İSTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

LIFE CYCLE and ECONOMIC ASSESSMENT of ELECTRICITY GENERATION from COMBINED HEAT and POWER PLANTS USING WOODY BIOMASS in TURKEY

M.Sc. THESIS

Zühal MEYDAN

Energy Science and Technology Division

Energy Science and Technology Programme

JANUARY 2011

İSTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

LIFE CYCLE and ECONOMIC ASSESSMENT of ELECTRICITY GENERATION from COMBINED HEAT and POWER PLANTS USING WOODY BIOMASS in TURKEY

M.Sc. THESIS

Zühal MEYDAN
(301091081)

Energy Science and Technology Division

Energy Science and Technology Programme

Thesis Advisor: Prof. Dr. Filiz KARAOSMANOĞLU

25 January 2011

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

TÜRKİYE'DE ODUNSU BİYOKÜTLE KULLANAN BİRLEŞİK ISI VE GÜÇ TESİSLERİNDE ELETRİK ÜRETİMİ YAŞAM DÖNGÜSÜ VE EKONOMİK DEĞERLENDİRMESİ

YÜKSEK LİSANS TEZİ

Zühal MEYDAN
(301091081)

Enerji Bilim ve Teknoloji Anabilim Dalı

Enerji Bilim ve Teknoloji Programı

Tez Danışmanı: Prof. Dr. Filiz KARAOSMANOĞLU

OCAK 2011

Zühal MEYDAN, a **M.Sc.** student of ITU **Energy Institute** student ID 301091081, successfully defended the **thesis** entitled "**LIFE CYCLE and ECONOMIC ASSESSMENT of ELECTRICITY GENERATION from COMBINED HEAT and POWER PLANTS USING WOODY BIOMASS in TURKEY**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. Filiz KARAOSMANOĞLU** ....
İstanbul Technical University

Jury Members : **Prof. Dr. Melek TÜTER** ....
İstanbul Technical University

Prof. Dr. Serdar YAMAN ....
İstanbul Technical University

Date of Submission : 14 December 2011
Date of Defense : 25 January 2012

To My Family

FOREWORD

The first person I would like to thank is my supervisor Prof. Dr. Filiz KARAOSMANOĞLU (Istanbul Technical University). Her overly enthusiasm and integral view on research, has made a deep impression on me and thought a lot during my research. Her help, support, encouragement, kindness and understanding gave me strength through-out my education.

In Germany, I would like to thank MSc. Enver Doruk ÖZDEMİR (IER, University of Stuttgart), for his endless support, extremely understanding, encouragement and kindness. Through my study, he guided and motivated me in order to prepareing a well MSc. thesis. I am glad to have the chance of working with him and I owe his gratitude for always being there to listen and give advice.

Appreciation is also extended to Dr. Sc.agr Ludger ELTROP (IER, University of Stuttgart) for the encouragement and advices during development of the study. Also, I would like to explain my great thanks to M.Sc. Maria STENULL (IER, University of Stuttgart) for her technical support and help.

Also I would like to thank TÜBİTAK for financial support through my education for 2 years. Even I am abroad as an Erasmus student, the support of TÜBİTAK is continued and I am really appreciated about that.

Special thanks to M.ScGüner EKŞİ for reading my thesis and helping to corrections patiently. I will be grateful to express my gratitude and appreciation to M.Sc. Aslı İŞLER for her great understanding, supports and for always listening and answering me.

Moreover, it is a pleasure for me to thank my friends who always support and encouraged me. They always believed in me and got in touch me as much as possible.

With all my heart, I thank my family. I would never be in that positions without my family, I would like to thank my parents Sevgiye MEYDAN and Özdemir MEYDAN who always provide me every possible opportunity, respect my decision in every area and save me from all the difficulty of life with an absolute love. Appreciations are also for my sisters Meral and Nihal MEYDAN I cannot skip their support and priceless encouragement in my life.

January 2012 Zühal MEYDAN

Chemical and Industrial Engineer

TABLE OF CONTENTS

Page

ABBREVIATIONS

BAP	: Biomass Action Plan
CHP	: Combined heat and power
CML	: Centre of Environmental Science of Leiden University
CO_{2eq}	: CO_2 equivalence
DH	: District heating
DN	: Diametre nominel
EIEI	: Electrical Power Resources Survey and Development Administration
EMRA	: The Energy Market Regulatory Authority
EU-27	: European Union 27 countries
EU	: European Union
EVET	: Energy Efficient Industrial Plant
FAO	: Food and Agriculture Organization
GDF	: General Directorate of Forestry
GHG	: Greenhouse gas
GW	: Giga watt
GWh	: Giga watt hour
GWP	: Global warming potential
ISO	: International Organization for Standardization
km	: Kilometre
ktoe	: Kilo ton equivalent
LCA	: Life cycle assessment
LCI	: Life cycle interpretation
LCIA	: Life cycle impact assessment
MARKA	: East Marmara Development Agency
MDF	: Medium density fiberboard
MJ	: Mega joule
MTEP	: Million ton equivalent petrol
MW	: Mega watt
MWh	: Megawatt hour
ORC	: Organic Rankine Cycle
RH	: Residential heating
SENVER	: Energy Efficiency in Industry 9th
TL	: Turkish Liras
TWh	: Terawatt hour
UK	: United Kingdom
USA	: United State of America

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIFE CYCLE and ECONOMIC ASSESSMENT of ELECTRICITY GENERATION from COMBINED HEAT and POWER PLANTS USING WOODY BIOMASS in TURKEY

SUMMARY

Biomass is a strategic renewable energy resource which is produced everywhere, renewable, environmental and derived into fuels for vehicles, which gives support to socio-economic development and from which electricity is produced. In this thesis, some selected wood fuel based energy generation pathways are observed regarding life cycle assessment (LCA), mass and energy balance and economic assessment for Turkish conditions. After these assessment methods global warming potential, mass&energy balance and economic feasibility is found.

First of all, there are different kinds of woody fuels such as chips, biopellets, and briquettes and these fuels also change depending on the size and raw material used. In this study biopellet made of sawmill residues and woodchips made of forest residues are obseved. Additionally, there are three wood based energy generation pathways. First pathway (Case A) produced biopellet from sawmill residues which are collected from Yalova and from two close cities. Produced biopellets are consumed in the Rankine cycle combined heat and power (CHP) plant and 26% of heat produced is used in biopellet drying. The rest of the heat is send to the district heating and produced electricity is sent to the existing grid. In the second chain (Case B) sawmill residues collected in Yalova and biopellets are dried with natural gas. Final chain (Case C) is based on forest residues wood chips. Forest residues are collected and chipped in the forest, and then wood chips are transported to CHP plant. The electricity and heat evaluation of three cases are the same. LCA and economic assessment is done regarding to lifetime of unit operations and whole cases. By the way mass and energy balances are calculated for three cases regarding 1 kWh of electricity generation and one year of production. In respect of given information, comparison of the cases is done with each other and Turkish electricity mix and electricity cost and prices. Application suggestions for the biomass based plant candidates are explained regarding the results of this study.

