Business Caucasus (APBC)

Carbon dioxide (CO2)

Czech Koruna (CZK)

Energy Information Administration of United States (EIA U.S.)

European Union (EU)

Food and Agriculture Organization (FAO)

Gigajoule (GJ)

Kilowatt (kW)

Kilowatt hour (kWh)

Million Tonnes of Oil Equivalent (Mtoe)

Renewable energy (RE)

United Nations (UN)

United Nations Development Programme (UNDP)

United States of America (USA)

1. Introduction and Literature Review

1.1. Introduction

Energy availability is the basic and at the same time key factor of modem economic and social development. As world economy and population grow, world energy consumption is increasing. It implies that solving the energy problem is critical for enhancing economic development. Traditional fossil energy sources as oil, gas and coal are limited and cause many environmental problems in the world. Moreover, their long-distance transportation is vulnerable to accidents, such as spills at storage facility, breaks of pipelines, sinking tankers etc. particularly it means and the infrastructure are in the poor state. Renewable energy (RE) sources are environmentally safe, have potentially unlimited prospect and diversify energy markets, satiated with fossil fuels, creating environmentally friendly alternatives.

International community demands better energy standards, as world's awareness of the need to protect environment has been increasing. Thus, development and using of RE has become popular in many countries. One of the oldest and most spread form of clean energy is from biomass. It is widely used in the world, because of its cheap price and renewable nature. Currently biomass energy became part of many international programs, policies and strategies.

The main source of heating in rural areas of Georgia is firewood. Its share as fuel ranges between 70-90 % depending on the region. The large-scale exploitation of forests of Georgia for the social purposes, which has been going on for the last 25 years, can soon lead to ecological catastrophe and socio-economic and energy shocks. According to the results of research conducted with forest management structures, annual consumption of firewood is more than twelve times of the annual, optimal amount of spare resources from forest, obtained by the principles of sustainable use. Country is currently in big deficit of firewood (CENN 2016).

In contrast, with increasing demand for biomass fuel, the pellet industries have rapidly developed all over the world. In Georgia, almost all agricultural and wood processing waste is underutilised. The country's current high usage of firewood, gives the ground for starting utilising biomass waste for processing woody biomass briquettes. The establishment of biomass industry can help reduce the impact of wastes on environment, increase cheaper fuel supplies on market, while promoting income generation in rural regions of the country.

1.2. Energy Policy of Georgia

The current policy document from Georgia of the energy sector emphasizes strategic actions directed towards energy security. Alongside with other directions, development of renewable resources is one of the main objectives of the government. Georgia is remarkably rich in hydro-power resources, which together with wind, solar, biomass and geothermal resources, can be used for creation of additional capacity by domestic and foreign investments to form a solid base for future energy supply to support industrial development of the country. It is vital to achieve this goal and to improve investment climate through the following steps:

- Creation of stable, transparent and non-discriminatory legal basis;
- Deepening strong and stable trading relations with neighbouring countries energy markets;
- Development of corresponding domestic and cross-border infrastructure;
- Supporting scientific research and development activities;

Following the above-mentioned steps should decrease dependence on imported energy and increase the country's energy security level. With the aim of achieving deeper economic and political relationships, gradual approximation of Georgian legislation with legislation of European Union (EU) is important. Part of this is utilization of RE resources and facilitation of energy efficiency oriented activities in the country through economically and ecologically feasible means ("Ministry of Energy of Georgia" 2019).

1.3. Literature Review

1.3.1. Need for renewable energy

Energy is driving force of the modern society and an essential aspect of the majority of industrial activities and transportations ("Biomass - European Commission" 2018). Therefore, energy helps to ensure a long-term and uninterrupted run of all economic processes (Stosic-Mihajlovic & Trajkovic 2018).

In the recent times, the world started facing a challenge of finding a balance between protecting the environment, satisfying business needs and creating more energy sources (Brożyna et al. 2017). As the world population and global economy continue to grow, so does the needs for more energy. The rise in demand can be seen by analysing energy consumption figures in recent years. In 2016, global energy consumption hit 13,761 Mtoe. In 2017, consumption grew by 2.1 % what was the fastest increase in the past years (IEA: International Energy Agency 2018).

Along with the need for more energy, as seen through the rising consumption data, there is also a definite need for finding more environmentally friendly energy sources. All due to the fact that the traditional sources like oil, gas and coal are negatively affecting the global environment. However, the main detriment from the list is carbon pollution, since carbon dioxide (CO2) emissions coming from fossil sources are one of the main reasons behind environmental problems that negatively affect different global issues like the climate change (Wuebbles et al. 2002). Alarmingly, in 2016, the carbon emissions hit all time high, reaching 32.5 gigatons (IEA: International Energy Agency 2018).

Additionally, the traditional sources of energy like coal, oil and natural gas are non-renewable and therefore, finite energy. According to Shafiee & Topal (2009), the world reserves for oil, natural gas and coal are limited and are estimated to run out in approximately 40, 70 and 200 years (respectively). Since the traditional energy sources are limited and have devastating impact on the environment, there is an emerging need of producing energy from renewable sources, which are sustainable with lowered emissions in a diversified energy systems.

In the 2014, United Nation (UN) general assembly announced a start point for the “Decade of Sustainable Energy for All”, which was a call for a coherent, integrated approach to energy issues across the global energy agenda (UN. Secretary-General 2015). Brown & Huntington (2008), indicated that REs have positive impact on energy safety. As most of the states are depending on energy import, diversifying sources, including REs would be a possible a part of the solution for countries with sufficient reserves of biomass. Therefore, international and national policies are seen as the main factors that helped to push the process of increasing the RE production, aimed to improve energy security, promote economic growth and most importantly, protect the climate (Benedek et al. 2018).

The EU has shown its deep consideration of the issue through its “Renewable Energy Directive”, published in 2016, for promotion and manufacturing of RE. The directive’s goal for 2020 is to replace 20 % of all energy consumption from non-renewable by RE sources. This will be achieved by specific targets for each member country. Correspondingly, the publication also states that minimum 10 % of transport fuel should come from renewable sources by 2020 (Pacesila et al. 2016).

In the figure 1 the estimated renewable share of total energy consumption of the world is showed for year 2016, which tells that the RE accounted for about 18.2 % of total energy consumption in the world (REN 21 2018).