TÜRKİYE'DE ODUNSU BİYOKÜTLE KULLANAN BİRLEŞİK ISI VE GÜÇ TESİSLERİNDE ELETRİK ÜRETİMİ YAŞAM DÖNGÜSÜ VE EKONOMİK DEĞERLENDİRMESİ

ÖZET

Biyokütle her yerde üretilebilir, yenilenebilir, sosyo-ekonomik gelişmeyi destekleyici, çevreci, elektrik üretilebilen ve araç yakıtı olabilen stratejik bir yenilenebilir enerji kaynağıdır. Bu tezde bazı biyokütle yakıtlarından enerji üretimi için seçilen çeşitli yöntemler yaşam döngüsü analizi, kütle ve enerji denklikleri ve ekonomik analiz bakımından incelenmiştir. Yaşam döngüsü değerlendirmesi çevre ve insan üzerine birçok farklı kategorideki etkileri değerlendirmektedir. Bu tezde ise küresel ısınma potansiyeli etki kategorisi olarak seçilmiştir. 1 kWh elektrik üretimi sonucu ortaya çıkan eşdeğer CO_2 emisyonu gram cinsinden hesaplanmıştır (gCO_{2eq}/kWh_e). Ekonomik analiz sonucunda elde edilen sonuçlar birim elektrik üretim maliyeti olarak gösterilmiştir. Tüm ekonomik hesaplamalar 2010 yılı baz alınarak hesaplanmıştır. İncelemeler sonunda küresel ısınma ve ekonomik fizibilite değerleri bulunmuştur. Aynı zamanda durumlar için kütle ve enerji denklikleri de hesaplanmıştır.

Odunsu yakıt çeşitleri boyutları ve hammaddelerine göre yonga, biopellet ve briket gibi isimlendirilmektedir. Çalışmada orman ürünleri işleme sanayisi artık talaşlarından yapılan peletler ve ormaniçi artıklardan yapılan yongalar incelenmiştir. Bu yakıtlar 3 farklı tedarik zinciri içinde değerlendirilmiştir.

İlk tedarik zinciri Durum A olarak isimlendirilmiştir ve biopellet hammadeleri Yalova ve çevresindeki 2 ilden (Kocaeli ve Sakarya) temin edilmiştir. Tesisler ise Yalova ilinde kurulmuştur. Yalova'nın orman ürünleri işleme sanayilerine yakın olması, % 50'den fazlasının ormanlarla kaplı olması, Marmara Kalkınma Ajansı (MARKA) üyelerinden biri olması bakımından tesislerin kurulumu için uygun bir bölgedir. İleride pellet tesisinin büyütülmesi, pelet satışının yapılması halinde deniz taşımacılığı bakımından da stratejik bir konumdadır. Farklı tedarikçilerden bilgi alınarak sistem için kapasite belirlenmiştir. 3 şehirdeki tüm firmalarla görüşülmemiştir; hepsi göz önünde bulundurulursa birleşik ısı ve güç tesisinin kapasitesi daha fazla olacaktır. 3 farklı şehirden gelen hammaddeler için ağırlıklı ortalama yöntemi ile ortalama taşıma mesafesi 58 km olarak belirlenmiştir. Odun sanayi artıkları peletleme tesisinde birleşik ısı ve güç sistemi yardımı ile kurutularak pellet haline getirilmiştir. Pellet üretim tesisi ve birleşik ısı güç tesisi entegre bir şekilde çalışmaktadır. Üretilen peletler Rankine çevrimine dayalı birleşik ısı ve güç sisteminde kullanılarak elektrik ve ısı üretilmiştir. Birleşik ısı ve güç tesisi 2.1 MW elektrik ve 4.2 MW ısı üretmiştir. Üretilen ısının %26'sı biopellet kurutma sürecinde kullanılmıştır. Kalan ısı bölgesel ısıtmaya ve üretilen elektrik şebekeye verilmiştir. Konut ısıtması doğal gaz ile ısınmanın yerini alacak şekilde düşünülmüştür. Isıtılacak konut sayısı belirlenirken Yalova ilinde bir konutun yıllık ortalama ısınıma eğrisi kullanılmıştır. 290 konutun bu sistem ile ısıtılabileceği tespit edilmiştir. Bölgesel

ısınma sistemi ek bir sisteme ihtiyaç duymadan bölgedeki konutların ısınma ihtiyacını karşılayacak şekilde düşünülmüştür. Konut sayısına göre yerleşim planı tasarlanmış ve gerekli tesisat uzunlukları hesaplanmıştır. Konut girişlerindeki ısı istasyonu yaşam döngüsü ve ekonomik değerlendirme için son noktalar olmuştur.

İkinci sistemde de biopellet kullanmıştır ve Durum B olarak isimlendirilmiştir. Durum B'de hammaddeler Yalovadan tedarik edilmiştir. Hammadde taşımadan kaynaklanan emisyon ve maliyet unsurları azaltılmıştır. Bu zincirde orman üzürnleri işleme sanayi ve pellet fabrikası birbirine çok yakın bir bölgede bulunmakta ve entegre tesislermiş gibi çalışmaktadırlar; fakat birleşik ısı ve güç tesisi pellet fabrikasının 20 km uzağında bulunduğu kabul edilmiştir. İlk tedarik zincirinden farklı olarak sanayi artıkları değil peletler taşınmaktadır. Pelet üretiminde kullanılan ısı ise doğal gazdan temin edilmiştir. Doğalgaz kullanımı çevresel etki yanında elektrik üretim maliyetlerini de arttırmıştır. Birleşik ısı ve güç sisteminde üretilen ısının tamamı bölgesel ısınmada kullanılabileceği için ısıtılan konut sayısı artmıştır. 460 konut için ısı temin edilmiştir. Bu sistem daha fazla konut ısıtmasına rağmen Durum A'dakinden daha fazla kullanılmayan ısıya sahiptir. Yaz aylarında konutlarda sürekli bir ısı talebi olmaması nedeniyle ısının %33 'ü değerlendirilememiştir.

Son tedarik zinciri Durum C olarak isimlendirilmiştir. Kullanılan hammadde ve yöntemler itibarıyla Durum A ve B'den farklılıklar göstermektedir. Orman içinde bulunan odun artıkları orman içinde toplanmıştır. Bu artıklar orman içinde bir yonga makinesi yardımı ile yonga haline getirilmiştir. Yongalar kamyonlarla birleşlik ısı ve güç stesisine taşınmıştır. Yongaların yakılması ile ısıtılan ev sayısı Durum B'deki ile aynıdır. Birleşik ısı ve güç sistemleri ile bölgesel ısınma sistemlerinin yerleşimi Durum B ve Durum C için özdeştir.

Yaşam döngüsü değerlendirmesi ve ekonomik analiz operasyonların ve sistemin genel ömrü dikkate alınarak yapılmıştır. Ayrıca durumlar için kütle ve enerji denklikleri 1 kWh ve yıllık elektrik üretime göre hesaplanmıştır.

Yaşam döngüsü değerlendirmesi sonucu elde edilen sonuçlara göre Durum A, Durum B ve Durum C için emisyon değerleri sırası ile -15.00, 74.43 ve -78.63 gCO_{2eq}/kWh_e olarak hesaplanmıştır. Türkiye elektrik üretim emisyonu değeri ise 523.94 gCO_{2eq}/kWh_e'dır. Türkiye elektiriği ile karşılaştırıldığında tüm durumlar göreceli olarak daha az emisyon ortaya çıkarmıştır. Hatta Durum A ve Durum B negatif emisyon değeri göstermektedir. Doğal gaz kullanımının yerine birleşik ısı ve güç sistemi kullanılması sisteme emisyon kazancı getirmiştir. Bu kazanç sistemin tüm emisyonundan fazla olduğu için negatif değerlere düşmesine yol açmıştır. Negatif terimin daha net bir şekilde açıklanması için Durum A emisyon değerlerine bakılması faydalı olacaktır. Eğer Durum A sadece elektriği değerlendirse idi 90.1 gCO_{2eq}/kWh_e emisyonu oluşturacaktı ama oluşan ısının doğalgazla konut ısısı yerine kullanıması -105.1 gCO_{2eq}/kWh_e kadar emisyon azaltılmasına yol açtı. Sistemin net emisyonu ise sadece -15.0 gCO_{2eq}/kWh_e olmuştur.