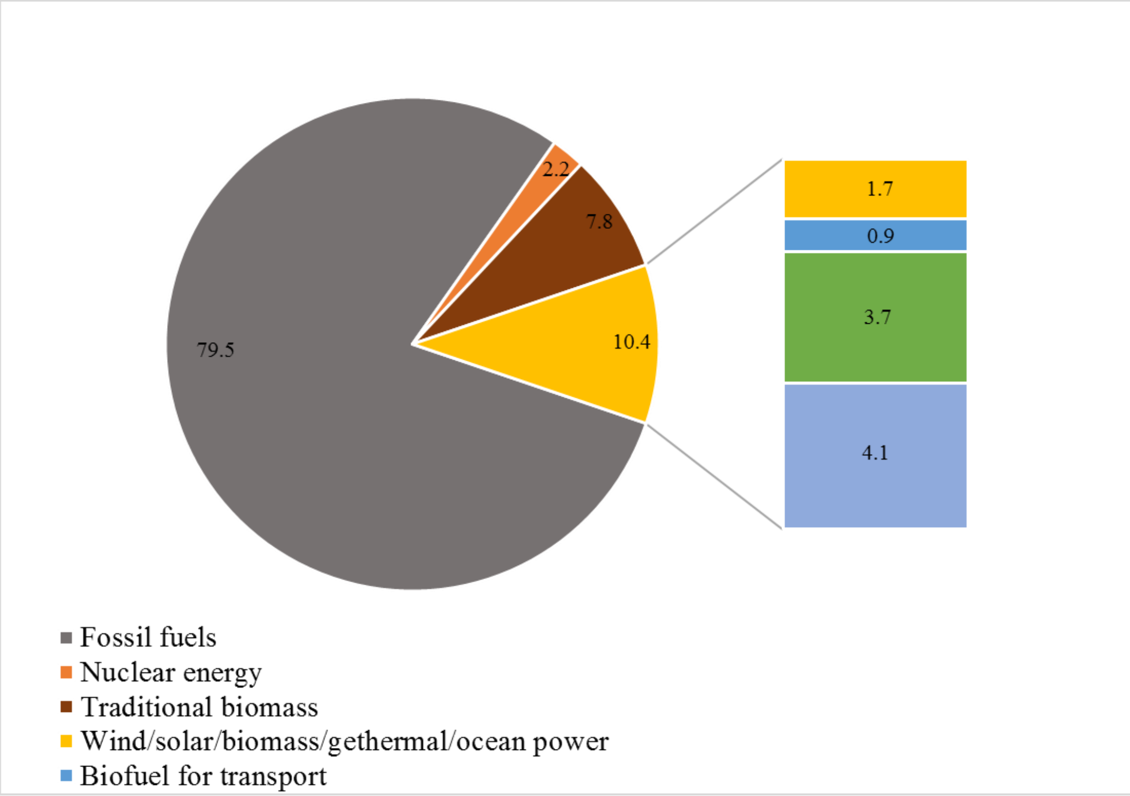


Figure 1. Estimated Renewable Share of Total Final Energy Consumption 2016.

(Source: REN 21 2018)

1.3.2. Using biomass as a direction of renewable energy

RE sources are those which occur naturally and, unlike fossil fuels, are theoretically inexhaustible. According to EIA U.S. Energy Information Administration n.d. (2018), main types of renewable energies are: biomass, which itself consists of: wood and wood waste, municipal solid waste, landfill gas and biogas, ethanol and biodiesel; hydropower; geothermal; wind and solar energies. Biomass is: "organic material of non-fossil origin, including organic waste - can be converted into bioenergy through combustion, either directly or via derived products." (Eurostat 2018)

One of the initial energy sources used by humans was biomass. So far it is largest RE source in the world (Zhang et al. 2014). Over thousand years, biomass has been used for energy and still, it is the primary energy source in many countries and regions, such as, Bhutan 86 %, Nepal 97 %, Asia 16 %, East Sahelian Africa 81 %. The main use of biomass energy in these countries is firewood for cooking and heating (Hoogwijk et al. 2005). Biomass is core supply of energy for more than half of the planet (Parikka 2004; Sims 2000). Annually around 4 billion cubic meter firewood is burned, half of it mostly for heating and cooking, in developing countries (Balat et al. 2006). According Ruppert et al. (2013), core resource of bioenergy is wood, agriculture supplies and wastes. White (2010) suggests, with current prediction of future, considering climate change and increase use of RE, forest and agriculture resources will be used more.

From total of 18.2 % RE, biomass energy contributed an estimated 12.8 % (including the traditional use of biomass) to total final energy consumption in 2016. The traditional use of biomass for heat is the burning of woody biomass or charcoal as well as dung and other agricultural residues in simple and inefficient devices. On the other hand, modern bioenergy (excluding the traditional use of biomass) contributed to 5 % of final energy consumption. Modern bioenergy transforms energy into electricity (REN 21 2018). Finally, Woody biomass contributed to 67 % in bioenergy mix (Bilgen et al. 2015).

Biomass energy can be essential and sustainable substitute in future energy needs. Reasons for increased interest in bioenergy is caused by variety of different factors. For example, according to Demirbas et al. (2009) it helps with decreasing poverty in developing countries, eliminating the need for pricey energy transformations to satisfy energy demand. Additionally, bio-energy could be used in different forms such as: heat, electricity, liquid and gas. Furthermore Bhattacharya et al. (2003) also highlight the fact that biomass is carbon neutral since the absorbed CO2 returns back to the atmosphere once the biomass is burned.

Considering the possible applications from economic and technical perspectives, bioenergy is ahead of current RE sources. “Bioenergy is a good option for energy security, climate change, and poverty reduction; the intersection of three great challenges of the world” (Bilgen et al. 2015). Diversifying energy sources can help to improve the political and environmental settings, since it can contribute to employment in rural areas, expand agricultural economy, and will thus, reduce poverty in developing countries (Demirbas et al. 2009). Moreover, bioenergy can be also considered as a leverage for energy importing countries against nations exporting fossil fuels (McCarl et al. 2010).

Katsaprakakis & Christakis (2016) indicate that factors like poorly planned projects, not readiness of regional communities, lack of general support, environmental constraints and insufficient RE potential surveys are the main reasons for unsuccessful project initiatives. Bai et al. (2016) recommend establishing pilot projects, where the sample project can be tested economically to ensure the achievement of highest economic impact in the region. Yin et al. (2004) underline some biomass technical characteristics as potential disadvantages due to high level of moisture, logistic costs and problems with crashers.

Despite massive contribution of woody biomass in bioenergy mix, its current consumption is below its full potential. Although, in 2050, the biomass energy is expected to cover 10–40 % of primary energy consumption of the world among all of the resources used in energy production (Haberl et al. 2010). There are many different researches done on the potential input of biomass as renewable replacement for traditional energy sources. McKendry (2002) claims that woody biomass is possibly the best primary direction for profitmaking energy production in the future.

1.3.3. The use of biomass waste – an efficient option

The technical potential of biomass energy is based on the geographical potential and the conversion technology efficiency (Hoogwijk et al. 2005). Geographic possibility plays one of the primary roles in choosing the source of biomass. Agricultural residues, such as cotton stalks, wheat and rice straws, grape branches and hazelnut shells, are all considered as biomass material. In developing countries, there are large numbers of vastly underutilized agricultural by-products. (Demirbaş 2001;

Parikka 2004) estimated that almost 60 % of harvested tree mass stays in forest thus, making logging residues important source of biomass. Moreover, based on Food and Agriculture Organization (FAO) research, 40-55 % of sawmill and plywood industry inputs end up in waste. Baxter (2005) endorses woody biomass and coal cofiring for its cheap cost, fast development and low risk.

Policy makers got interested with biomass energy potential, due to the massive amount of unexploited woody biomass resources and positive environmental effects (Lauri et al. 2014). Romallosa & Kraft (2017) describe how biomass wastes are well recognized for fulfilling needs of small-scale community demands. Likewise, the authors saw biomass wastes as a potentially attractive source for both big and medium scale productions. In his work Bajwa et al. (2018) focuses attention mainly on wastes and litres as feedstock. He writes : “These sources are not subject to “food or fuel” conflicts and trade-offs that beset many purposes of grown biomass feedstocks.” Chen et al. (2009) also describes benefits of bioenergy from agricultural waste that can be used as a source of sustainable and clean energy for countryside, which can also boost industrial development of agronomy and limit pollution risks of ecology, while increasing economic development and income in rural areas.

To summarize, using biomass waste as main input resource has several positive economic and environmental factors:

- Given how many companies in developing countries often dump their wastes in nature, using biomass waste will help wood processing factories to avoid sanctions and/or penalties for pollution, while additionally providing an option to dispose of waste easily and helping them to cut their cost for managing waste.
- For energy producers, it can be a cheap raw material for creating energy which is carbon neutral and does not harm nature.
- For general environment, as it will avoid unethical dumping of waste in rivers and forests, thus polluting environment.

1.3.4. General overview of technologies

Biomass energy can be found in three different states - liquid, solid and gas. The liquid state can be seen in the form of fuel, ready to be used straight away in transportation or in electric power generation. Solid and gaseous types are mostly consumed for electrical or heat energy.

Biomass resources include primary, secondary, and tertiary sources. Primary biomass resources are produced by photosynthesis and are taken directly from the land. Thus, they include woody crops, herbaceous crops, agricultural residues and forest trees. Secondary biomass resources result from the processing of primary biomass resources either physically, chemically, or biologically. Tertiary biomass resources are post-consumer residue streams including animal fats and greases, used vegetable oils, packaging wastes, and construction, demolition debris (Ashter & Ashter 2018).