Ekonomik inceleme sonucu elde edilen sonuçlara bakıldığında Durum A, Durum B ve Durum C için birim elektrik üretim maliyeti sırasıyla, 0.276, 0.294 ve 0.166 TL/kWh olarak hesaplanmıştır. Yenilenebilir enerji kaynaklarından elektrik üretimine ilişkin kanuna göre biyokütle kullanarak üretilen elektrik için devlet yaklaşık 0.206 TL/kWh (13.3 US$cent/ kWh) ücret garantisi vermektedir. Bu durumda odunsu yakıtlardan elektrik üretimi yalnızca yonga kullanan durum için karlı gözükmüştür. Ayrıca Türkiyede ortalama elektrik üretimi 0.125 TL/kWh gibi bir maliyete sahiptir. Yenilenebilir kaynakların çevresel etkisi göz önünde bulundurulduğunda yatırıma teşvik için daha çok destek verilmesi gerektiği açıkça görülmüştür. MARKA destekleri de hesaplamalar içine katıldığında elektrik maliyetinde iyileşme görülmekte fakat bu yeterli olmamıştır. Çalışmada eğer tüm ısı satılsaydı durumda bir değişiklik olurmu bu da incelenmiştir. Durum A, Durum B ve Durum C için elektrik üretim maliyeti sırasıyla 0.234, 0.227 ve 0.099 TL/kWh_e olarak hesaplanmıştır. Durum A ve Durum B için devlet fiyat garantisinin yeterli olmadığı, Durum C için maliyetlerin ortalama Türkiye elektrik üretim maliyetlerinin altına düştüğü hesaplanmıştır.

Sonuç olarak çevresel etki bakımından biyokütle kullanımının olumlu sonuçlara sahip olduğu bulunmuştur. En etkili sonucu orman yongası kullanan Durum C vermiştir. Ekonomik olarak bakıldığında ise biyokütleye yatırım yapılmasını sağlamak amacı ile devletin desteklerini arttırması gerekmektedir. Mevcut durumlarda yatırım yapılabilecek tek tedarik zinciri Durum C'dir. Tedarik zincirlerinin ekonomik açıdan iyileştrilmesi için tüm ısının kullanılması sağlanmalıdır. Bunun için ısı talebi sürekli olan sanayilere ısı sağlamak gibi seçenekler değerlendirilebilir. Çalışmanın son kısmında sonuçlar ışığında biyokütle yakıtlı güç santralleri kurmak isteyenler için tavsiyeler ve öneriler verilmiştir.

1. INTRODUCTION

Recently, awareness about efficient energy supply and economic energy consumption rises all around the world. Turkey also started to focus on renewable energy resources and local energy resource evaluation. Biomass utilization in Turkey is common in rural areas with traditional combustion methods [1]. Nowadays, biomass conversion routes are depending on municipal waste treatment and combustible gas production in Turkey. Some commercial companies especially food industry, use their biomass production residues as the feedstock of energy generation. These applications seem promising for the biomass usage. In this study woody biomass based combined heat and power generation plants are observed in terms of environment and economy [2].

In a situation where energy systems on all levels should be changed into improved ones, CHP systems are one of the applicable ways. In this thesis CHP systems using woody biomass are observed to find the feasibility of these cases regarding to environment and economic aspects. In literature it is existed that providing a low operating cost and keeping investment on small district heating and CHP systems, it should be used biopellets instead of kind of biomass resources [3].

Moreover, Marmara region is a suitable place for biopellet and wood chips based systems, because Marmara region has the biggest share of forest goods production capacity in Turkey. There are several sawmills in the region, which produces large amounts of sawmill residues. Some of the timber, plywood and furniture plants production data are collected as m^3/year in order to decide the capacity of the biopellet plant [4]. In this study, all the energy generation plants are located in Marmara region. Yalova is selected as the plants location. Government also promote investment in some cities in Marmara with East Marmara Development Agency (MARKA). Yalova is also a participant of MARKA.

In Turkey, imported fossil fuel dependency is about 70% of its primary energy demand [5]. Electricity is generated mostly from fossil fuels as well. Fossil electricity generation in 2009 has 80% of the total electricity generation. Fossil based electricity generation have more negative environmental effects. Turkish electricity mix causes 523.9 gCO_{2eq}/kWh_e in 2008. Turkey needs to find alternative energies to fossil fuels in order to lower energy dependency and environmental effect of energy generation. Renewable-based energy is an alternative energy option for Turkey. In Turkey there are some governmental regulations on promoting renewable-based energy. These regulations support a feed-in tariff for renewable-based electricity, reductions in licensing fees and guarantee of purchasing [6]. Also distribution and connection priorities are given for the renewable-based electricity. Derivation of biomass into energy can be a solution of the environmental problems and fuel dependency in a sustainable way. In this study whether these motivations are sufficient or not will be evaluated after economic assessment.

1.1. Purpose of the Thesis

The aim of the study is to inestigate and to estimate of the possibility of woody biomass usage in energy generation, their environmental aspects and economic feasibility within Turkish specific context. Life cycle assessments of different woody furl-based pathways as well as life cycle economic assessments of all cases are performed. Global warming potential (GWP) is chosen to detect the environmental aspects in Turkey. Moreover, economic profitability is evaluated to find out the operability of wood system depending economy. Economic calculations are done according to all the possible cost during life time of the cases except disposal costs.

Also, this thesis provides the information about weak points and strengths of each unit process in the chain as economically and environmentally. As a result this, thesis can be a guide for systems improvements.

Furthermore, whole production chains are investigated until the grid connection for electricity and house connection for district heating. Through, the energy consumptions and environmental effects of the cases and expenses are defined for each operation. Cases are flexible and open to make changes, also sensitivity analysis or system improvement can be applied easily.

The results of this thesis show that it is possible to have a conclusion and recommendation for the better wood based energy generation pathway considering

Turkish specific context. Investment decisions can be done according to economic assessment.

Moreover, LCA approach, which is widely applicable and provides a systematic methodology, is preferred for the calculating environmental effects. A LCA may be performed for the purpose of: decisions involved in product and process development; decisions on buying; structuring and building up information; eco-labeling; environmental product declarations; and decisions on regulations [7].

There are several studies in recent years about bioenergy generation routes in the countries overall the world. Although there is biomass awareness in the world, there is no LCA based studies about biomass in Turkey. This thesis can be a starting point.

Mass and energy balance are calculated in order to observe cases properly. Energy efficiencies of all the cases are found out. Fossil and renewable-based energy requirements are calculated as well.

Additionally, the other assessment in this study is based on economy of the entire cycle. In economic analysis future operational and investments can be determined. All the costs are observed from construction to investment, maintenance, repair, and replacement, energy, and residual values [8].