Mckendry (2002) mentioned following aspects that effects the decisions when choosing conversion process: the type and amount of biomass feedstock, choosing between the desired form of the energy, financial budget for the given process, environmental standards and other specific factors of the project. One of the simplest methods of creating biofuel from biomass is through densification. The densification process has been around since ancient times and there are different methods used to produce densified biomass which can be seen in the form pellets and/or briquettes. In the figure 2 and 3 you can see examples of densified biomass products.

Figure 2. Pellets.

Figure 3. Briquettes.

(Source:“www.endswasteandbioenergy.com” 2019)

(Source:“www.cumbriaecofuels.co.uk” 2019)

The densification procedure means putting biomass residues and/or wastes into special machinery and using mechanical force to press it into a solid form. Aim of densification is to raise volumetric energy density to help reduce moisture, logistic costs and make waste simple for storage and handling (Chen et al. 2015). There are several important factors determining quality of pellets and briquets. This includes: fibre sources, moisture content, particle size, temperature, biomass feed rate, die size and shape and speed of compacting and die temperature (Manickam et al. 2006). Compared to woody residues, agricultural waste has different physio-chemical characteristics such as moisture and ash content and flow characteristics, which may complicate treating and burning (Chen et al. 2009).

1.3.5. Economic benefits and costs

The benefits of using biomass for energy include the impact on local and regional economy which can serve as another motivation for promotion of biomass for production of bioenergy. There have been many different researches done on economic evaluation of processing biomass. Some are focused on biomass input source, physical distribution of resources, size of production plant.

Sultana & Kumar (2012) analysed natural and economic leverage of production of wood, straw, alfalfa, switch grass and poultry litter pellets, and concluded that wood pellets have better technical and environmental aspects. Therefore, the wood pellets graded first, after switch grass. With regards to economic model, wood pellets were second and switch grass first.

In his paper, Kebede et al. (2013) used Input Output Table approach to assess 4 different wood pellet plants in forest based districts in Alabama, USA. Research implicated that the influence of forest residue consumption increased with relation to size of the plant. It showed multiplier effect on economy, on forest services, retail stores, health services and taxes for government. Additionally, it reduced utilization of fossil fuels and created sustainable employment and boost of local economy.

Techno-economic appraisal of wheat straw densification and biofuel production, was done by (Mupondwa et al. 2012). The research showed that bailing has significant economic benefits for densification and following transportation. However, distance from source to production plant found to be crucial, as transportation costs raise significantly when distance reached more than 250 km.

Portugal-Pereira et al. (2015) emphasize positive economic effect of using agricultural residues for bioenergy production, as distribution of resources locally will be easier and will bring stimulus to economy. For developing local biomass production plant, Benedek et al. (2018) lists different advantages. The author stresses that the plant can boost local entrepreneurship, raise local income, bring energy stability, cooperation and generate new jobs.

In the figure 4 you can see the estimated number of jobs created globally within renewable energy sector in 2017. With more than three million jobs created, biomass is second biggest RE industry after solar power (REN 21 2018).

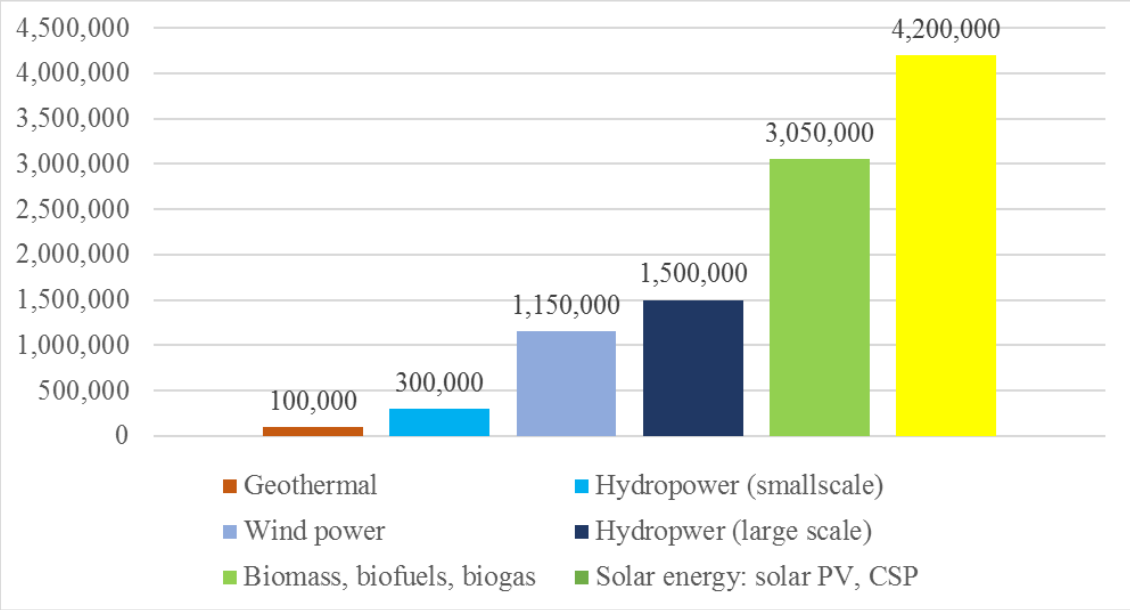


Figure 4. Jobs in Renewable Energy sector.

(Source: (REN 21 2018)

2. Aims of the Thesis

The aim of the thesis is to analyse the potential of underutilised agricultural production waste in the region of Imereti, Georgia and to assess competitiveness and efficiency of biomass products as briquettes. This overall goal is translated in 5 specific objectives.

Specific objectives are:

- Identify available biomass resources in Imereti region.
- Estimate machinery cost for solid biomass production: select technology options.
- Calculate production costs.
- Compare with current fossil energy sources and prices.
- Test sensitivity to changes by scenarios.

Hypotheses:

Recycling agricultural and wood processing wastes in biomass briquettes pays off economically in Georgia in spite of relatively low prices of fossil sources of energy.

Obviously, economic viability of recycling biomass waste will support its adoption for the benefit of the environment.

3. Methodology

Before we introduce the methods, we say couple of words about the study region.

3.1. Profile of the Study Site

Region of Imereti (Figure 5) is located in the central part of Georgia. The territory of the region occupies 6518,8 km^2, which amounted for almost 20 % of the country with population of 703,8 thousand people.

Figure 5. Region of Imereti, Georgia.

(Source:“Google Maps” 2019)

Georgia is dependent on imported gas and oil. Initially country depended on imports from Russia which later changed on the import of these products from neighbouring Azerbaijan. Until 2003, the country was experiencing an energy crisis – when electricity, gas and water were available only on schedule. Presently the situation has improved, however, energy prices stays problem for a big part of the population in the regions.

Biomass use in Georgia is inefficient and unsustainable. Wood covers little over 70 % of the demand for energy in countryside. According study of (CENN 2016), in Imereti there are 183,768 households, out of which 120,645 are staying in region all year round. According the data, 93,488 are consumer of firewood. Other than wood, practically no other biomass is used in Georgia.

Association Peaceful and Business Caucasus – APBC is a non-governmental organization founded in 2004, working to support building a peaceful relation between the warring parties in Georgia and the South Caucasus through economic factors. One of the constituent parts of APBC is the Business Incubator - the centre of internship and employment of marginal groups with a focus on environmental technologies. The organization has industrial areas with a total size of 10,500 m^2 and agricultural land with a total area of 5 hectares. The APBC is located in the city of Kutaisi, which is the centre of the Imereti region Georgia.

APBC responded to the unsatisfactory energy situation by conducting the research on available biomass resources in the region. Since conditions in Imereti do not allow for the active use of solar and wind energy, the waste from agricultural activities and the wood-processing industry represents a significant source of potential energy. Gathered data showed sufficient amount of raw material for production of woody pellets from agricultural wastes. Precise details of available resources can be found in chapter 4. The potential of the Imereti region with raw material and focus of the APBC resulted in this feasibility study of energy processing of wastes of agricultural production.

In addition to energy and economic benefits, the conversion of woody type waste can also be great beneficial from the environmental point of view. Virtually none of the 540 Georgian wood-processing plants use sawdust and other waste for further processing. Sawdust is usually dumped into a river or buried in nearby areas. Possibility of using agricultural waste with the help of environmentally friendly technologies may create advantages in the production and use of biofuels in the Imereti region and potentially other regions in the future.

To create a future opportunity, focused on biofuels and address the environmental issues in the region, this study is prerequisite for the possibility of using agricultural waste with the help of environmentally friendly technologies.

3.2. Accounting approach

This thesis uses data from both the secondary and primary sources. A survey of primary data was conducted in Kutaisi. This included mainly interviews with APBC experts and holders of the biomass waste. It helped to gain insights into the subject, extent of resources, capacity of stakeholders, and the overall regional situation. In addition to data on available resources, information on transportation options, costs and approximate wages for the workers were gathered from APBC specialists.

Part of the data was acquired through desk research. Information from similar work on the topic assisted to gain knowledge on the subject and to better structure the data gathering, and afterwards, in formulation of the discussion part of this work. Information from literature review was gathered through online research based on scientific databases such as: Web of Science, Science Direct and Google Scholar. Data on fuel and energy prices and government policy were gathered from official governmental websites, private energy supply companies and the national statistical agency of Georgia. With the assistance of Michel Kolarikova from the Research Institute of Agricultural Engineering in Prague, suitable machinery lines were chosen. Detailed technical information on machinery for grinding and briquetting were gathered online from web pages of manufacturers. Keyword research tools were used to find internet based information. Data was gathered in 2016.

As we stated in Part 2, the thesis aims to evaluate economic potential for use of agricultural waste to produce energy sources in the Imereti region of Georgia. Specifically, the cost of products from biomass energy production are to be compared with present available fossil sources, such as natural gas, diesel, coal, and electricity. In order to achieve our aim, the procedure was divided into several steps. Data gathered from APBC experts provided a good view on available resources in the region. For the assessment in the thesis, waste from agricultural production was chosen. (However, we found that, vast amount of wood processing waste, accumulated in Imereti region too.) Afterward, technical and technological solutions of the project were selected. This step included a survey and choosing appropriate equipment available on the market. Based on available literature and internet resources, requirements and locations, the following pre-processing were identified.

Depending on resources, technological processes for making pellets from agricultural waste slightly differ from each other.

- Sawdust must be first dried and later briquetted or granulated.
- Hazelnut shell can be used directly.
- Laurel, tea bush and waste from pruning vineyards is possible to process in two different ways.
  - By splitting and drying in solar dryers, afterward crushing, granulating.
  - Or by drying on-site, splitting and briquetting after a year.

For any of the above options, the next stage can be either crushing and granulation, or simply briquetting the split material.

In the base model, the following raw materials and processing steps were chosen: Waste from cutting of a tea-plant, vineyards and a branch of a laurel tree, will be dried up on site and after a year shattered to the state suitable for briquetting. Afterwards, raw materials will be transported to the place of briquetting which is the last technological stage of process. Costs of warehousing of chips and briquettes in this model were considered to have no additional charge, as it will be happening on the territory of APBC. In spite of the fact that raw materials are production waste for other businesses, additional costs can emerge if the same producers decide to make a profit as opposed to giving away raw materials for free. In this model, we assume that all three types of raw materials will be available for free and without additional expenses.

In the model calculations were carried out for the expenses connected with investment and operation of the equipment for processing biomass into briquettes (for burning in ordinary furnaces and coppers). Cost calculation scheme is presented in figure 6. Based on calculations of direct costs, at each stage of the technological process, the total direct costs were calculated. Next, indirect expenses were added, that led to the received total costs of 1 ton of briquettes. In this model, indirect expenses were accountable for 10 % of total cost, therefore its value subsequently varies depending on the scenario.

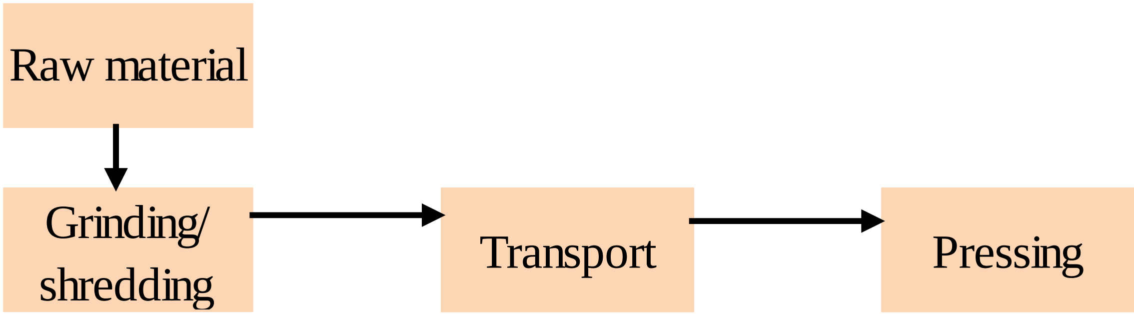


Figure 6. Scheme of cost calculation for processing biomass.

Based on heat value of the briquettes, cost per heat unit in Gigajoule (GJ) was calculated. For comparison and determination of cost efficiency, we generated costs of thermal energy from fossil sources. The final step was a comparison of the cost of an estimated heating value of these briquettes to the cost of thermal energy received from fossil sources (natural gas, electric energy and coal). Figure 7 depicts a scheme of heat cost efficiency comparison. The comparison was carried out in the Georgian Lari (GEL) on 1(GJ) and is based on estimated optimum efficiency of transfer of heat from its source (excluding the costs of equipment). Calculations have rather approximate character and for their further use (especially for practical applications) it is necessary to take into account a way of conversion of energy from a source in the thermal energy and other expenses connected with processing of materials like warehousing, taxation, etc. Expenses and the carried-out comparison do not consider the VAT.

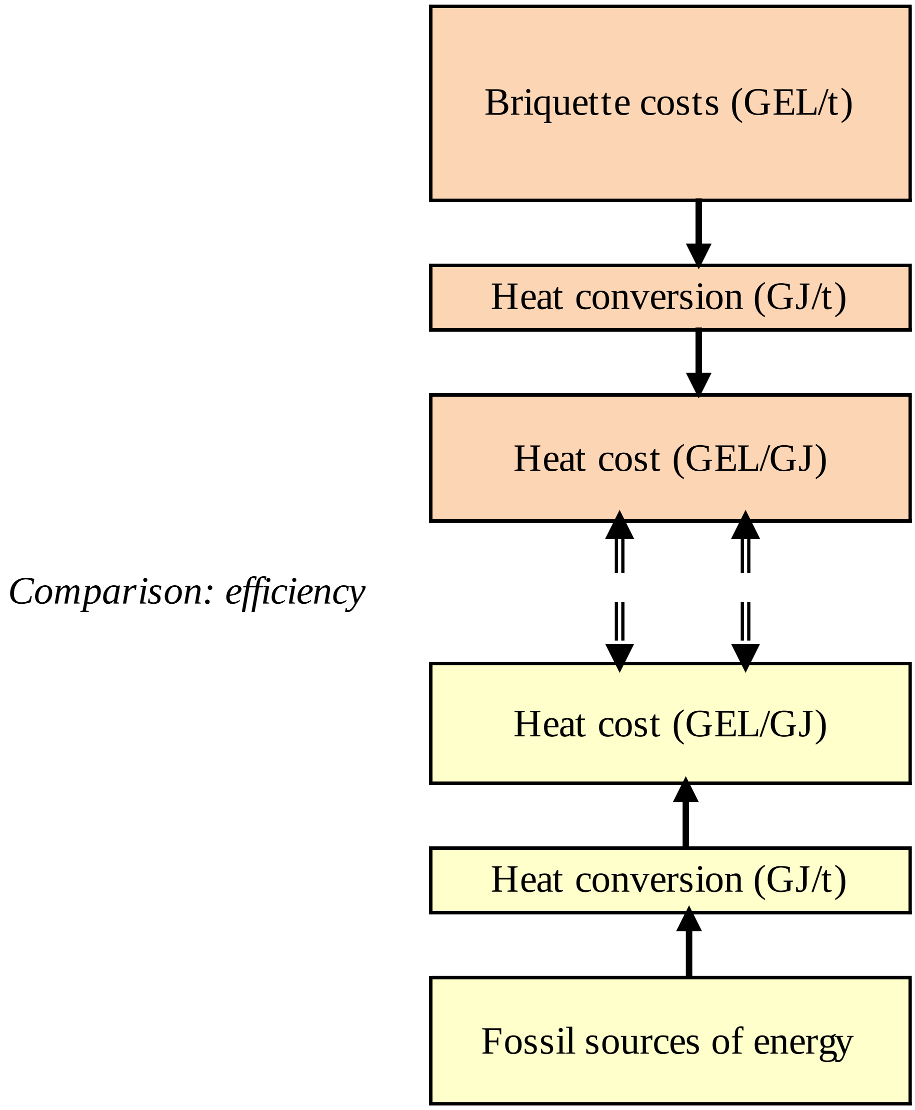


Figure 7. Scheme of Heat Cost efficiency comparison.