In conclusion, the aim of this thesis can be summarized as to identify the GWP potential that is emitted on a life cycle horizon for the wood fuelled electricity generation in CHP plants and calculate the economy of the production based on Turkish conditions. This thesis comprises LCA methodology and economic assessment to observed woody fuel-based pathways with CHP technology. This study is useful to determine future operational occasion, savings and improvements. The main outputs of the thesis are explained in the text above. The important answers can be listed as follows as well:

- Obtaining global warming potential of the observed cases for per kWh of electricity generation
- Comparing the current electricity generation pathways and observed wood fuelled systems
- Calculating energy mass and balance in order to observe and compare cases
- Calculating specific electricity generation cost of three systems regarding Turkish conditions

- Comparing the specific electricity cost with feed-in tariff and average electricity generation cost in Turkey
- Observing whether current renewable-based energy policies of Turkey are sufficient for investing on these cases.
- Determining the operational occasions, saving and improvement areas

1.2. Outline of the Thesis

This thesis comprises four main chapters: introduction, theoretical part, application part and conclusion and recommendation.

In the introduction part, purpose of the study is explained, background information of the systems are indicated.

Following to the introduction, general information about bioenergy, situation of renewable-based electricity generation in the world, renewable-based energy profile of Turkey, applied methods are stated in chapter 2 theoretical part. Biopellet market and case studies about woody biomass and power plant applications are also clarified. Biomass potentials and market conditions are invested to understand the availability of biomass investments in Turkey. Policies and regulations related to renewable-based energy and biomass is given for Turkey. Second chapter is assigned to the methodologies used in this study during environmental assessment, mass and energy balance calculations and economic assessments. Steps of LCA are introduced. Short introduction of the theoretical framework is given and each step according to International Organization for Standardization (ISO) 14040 et seq. is described theoretically. Information about mass and energy balance calculations are explained. Furthermore, economic analysis and its application are summarized.

Third chapter includes the application of LCA, mass and energy balance and economic assessment. The details of observed cases are explained. Two cases (Case A and B) are based on biopellet from sawmill residues and the third one (Case C) is based on chips from forest residues. The supply chain routes of the each process are different than each other. Variations of the systems are taken into consideration during these calculations. Interpretation is the final step of LCA which is presented in chapter three. Results are first displayed separately for each system. After that, comparison between cases and conventional technologies are introduced.

Additionally, economic analysis is performed for three cases with different supply chains. Electricity production costs are compared with the prices of feed-in tariff defined by government for each system. The most feasible system is found, by the time cost proportions are explained. Some improvement areas for making systems are found out after the economic analysis.

Conclusion and recommendations are given as Chapter 4. Furthermore, recommendations for themes of further studies are suggested.

2. THEORETICAL PART

In this part of the study, theoretical study results will be presented on following subjects, respectively:

- Bioenergy
- Renewable-Based Electricity in the World
- Renewable-Based Electricity in Turkey
- Methods of the Study
- Literature Review

2.1. Bioenergy

Biomass is the biodegradable components of products, waste and residues from agri-culture (including vegetal and animal substances), forestry (plants, energy forests, tree residues) and related industries, industrial and municipial waste. By the help of different conversion pathways biomass is derived into heat, cold, electricity, fuels and energy carriers [9-10].

Biomass refers a wide range of material recent biological origin that can be used as a resource of energy. Even in the ancient time biomass is used as an energy resource. Actually, it contributes around 10–14% of the world's energy supply. It has a great potential as a renewable energy resource, both in the developing countries and the developed ones [11].

As biomass is a potentially reliable and renewable energy resource, bioenergy fuel is being considered as one of the most promising energy carrier of the future generation. Bioenergy, or bioenergy, is stored in organic matter with the help of the sun [12].

Moreover, when biomass fuels are used for energy generation purpose, the energy is called as bioenergy. Solid, liquid and gaseous fuels are secondary products of the systems. They are energy also called as energy carriers and they cover variety of fuels, with applications in all the major sectors of consumption for example power generation, transportation, industry, households, etc. Bioenergy consumption is increasing because it is a modern and efficient way for production of energy forms [13-14].

Bioenergy refers to renewable-based energy from biological resources that to provide heat, power or combined heat and power is a link in the energy chain from producing biomass resources. A clean, renewable-based energy that could dramatically improve our environment, economy and energy security is provided by biomass resources. Generating less air emissions than fossil fuels, reducing the amount of waste sent to landfills and decreasing our reliance on foreign oil is some of the benefits of bioenergy. It also creates thousands of jobs and helps revitalize rural communities [11, 14-15].

2.1.1. The biomass resources

Biomass can be obtained from various resources and the basic resources of bioenergy are living plant and animal materials. Biomass resources can be classified into four categories according to the supply areas:

Woody biomass: is produced in forests and agro-industrial plantations, bush trees, urban trees, and farm trees.

- Forest arising (short rotation forestry (willow, poplar) and herbaceous (grasses)
- Wood process residues
- Recovered wood fuels from activities such as land clearance and municipal green waste **[**9, 11, 14].

Agricultural biomass: is produced in crop residues as straw, leaves, and plant stems processing residues like saw dust, nutshell, and husks and domestic wastes (food rubbish and sewage, etc.)

- Energy crops, short rotation and annuals
- Water vegetation (algae, water hyacinths, seaweeds, salicornia)
- Agricultural by- products (field crop residues, starch crops (maize, wheat, corn, barley), oil crops (rape seed, sunflower) and sugar crops: sugar beet, sweet sorghum, etc.)
- Animal by- products (cattle, pigs, horses and poultry as well as humans)

- Agro-industrial by- products (bagasse, rice husks, etc.) [9, 11, 14].

Industrial by-products:

- Residues from food, and wood based industries: Fibrous vegetable waste from paper industries
- Industrial waste wood, sawdust from sawmills [9, 11, 14].

Waste:

- Dry lignocelluloses: residues from parks and gardens (e.g. pruning, grass)
- Contaminated waste: municipal solid and liquid residues and landfill gas, demolition wood, sewage sludge. Some of the biomass examples are shown in Figure 2.1. [9, 11, 14].

Figure 2.1: Chipping of forest residues, straw bales and a rapeseed field [11].

2.1.2. Biomass as fuel

In the 21st century, the bioeconomy has been increased. There are three kinds of biofuels as solid, fuel and gas. It is expected that biobased products and biofuels will be introduced into daily life with an increasing rate. Products with energy contents are: solid biofuels (pellets, briquette, charcoal, etc.), liquid biofuels (vegetable oils, bio-oil, biomethanol, bioethanol, biodiesel, biodimethylether, ethyltertiarbuthylether, FT-fuels, etc) and gas biofuels (biogas, biomethane, etc) [16-18].

In this study two kinds of solid woody fuel: biopellet and chips are evaluated. Pellets are solid biofuel which is produced from wood or woody residues currently. Production of biopellets includes milling, drying and compacting which require small amounts of energy, simple and relatively cheap [19]. Woody pellets are made of sawdust and wood shavings compressed under high pressure and a convenient and clean fuel. Today, some places also log wood from thinning is used to produce pellets [19].

Biopellet form is short cylindrical or spherical. Their diameter is generally 6-12 mm, length is 10-30 mm and mositure content is less than 10% for the pellets. Residues of the wood processing industries are derived into biopellets for using heating and electricity generation. Biopellet has some properties that make it suitable in small heating systems for instance automatic heating process, easy storage as they do not degrade, relatively low cost comparing with fossil fuels and a very low amount of ash and other emissions released [20]. Biopellets and wood chips are presented in the Figure 2.2.