The model was made with Microsoft Excel and allowed to consider different types of the equipment, various levels of servicing, changes of exchange rate and the changes in price of energy.

3.3. Simulations

Most of the parameters for calculations were changeable according to scenarios. Nonetheless, some parameters were constant. First, the fundamental assumption was that raw materials would be provided free of charge. Therefore, this was the first constant parameter in all scenarios. The next assumption was that crushing would take place on sites where production of waste biomass (on tea plantations, in vineyards or in the place of processing a laurel tree). The second constant parameter in calculations, were assumptions that crushing will be possible at most 100 days in a year (take into account weather conditions and other types of work in fields and in production). It was assumed that pressing would take place in the room which is specially prepared for this purpose, on the territory of APBC in Kutaisi. Third, the non-changeable criteria in calculations was the distance between raw material and the pressing site: for tea bushes was assumed 20 km, for vineyards – 10 km and for laurel trees – 5 km. The next important assumption was that the press will be used 200 days in a year, out of which 20 days would be allotted for maintenance and repair. This assumption was used in all scenarios therefore, this was our fourth constant. The fifth and last constant parameters was that all machines (crushers and press), would have an estimated term of operation of 10 years, while annual expenses on repair would make up 3 % of the cost.

In calculations, the first variable was the crusher. Four different types of crushers and chipping machines were considered. For a unified form of calculations, machinery working on electric motor was chosen. The offered crushers are rather powerful and process 2-3 tons of biomass an hour. The second variable was means of transportation, there was an option to choose between two types of lorries (small – 3 tons, and big – 20 tons). As the wood, even though shattered, is rather light, it was assumed that the small car would include at most 1.5 tons, and the big car– at most 10 tons. The model considered 4 types of briquetting press from the Czech vendor of Briklis LLP. This was the third variable, changing according to the scenarios. The presses differ in the size and power, however from the technological point of view they are similar. The power consumption of the considered presses range from 4.4 to 16 kilowatt (kW), which corresponds to production between 30-200 kg of briquettes per hour. It was much less, than at crushers therefore it is necessary to synchronize both processes properly. In the model, it was assumed that synchronization is achieved and the equipment does not stand idle. As the cost of machinery was in Czech Korunas (CZK) and calculations done in GEL, 3 different exchange rate were used, CZK/GEL 9.5; 10.5; 11.5. This was fourth variable in the scenarios. In Georgia, energy prices differ for commercial customers and households. As counting was done for small production, both prices were taken into consideration. One of the biggest expenses relates to machinery workers. Therefore, in the calculations it was possible to consider options of a workforce with 1, 1.5, 2 or 2.5 labourers. The fifth and last variable was this parameter.

4. Data

4.1. Energy costs

On table 1 are prices of fossil fuels available on the market in Georgia. There are 2 prices presented wholesale (for commercial use) and retail (private use).

Table 1. Price of Energy.

	Unit Measure	GEL	GEL
The type of energy		Wholesale	Retail
Electricity	Kilowatt hour (kWh)	0.1407	0.21105
Natural gas	m3	0.289373	0.5159
Diesel	1 Litre	0.8911	1.5946
Coal	1000kg	40.5685	50.8865

(Source: "National Statistics Office of Georgia" 2019)

Comparative costs of unit of thermal energy in (GJ) from fossil sources are given in the table 2. We see that expenses are lowest when using natural gas.

Table 2. Costs of unit of thermal energy (GJ) produced by fossil fuel.

	Natural gas	Coal	Diesel	Electricity
Price	GEL / GJ	GEL / GJ	GEL / GJ	GEL / GJ

Retail	8.51	16.23	22.28	43.43
Wholesale	15.17	20.35	39.87	65.14

4.2. Available energy in biomass

The idea of the project is based on a possibility of use of biomass from the territory of Imereti region in Georgia. On the figure 8 you see close view of districts in the region of Imereti and distance from Kutaisi. As mentioned in chapter 3.1 the research of potential amount of raw materials was conducted by APBC experts. Priority was the waste accumulated through agricultural activities.

Figure 8. Map of Districts of Imereti region.

(Source: “Vestnik kavkaza” 2019)

Wood scraps and sawdust

First source is the CRPWOOD wood processing plant in Kutaisi, in the free economic zone, with 800 m3/ residues a year. There are many similar small sources in the region of Imereti, with approximate distance of 10-80 km from APBC. The plant in the territory of the free economic zone is the largest. Other 7 plants produce in total about 1600 m3/ year. The general annual output of scraps and sawdust in Kutaisi is about 3,500 m3, however, about 20-30 % of sawdust is used without processing for heating of production shops, dryers. The rest is not used and lies in the open space, what contributes the environment pollution. In figure 9 and 10 you can see example of wood Scraps and sawdust accordingly. In other municipalities of Imereti like: Vani, Baghdadi, Kharagauli and Sachkhere, about 3,000-3,500 m3 of scraps and sawdust a year is accumulated. In the neighbourhood municipalities of Imereti region Tkibuli and Racha, approximately in 100 km from Kutaisi, it is possible to use about 8,000-9,000 m3 of scraps and sawdust a year. As distance plays, most important role in price creation for raw material, it is recommended to set up small productions on the place of originating the wastes.

Figure 9. Scraps.

(Source:"biomass.ge" 2019)

Figure 10. Sawdust.

(Source:"crpwood.com" 2019)

Hazelnut shell

In Kutaisi in a year about 500 tons of hazelnut shell is produced. However, farmers are selling the shells, for the price of 0.17-0.23 GEL for kg. In other areas of Imereti about 6,000 tons a year is produced. The neighbouring regions (Guria and Samegrelo) produce about 10,000 tones. On the figure 11 you can see example of hazelnut shell. In base model calculations hazelnut shells were not included as it was not provided for free. Future calculations must be done to evaluate its thermal energy price efficiency.

Figure 11. Hazelnut shell.

(Source "georgianhazelnuts.ge" 2019)

Waste of subtropical plants: laurels and tea bushies

In the region of Imereti there are around 3.5 thousand tea plantations located. On the figure 12 and 13 you can see tea plantation and laurel in Imereti. Annual cutting of bushes usually takes places in December or February-March. The total amount is estimated for 10,000 tones a year. The laurels are grown up in the western parts of Georgia on approximately 12,000 hectares and about 2,000 hectares in Imereti. Collection of leaves and scrap is carried out within 9 months, except the monthes of April-June. Waste is the cutted branches of laurels.

Figure 12. Tea-plant before harvesting.

(Source: “bfm.ge” 2019)

Figure 13. Laurel.

(Source:“agrokavkaz.ge” 2019)

There is an aspiration to restore the destroyed tea plantations which in Imereti accounted for about 20,000 hectares. The restoration includes cutting of the whole bushes, including weeds. This means, about 5 tons of a dendromass in a dry state from hectare will be available for disposal which can serve for energy processing. The total amount of this waste will be about 100,000 tones. In figure 14 it is visible in what state the plantation are currently.

Figure 14. Unattended tea plantation. September 2017.

(Source: APBC)

Waste from vineyards

The area of vineyards in the region of Imereti is about 12,000 hectares. Example of Vineyard waste is on the figure 15. These are rest after pruning. When undercutting vineyards about 2 tons of waste from hectare are formed, therefore 24,000 tons of raw material would be accessible.

Figure 15. Vineyard waste.

(Source: “Soplidan.ge” 2019)

4.3. Description of the machinery

On the technical side, the main idea was to use simple technological systems available on the market. For processing, raw material into biofuel, it was possible to use briquetting or granulation technology. Both technologies demand the preparation of raw materials consisting of the correct disintegration and drying. Further are given several possible examples of the equipment.

For grinding and shredding were evaluated following machinery:

VOTECS Figure 16.

Model: EZ 5/1

Producer: VOTECS

Performance: 2.52 t/hour

Installed electric power: 11 (kW)

Price: 360000 CZK

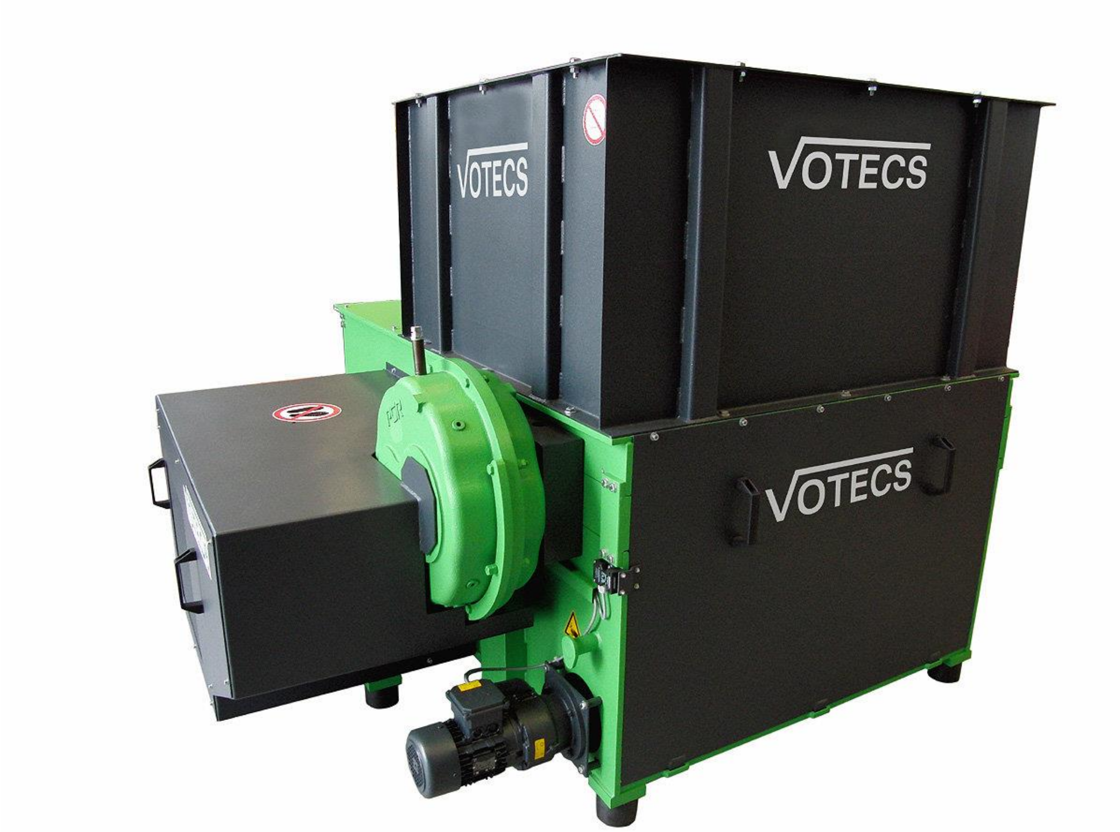


Figure 16. VOTECS EZ 5/1.

(Source:“hoechsmann.com” 2019)

ROJEK Figure 17.

Model: DH 12 TP

Producer: Rojek

Performance: 2.66t/hour

Installed electric power: 11 (kW)

Price: 215000 CZK

Figure 17. Rojek DH 12 TP.

(Source: “rojek.cz” 2019)

Pirba 11KW Figure 18.

Model: PIRBA 11KW

Producer: Bystron – Integrace

Performance: 1.96t/hour

Installed electric power: 11 (kW)

Price: 63000 CZK

Figure 18. Pirba 11KW.

(Source:“bystron.cz” 2019)

SV 11 Figure 19.

Model: PIRBA 11KW

Producer: STOZA

Performance: 2t/hour

Installed electric power: 11 (kW)

Price: 80000 CZK

Figure 19. Stoza SV 11.

(Source:“stoza.cz” 2019)

For pressing briquets, BrikStar machines were evaluated, from manufecturer Briklis.

BrikStar Figure 20.

Models: Brikstar CS 25, 50, 100 and 200

Producer: Briklis

Performance: Number of model corresponds with performance kg/hour

Power: 4.4 (kW), 5.4(kW), 9.3(kW), 16(kW).

Price: 260000 CZK; 324000 CZK; 480000CZK; 520000CZK Respectivly.

Figure 20. Briquetting press BrikStar CS 200.

(Source:"briklis.cz" 2019)

5. Results

5.1. Baseline calculations

Detailed calculations of expenses were made for both technological stages: crushing and briquetting. In both cases, expenses were divided identically in three categories: depreciation, compensation labour and operating costs. Expenses for worker compensation and machinery operation are directly proportional to the use of the equipment, while depreciation is always calculated for a year, since the equipment is not used for other purposes. Operating costs consist of three parts: maintenance (servicing and repair), energy consumption (in this model the electric power) and other direct costs like: lubricant, bags, cleaners, etc.

Equipment is generally from Czech manufacturers, however, the prices of the machines, are presented in GEL. In basic model calculations of expenses are given in

GEL with exchange rate 10.5 CZK/GEL. In table 3 calculation of expenses for basic model for crushing using Pirba crusher from “Bystron – Integrace” are given. In table 4 calculation of expenses for basic model for briquetting with use of a press of BrikStar 200 from “Briklis“ are given, which produces up to 200 kg of briquettes an hour.

It is obvious at the first sight from tables, that costs of pressing exceed costs of crushing by ten times. Therefore, the choice and use of a briquetting press will be critical for production efficiency of energy from waste biomass. The main item of costs for both technological stages are expenses for compensation of workers which make about 50 %. In calculations, it is assumed that, necessary number of personnel to be two people, however it is possible to think of smaller participation of labour, especially in briquetting.

Table 3. Costs of crushing in basic model with use of the Pirba crusher.

Grinding/ shredding	Investment	Life	Capacity	Cost
	GEL	years	t/year	GEL/t
Depreciation	6000	10	1568	0.38
	Wage + Taxes		Capacity	Cost
	GEL/person/year		t/year	GEL/t
Labour	2880		1568	3.67
			Capacity	Cost
	GEL/t		t/year	GEL/t
Maintenance	90.00		1568	0.06
	Price		Capacity	Cost
	GEL/kWh		t/year	GEL/t
Energy	0.14		1568	0.79
			Capacity	Cost
	GEL		t/year	GEL/t
Other direct cost	285.71		1568	1.91
				Cost
				GEL/t

Operation cost	2.8
Total	**Cost GEL/t 6.8**

With big amount of production, depreciation of the Priba crusher represents rather small part of expenditure (6 % of direct costs). However, with more expensive crushers these expenses can grow up to 25 %.

Table 4. Costs of briquetting in basic model with use of a press of BrikStar 200.