Figure 2.2: Illustration of pellets from different wood chips [20].

Wood chips can be defined as a medium-sized solid material made by cutting, or chipping, larger pieces of wood. Woodchips may be used as a biomass solid fuel. Other usage area of the wood chips are organic mulch in gardening, landscaping, and restoration ecology. Bark chips and the woodchips processed in different processes regarding to the different chemical and mechanical properties of the masses, the wood logs are mostly peeled. [21-23].

2.1.2. Bioenergy conversion technologies for electricity

There are some types of energy technologies can turn biomass into useful energy: thermo-chemical, biological, and physo-chemical. In order to produce electricity some of energy conversion processes are required. These technologies include combustion, gasification, as well as anaerobic digestion, pyrolysis and co-firing processes. Other technologies, such as oil or liquid fuel production methods are not direct related to bioelectricity generation. The entire path for bioenergy conversion technologies and product are illustrated in the Figure 2.3. The options for biomass conversion to electricity are remarked below according to technologies and products.

Increased efficiencies and decreased capital costs may be possible if the solid biomass feedstock is first converted to an intermediate liquid or gaseous fuel that may then be used in gas turbines or engines. The integration of sustained feed production, feed conversion and high efficiency electricity generation as shown in Figure 2.3 may be the key to generating electricity from biomass at a lower cost than is currently possible. A number of wastes to energy technologies are supported through the renewables obligation to stimulate a greater contribution to renewable-based electricity generation from waste biomass. These are anaerobic digestion, gasification, pyrolysis and energy from waste with good quality combined heat and power [24-25].

2.2. Renewable-Based Electricity in the World

Energy is considered as a key player in the generation of wealth and also a significant component in economic development as a result of this energy resources become extremely significant in the world [26]. Renewable resources are expected to have increasing share of the primary energy resources for the production of electricity.

The potential role of renewable-based energy, such as solar electric, wind power and bioelectricity are becoming increasingly important as they offer numerous advantages over non-renewable, conventional energy resources in terms of environmental health and safety [27-28]. As seen in Figure 2.4 renewable-based energy represents 16% of world final energy consumption in 2009. Traditional use of biomass, which contains usage for cooking and heating in rural areas, has the biggest share in renewable-based energy [29].

Renewable-based electricity generation capacity, except large hydropower, reached an estimated 312 GW worldwide in 2010, an increase of 25% over 2009 (see Table 2.1). Large hydro power supplied 23.5% of global renewable-based electricity production in 2010. Among all renewables, global wind power capacity increased the most in 2010, by 39 GW. Small hydropower has been growing annually by about 30 GW in recent years, and solar PV capacity increased by more than 17 GW in 2009 [29].

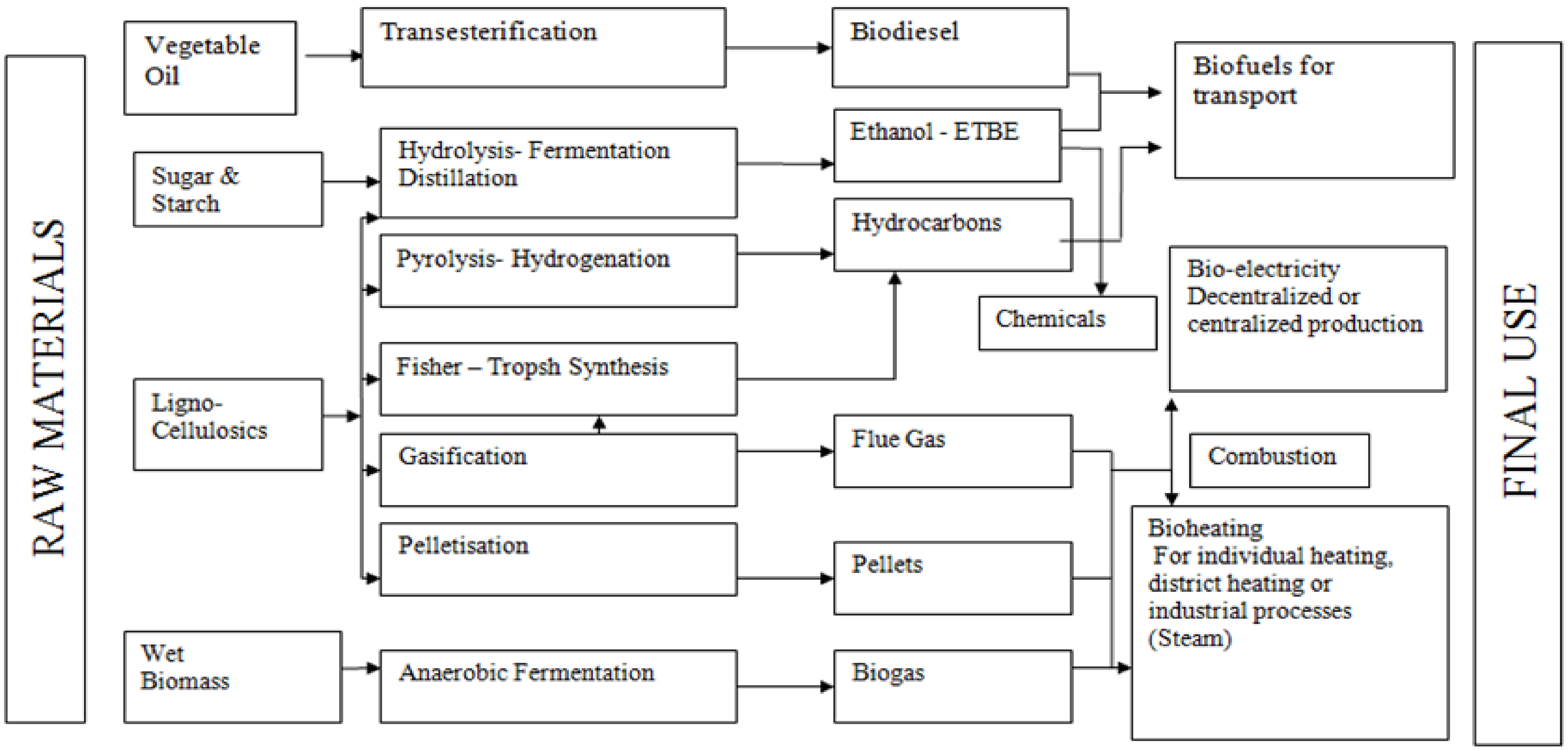

Figure 2.3: Conversion processes, products and applications [9].

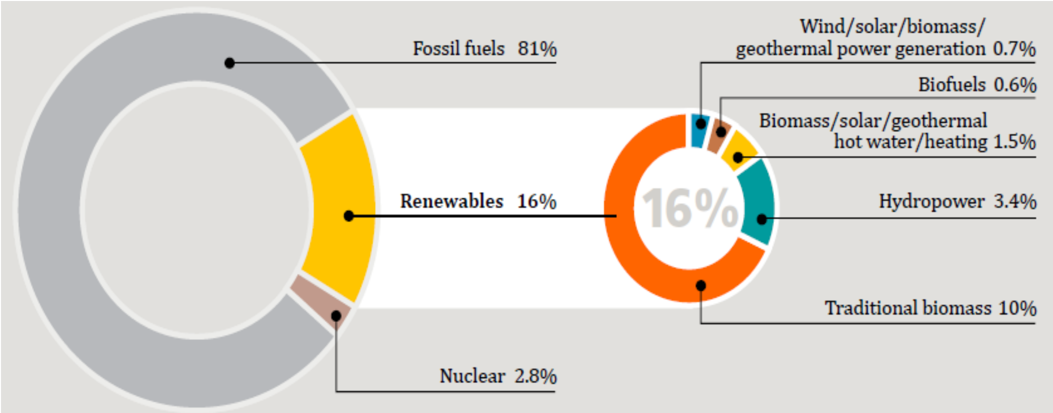

Figure 2.4: Renewable-based energy share of global final energy consumption in 2009 [29].