Pressing	Investment	Life	Capacity	Cost
	GEL	years	t/year	GEL/t
Depreciation	49524	10	320	15.48
	Wage + Taxes		Capacity	Cost
	GEL/person/year		t/year	GEL/t
Labour	5760		320	36.00
			Capacity	Cost
	GEL/t		t/year	GEL/t
Maintenance	1486		320	4.64
			Capacity	Cost
	GEL/kWh		t/year	GEL/t
Energy	0.14		320	11.26
			Capacity	Cost
	GEL		t/year	GEL/t
Other direct	190.48		320	6.25
				Cost
				GEL/t
Operation cost				22.1
				Cost
				GEL/t
Total				**73.6**

Another considerable expense, (together with previously mentioned labour costs) was depreciation, which made up is 21 % of direct costs. In spite of the fact that at less powerful, and therefore relative cheaper models, depreciation is lower, the expenses on 1 ton of briquettes were higher. Costs of energy make about 15 %.

5.2. Comparison

Table 5 shows calculation of costs for 1 ton of briquettes. Recalculation of total cost of briquettes in unit of thermal energy (GJ) is presented on the table 6. Values differ in the size of transportation costs, depending on remoteness, of the place of emergence of waste biomass from the place of pressing and a heating value of the pressed biomass. Costs of 1 ton of briquettes are in range between 96-119 Georgian (GEL). Costs of 1 GJ of thermal energy are in range of 5.66 – 7.96 GEL.

Table 5. Calculations of total cost of 1 ton of briquettes from agricultural waste biomass.

Raw material	Crusher, Pirba Bystron-Integrace	Average distance	Transportation	Press BrikStar CS 200	Total direct costs / ton	Indirect costs	Total cost/ ton
	GEL / t	km	GEL / t	GEL / t	GEL / t	%	GEL / t
Waste from the revitalization of tea plantations	6.8	20	28	73.6	109	10 %	119
Branches of laurel tree	6.8	5	7	73.6	87	10 %	96
Vineyard pruning waste	6.8	10	14	73.6	95	10 %	104

Table 6. Costs of ton of briquettes recalculation on unit of thermal energy.

Raw material	Calorific value	The cost per unit of heat energy

	GJ /t	GEL / GJ
Waste from the revitalization of tea plantations	15	7.96
Branches of laurel tree	17	5.66
Vineyard pruning waste	14	7.43

In table 7 costs of processing briquettes from waste biomass is compared with cost of alternative fossil fuels available on the market. The comparison is carried out in costs of GJ of thermal energy. The blue indicators are ratios between costs of the thermal energy received from waste biomass and costs of the thermal energy received from fossil sources. If the indicators allocated in blue are less than 1, it means that generation of thermal energy from briquettes is more effective than from the corresponding fossil fuel.

Table 7. Cost efficiency of production of briquettes from waste biomass (comparison of costs of unit of thermal energy).

	Costs of unit of thermal energy	Comparison			
	GEL/GJ	Natural Gas	Diesel	Coal	Electricity
Waste from revitalization of tea plantations	7.96	0.94	0.36	0.49	0.18
Branches of a laurel tree	5.66	0.67	0.25	0.35	0.13
Waste from cutting of vineyards	7.43	0.87	0.33	0.46	0.17

5.3. Simulation

Results in the previous chapter show that production of thermal energy from biomass is more efficient, than its production from fossil sources. Calculations were carried out for all three types of waste biomass (waste from cutting of tea-plants, branches of a laurel tree, waste from pruning vineyards). Since the costs of different types of biomass differ primarily in transportation costs due to distances, the shifts of the curves in the graphs in figures 21 and 22 reflect it. With increasing distance, costs increase, and efficiency decreases.

Regarding the influence of labour on cost efficiency of pressing of biomass simulations of the use of workers-machine operators from 1 to 2.5 was carried out (Figures 21 and 22). The effect of labour input is plotted in curves; the more workers is involved, the higher expenses - movement along the curve (Figure 21). If we consider the cost of thermal energy from natural gas as a benchmark (dashed red line in Figure 22) we can state, the threshold efficiency for labour input and transportation distance. Crossing of the biomass cost curves above the dashed red line designates the region of efficiency loss (in this region the use of natural gas becomes more efficient). Notice that this simulation illustrates also the impact of changes of labour costs in connection with decrease or growth of salaries on cost efficiency of production of briquettes and thermal energy from waste biomass.

Figure 21. Cost per heat unit.

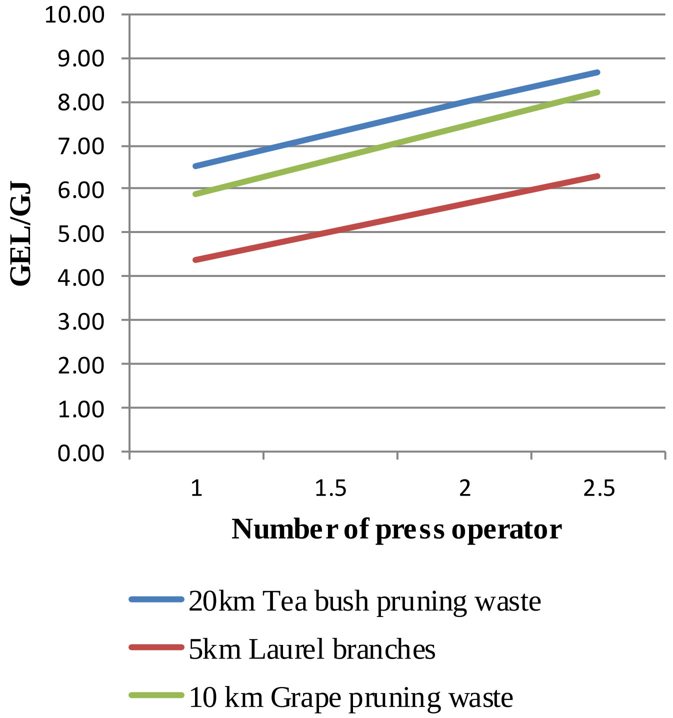
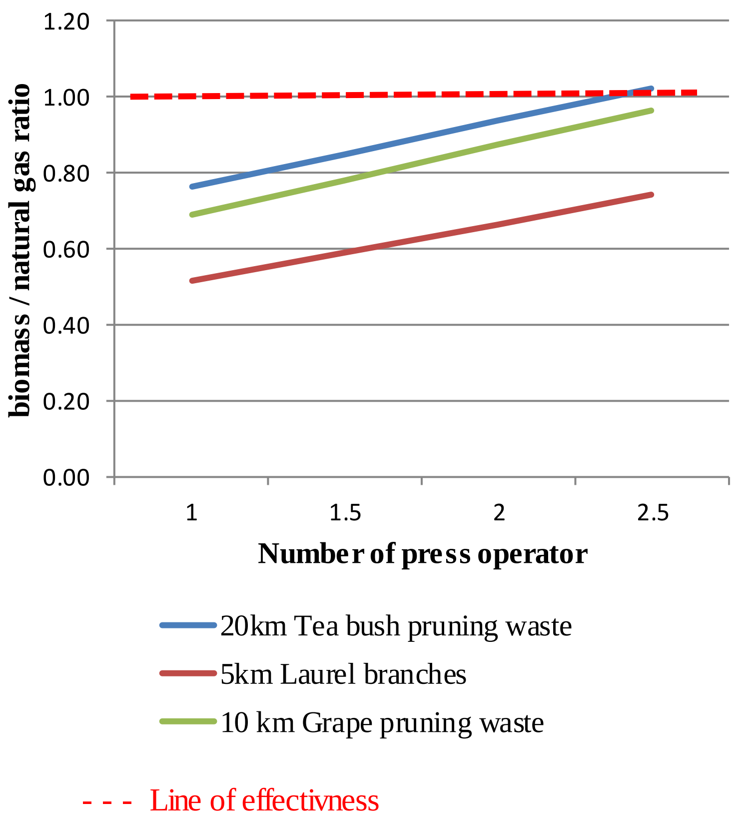


Figure 22. Economic efficiency based on natural gas.



Regarding the effects of shifts in the exchange rate between the Czech crown (CZK) and Georgian Lari (GEL) on cost efficiency of the production of briquettes from waste biomass we conducted several simulations within the range of the rates from 9.5 to 11.5 CZK/GEL. The exchange rate influences first of all costs of purchase of the equipment and the prices of spare parts. Figure 23 and 24 depicts influence of exchange rate on costs of production of briquettes from waste biomass.

Figure 23. Cost per heat unit.

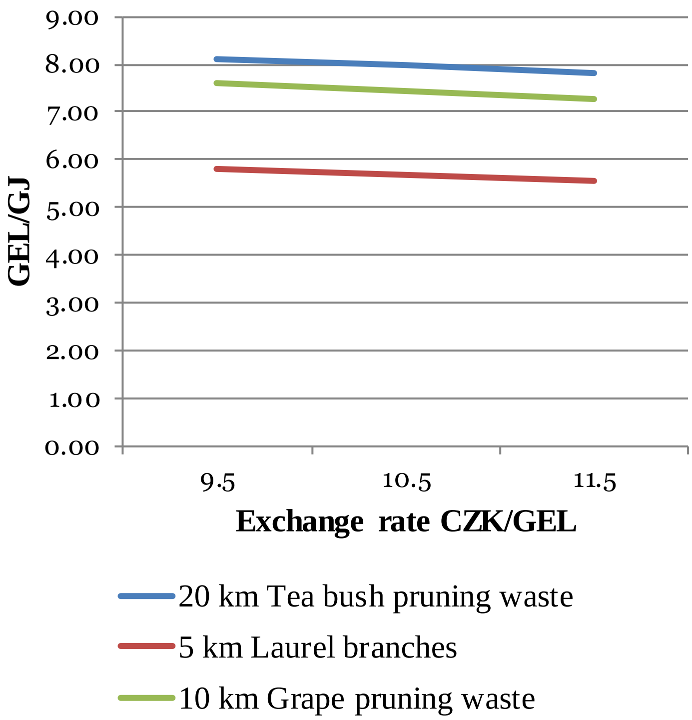
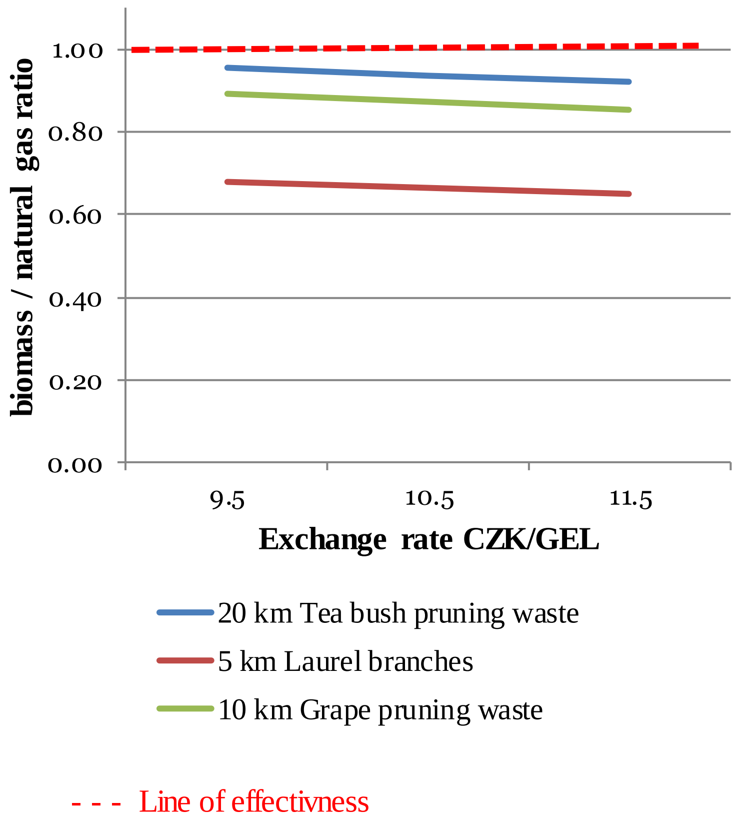


Figure 24. Economic efficiency based on natural gas.



Graph above (Figure 24) show how strengthening of the Georgian Lari in relation to Czech koruna lowers costs of briquettes from waste biomass (the corresponding thermal energy). The dashed red line represents the ceiling of efficiency; the values above this line would indicate inefficient position in respect to thermal energy from the natural gas. As it is evident, even depreciation of GEL to 9.5 CZK per GEL will not break the ceiling. We can conclude that the project of the establishment of a plant for producing biomass briquettes will not be threatened by the deterioration of the exchange rate (up to 9 CZK per GEL).

5.4. Discussion

Through desk research only one similar study was found that was also done in Georgia. The study “Detailed feasibility assessment of pilot biomass plant in Tbilisi and complete feasibility study for installing biomass boilers in Tbilisi municipal facilities” by New Technology Centre was done in 2014. It was requested by the United Nations Development Programme (UNDP) Tbilisi office. Study provided evaluation of biomass resources in Tbilisi and its surroundings and cost calculations of running full scale briquetting production.

The assessment studied potential availability of wide range biomass sources in Tbilisi and its surroundings. For further investigation, woody, non-woody sources and dry agricultural residues were selected. Dry agricultural residues including: straws, corn stover, nut shell, poultry litter and fruit stones. According to the research, up to 90 % of companies in agricultural business, were not having solid biomass waste after secondary processing. Only one company accumulated 1.3 tons of waste annually, in Tbilisi. This was very little amount of biomass. In surrounding parts of the capital, large agricultural companies were selling their residues for 200-450 GEL per ton. However, in total including type of residues apart from agricultural, they estimated to accumulate 15,222,30-ton waste per year.

Basic assumptions of the feasibility study of wood chip and pellet production was to take 10-year loan with interest rate of 12 % and renting a land with building for production. This is the fundamental difference with our study, as those costs, were not considered or were provided for free, in case of production space. In our case, we assumed that the equipment will be provided as a donation from the Czech development agency and thus we considered only the cost of its (future) replacement The UNDP financed research calculated initial plant investment for annual 2000-ton production, to be 1,246,000 Euros. Regarding raw materials, they assumed that it would be provided for free from wood processing facilities, however transportation would be needed. Cost of biomass material would be simply its transportation cost to the pellet production place. Difference with our study is that we noted this cost directly as transportation cost.

As for operational cost, results were quite similar with our study. Biggest part of expenses was the labour cost, accounting for as much as 45 %, when in our case it reached a 40 %. As per their calculations: total cost of a 1 ton of biomass fuel was 256

GEL per ton, which is 156 % more compare to our calculation. However, this was conditioned by the fact that approximately 50 % of total cost per ton of pellets or chips was generated by capital investment and interest payment to cover loan for capital investment. Therefore, cost structure is heavily affected by the costs of establishing of production. If we consider this factor and remove loan and interest costs, then 1 ton of briquette price per their calculated would make up 128 GEL.

6. Conclusions

Data showed that, in the region of Imereti, there is sufficient amount of biomass raw materials for starting sustainable small scale production of woody briquettes. Current markets offer wide range of specialised machinery, with a price range 6000-50000 GEL (considered in this work) and power between 4.4-16 (kW) for every technological stage: shredding and pressing. Production cost varied between 96-116 GEL for 1 ton of waste woody biomass briquettes. The analysis of cost efficiency showed that production of briquettes and thermal energy from waste biomass can be competitive in comparison with fossil energy sources: natural gas, diesel, coal and conventional electricity. Cost calculation and different simulations pointed out some crucial aspects.

It turned out that most important factors affecting efficiency and competitiveness of production of thermal energy from waste biomass are:

- Distance between the source of waste biomass and the place of pressing of briquettes. (With increasing distance cost increases and efficiency falls)
- Number of the workers involved, the amount of salaries and obligatory assignments. (More workers involved, expenses are higher)
- Exchange rate between Czech Koruna (CZK) and Georgian Lari (GEL), have little impact on the production.

For creation of the biomass power production and for further use in practice the model will need to be expanded that it included all expenses and to specify items of expenditure: Other direct costs, indirect expenses, taxes, logistic of finished product must be included. Moreover, for starting actual production, initial investment capital needs to be accumulated, while in our case the assumption was based on getting investment money from a grant. A possible option for business will however be to take out a bank loan to finance the investment, which will result in costs to pay interest rates. Thus, loans and interest rates need to be taken into account for future calculations of the production price.

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