An estimated 62 GW of biopower capacity is existed in 2009 as seen in Table 2.1. Biomass represents 5 % of global renewable-based electricity capacity. The largest renewable resource is large hydropower, which provides 76.5% of world renewable-based electricity. The contribution of new renewables: solar thermal power, geothermal and ocean energies, to renewable energy resources supply is still very marginal with a total renewable based electricity share of 0.94% and 12.4 GW production. Solar power's contribution developed on a large scale in Germany and Spain and is becoming significant. The renewable based electricity power capacity of the world in 2010 is listed in Table 2.1 [29].

Table 2.1: Renewable-based electric power capacity, existing as of 2010 [29].

Renewable Technology	World Total (GW)
Wind power	198
Biopower	62
Geothermal power	11
Solar photovoltaic-grid	40
Solar thermal power-CSP	1.1
Ocean (tidal) power	0.3
Large hydropower	1010
Total renewable-based power capacity	1230

Renewable-based electricity output increases across the European Union. Countries have their own renewable energy resources consumption targets as well as European Union target. In 2010, Germany and Hungary are the most successful countries that reach the goal. Rest of the countries has another two years left to achieve their goals. The renewable-based energy targets and achieved amount for European Union 27 (EU-27) in 2009 are shown in Figure 2.5.

Supporting policies make most of the countries reach close to their target. Although hydro energy is the main resource for renewable-based power production, wind and solar energy will come into essential [30]. In Europe, the solid biomass industry grew more than 2 percent from 2007 to 2008, providing 5.6 TWh of electricity, with an increase of 10.8 percent during this period. The other growing biomass sector is heat and power generation. Wood biopellet market is a the subsection of this industry: however it is strengthened in 2009 following a fall in shipping costs, which can account for as much as 50 percent of the biopellet supply expense. As a result of this demand co-firing power plants are increased in Europe [29].

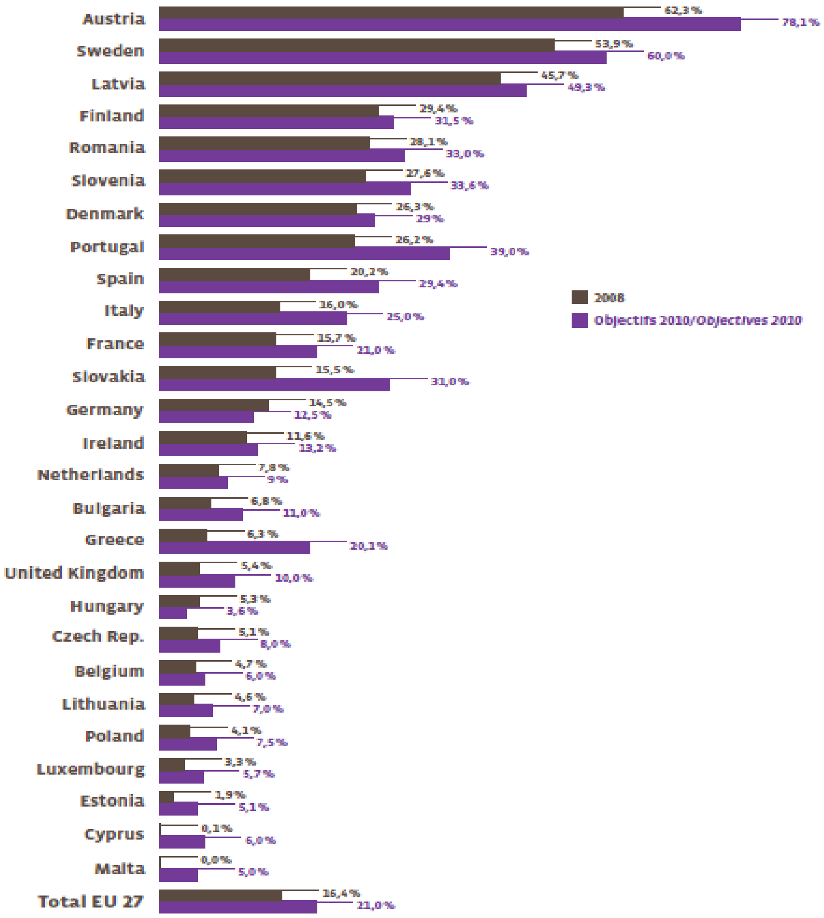

Figure 2.5: Renewable-based energy share in gross electricity consumption for EU-27 [30].

2.2.1. Bioelectricity generation in the world

Biomass is by far the greatest resource of renewable resources due to widespread non-commercial use in developing countries. Developing countries consume virtually two-thirds of biomass for the purpose of cooking and heating. The traditional biomass consumption shows different manner in some regions as such increment and decrease due to replacement of more efficient and modern energy forms. World provides 13% of global final energy consumption to traditional biomass use [29, 31]. Remaining biomass consumption is in the developed countries that have the different applications such as industrial applications within the heat, power, and fuel production for road transportation sectors. Biomass is important for both sectors industry and district heating. On the other hand, the countries with large forestry sector such as Sweden, Finland, and Austria give remarkable importance to forest based biomass [31]. Electricity generation purpose biomass is used as both solid and biogas form. However, in this section especially solid biomass is explained.

The contributions of bioenergy to the total renewable-based electricity supply for some countries are even more diverse as shown in Figure 2.6. European countries provide more electricity from renewable resources. Bioelectricity also takes part in EU-27. China total renewable based electricity generation is as the same as EU-27 but important part of it is hydroelectricity. Several developing countries such as Brazil, Costa Rica, India, Mexico, Tanzania, Thailand, and Uruguay have an increasing interest on biopower. China shows the impressive increment with 14 percent in 2009 to 3.2 GW, and by 2020 they plans to increase capacity to 30 GW [29]. India another important developing country generates 1.9 TW_h of electricity with solid biomass in 2008. There are installed 835 MW of solid biomass capacity fueled by agricultural residues (up about 130 MW in 2009) and more than 1.5 GW of bagasse cogeneration plants (up nearly 300 MW in 2009, including off-grid and distributed systems) [29]. The capacity is planned to increase 1.7 GW by 2012. Brazil has over 4.8 GW of biomass cogeneration plants at sugar mills, which generated more than 14 TW_h of electricity in 2009: nearly 6 TW_h of this total was excess that was fed into the grid [29].

Since 2001, gross electricity production from biomass is increased almost three times in the world. 800 solid biopower plants that burn wood, black liquor, or other biomass to generate electricity, operate at the beginning of 2010. Their capacity is estimated as 7 GW. Wood owner countries such as Scandinavia, but Germany and Austria have the major scale and number of such plants and have also experienced significant growth recently. Most of this increase in biomass capacity has resulted from the development of combined heat-and-power (CHP) plants [29].

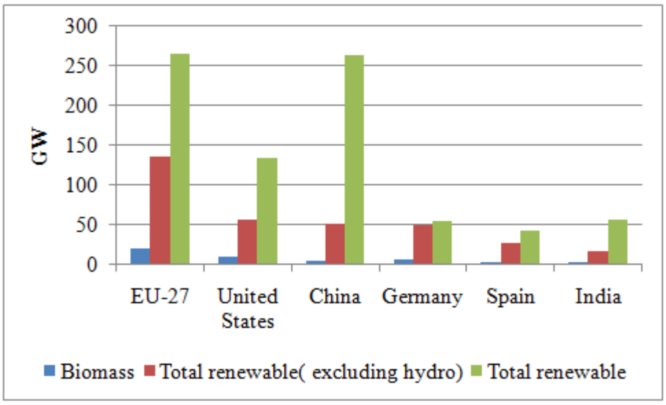

Figure 2.6: Bioelectricity comparison of different countries [29].

Solid biomass produced from wood, wood residues, organic and animal wastes comprise an important share of renewable-based energy in 2008. Energy production from biomass takes place in the entire EU. France, Sweden, Germany, Finland and Poland are the five leading countries which produce 56.1% of European solid biomass-derived primary energy [30].Growth in solid bioelectricity output was sustained in 2008 (at 10.8%) which made total production across the EU rise to 57.8 TWh. Although the entire EU members solid bioelectricity sectors are active, Germany, Sweden and Finland have the biggest share more than half of the production (51.2% in 2008) [32]. In the Figure 2.7 gross electricity production from solid biomass is presented for EU-27. At the end of 2009, more than 50 countries have solid biopower plant and biomass share of electricity generation increases. Biomass heating markets are expanding steadily, particularly in Europe. Trends include growing use of biopellets, use of biomass in building-scale or community-scale combined heat and power plants (CHP), and use of biomass for centralized district heating systems [30].

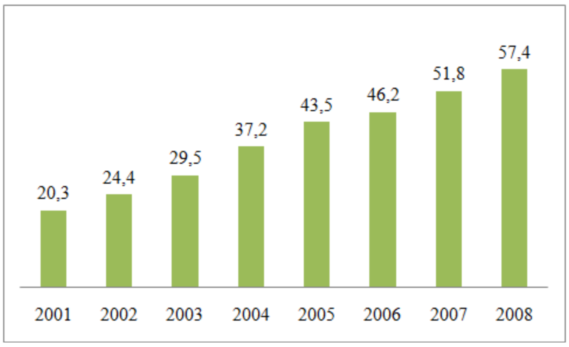

Figure 2.7: Evolutions of gross electricity production from solid biomass of the 27-state EU (in TW_h) [30].

2.2.2. Policies supporting bioenergy in Europe

Early policies with regard to bioenergy perspective are mentioned in this part briefly. The Green Paper of March 2006 - "A European Strategy for Sustainable, Competitive and Secure Energy", brought increased discussion on energy -fossil and renewable. Six major areas are focused on: competitiveness and the internal energy market, diversification of the energy mix, solidarity (to prevent supply crises), sustainable development, innovation and technology and external policy (for energy supply) [9, 33].

In December 2005, the Commission released the Biomass Action Plan (BAP). Biomass potential in EU renewable-based energy mixture definition and being a map for how to harness this energy in a sustainable manner is the purpose of this plan.

Following on from the BAP is renewable energy resources and are covered by this directive: electricity. Further specifications are included in the EU Strategy for biofuels released in February 2006. Objectives of the report are further promotion of biofuels in the EU and in developing countries, preparation for the large-scale use of biofuels, and elevated cooperation with developing countries in the sustainable production of biofuels [33].

The Renewable Energy Roadmap (Jan, 2007) indicates a new approach to the policy orientation. Renewable-based energy moves closer to the top of the EU's agenda. European Commission road map is approved by leader countries in March 2007. The target of renewable energy resources become as 20% of EU's overall energy mix by 2020 (current target is 12% for 2010) and an obligation to have 10% biofuels in the EU transport fuel mix by 2020 (current target 5.75%) [9, 33-34].

The Commission published the legislative proposals designed to support the recent roadmap outlined above in its energy and climate package on the 23 January 2008 [33].

Renewable objectives are embedded in a legislative Directive (2009/28/EG: 23 April 2009), which would ensure the equitable participation of all EU member states. The objectives concerns the share of energy from renewable resources in gross final consumption of energy in 2020, set at 20% [33].

There are three options that mentioned by EU directive for reaching, 20% renewable goal" in 2020. These options are using renewable for electricity generation, using renewable in order to heating and cooling and the use of renewable transportation fuels (e.g. liquid biofuels). Heating, cooling and electricity generation options can be satisfied by biopellet usage. Biopellets can be used as lignocelluloses feedstock in biorefineries for producing liquid second generation biofuels recently [35]. Current usage of biopellets due to dedicated policies supporting market development is supported by only few countries. Without significant political support is not easy to penetrate the existing market for a new technology [19].

2.2.3. Biopellet market in the world

First pioneer European countries have started to use biopellet for heating purpose since mid of 1980s [21]. The energy and environmental taxes on fossil fuels and partly the situation in the biofuel market become driving force for the biopellet industry rapid increment during the 1990s [36]. When the particleboard industry decreased production, available excess sawdust occurred in the market. One of the most important factors for the realization of the biofuel combines was a surplus of the by-products bark and sawdust, which at the same time serve as raw material for biopellets [36]. Actually, small amount of countries including Sweden, Denmark, the Netherlands, Belgium, Germany, Austria and Italy are currently focused on biopellet. An important market penetration is achieved by biopellets only in these countries. Although the other countries markets show signs of dynamic growth, they are still in an early stage of development with very low market penetration. The experiences results indicate that biopellet utilization can grow extremely fast, if the proper frame conditions exist. Growing fossil fuel prices support this trend as well [35].

The biopellet market can be classified into four categories. First market is the biopellet dominated by the utilization of biopellets in large scale power plants. The representative examples of this market are Belgium, the Netherlands and Poland. Replacement of current coal fired power plants to wood based plant makes the United Kingdom (UK) become another large market [19, 35].

The medium scale consumer of bulk wood biopellets for district heating arises as a second group of market. Sweden is leader of this category [35]. The third market has the application of small scale bulk delivery for heating. Biopellets are consumed in house heating and, more commercial, industrial boilers for heating especially in Austria and Germany.

The last category is small residential consumers use stoves for heating that is fuelled by bagged wood biopellets. Stoves market should be considered with biopellet market developments [35]. The main actors of stoves market are Germany, Italy, France, other southern European countries and United State of America (USA). On the other hand some countries generate wood biopellet for exporting and have lower domestic demand comparing importers [19, 35].

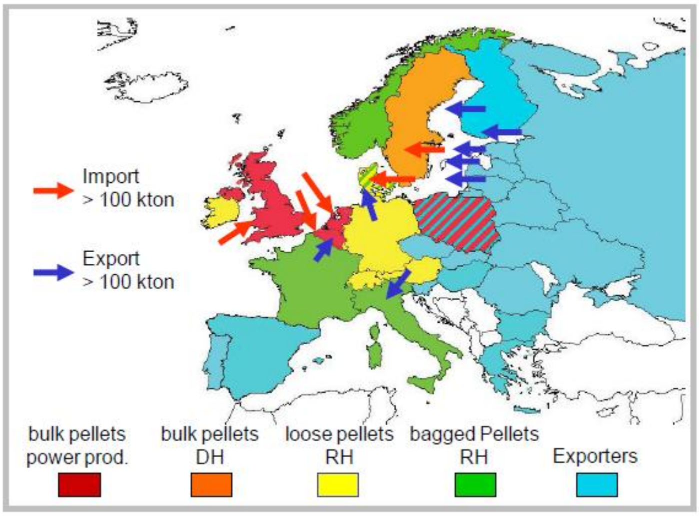

Figure 2.8: Overview of European biopellet market and main market types per country (2008/2009) [35].

The actors of biopellet market are illustrated in Figure 2.8 according to their main biopellet usage category. District heating (DH) is shown by orange colour and residential heating (RH) is shown by yellow and green colours depending on biopellet packaging type. The main actor countries encourage the consumption of wood biopellet in co-firing with supporting governmental incentives and obligations. Countries like the UK and Netherlands needs to import wood biopellet because they use biopellet for several other areas and they have not enough domestic production. In contrast, Belgium is developing a considerable residential biopellet heating market and biopellet production capacities, besides the enormous biopellet co-firing market [37].

Biopellet end use shows variation from country to country. In Figure 2.9 the consumption value of biopellet for some pioneer countries is presented. Netherland and Belgium use biopellet for electricity generation however Germany, Austria, Italy, France and Spain consume biopellet for heating. In these countries almost 2.7 million ton biopellet is consumed for heating purpose in the boilers with 90% of efficiency. By the way 3.3 million tons of biopellet combusted in the power plants for electricity generation with average 30% efficiency [20].

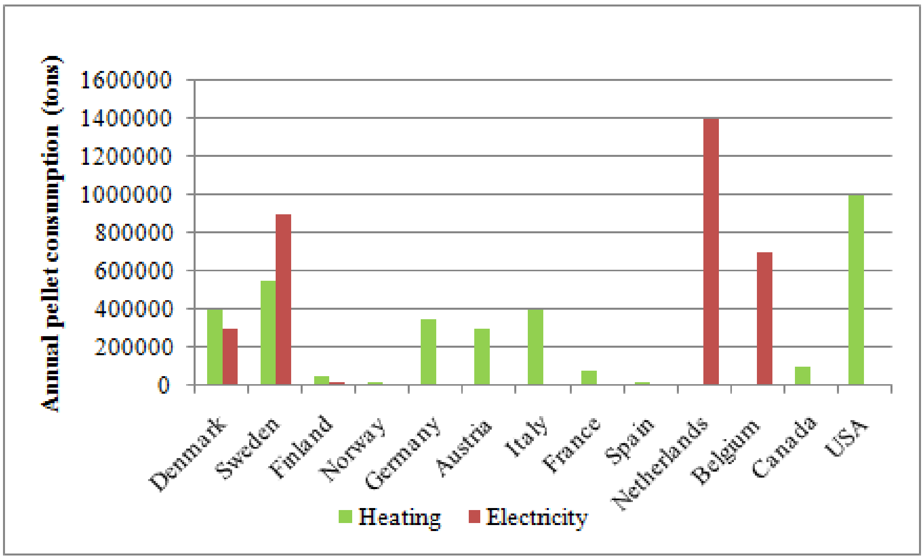

Figure 2.9: Comparison of international biopellet markets in 2008 [20].

In Europe nearly 630 biopellet plants generated approximately 8.2 million tonnes of biopellet in 2008. More than 50 percent of the biopellet plants are small scale that have less than 30,000 tonnes per annum production capacity. Market dynamic causes continually increase in the number of plants [19]. European big producers Sweden and Germany generate 1.4 million tonnes biopellet together by using sawmill residues as feedstock. European recent third largest biopellet producer Italy, have integrated biopellet plants including 0.65 million tonnes of capacity. In 2008, Sweden, Germany and Italy have the utilization rates of production capacities respectively 64%, 56% and 87%. On the other hand United States generated 1.8 million tonnes wood biopellet that was 66% of capacity in 2008. Canada produces 1.4 million tonnes which is its 81% of capacity. The economic crisis is affected the sawmill-operations and the output of sawdust and shavings so that production of both countries are reduced in 2008. This decrease is resulted bys also more recent start-up of the plants [35].

2.2.4. Case studies of biopellet applications

In this section several case studies of the current biopellet application will be presented.

Skelleftea CHP plant

In Sweden, there are applications of heat, electricity and biopellets production combinations. Skelleftea Kraft has two CHP plants using woody fuel and a number of different heating plants using wood, peat and oil as fuel. Skelleftea CHP plant 1 is fuelled with biomass-residues, amounting to about 200,000 wet-tonnes (450 GWh) a year, which consist mainly of sawdust, but also of bark, peat, and the branches and tops of trees that are trimmed off when they are cut. The CHP plant test operation started at the end of 1996. It has an output of approximately 63 MW of heat and 35 MW of electricity [38]. It consists of an integrated biofuel-based CHP plant and biopellet manufacturing facility, producing a yield of 59% fuel biopellets, 12% electricity and 20% heat at design load [36, 39].

Skelleftea Kraft produces biopellets in its bioenergy combines in Storuman and Hedensbyn, Skelleftea. Only the highest quality raw materials resourced from the by-products of logging, sawmilling and wood working industries are used in their production. Storuman bioenergy combine is started up in 2008 for producing district heating, biopellet and renewable-based power. The total production of the . Hedensbyn bioenergy combine 260 GWh heat, 170 GWh electricity and 130000 tonnes biopellets [40]. The flow diagram of the bioenergy combine plant is presented in Figure 2.10.

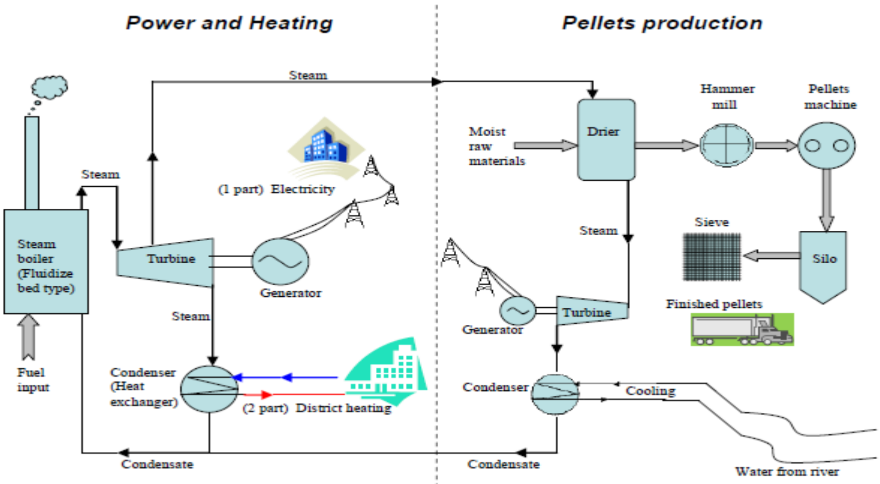

Figure 2.10: Bioenergy CHP with biopellet production at Skelleftea plant [41].

Avedore Unit 2

In Denmark, biopellets had been primarily used for heat production only: however since 2003 a new CHP plant partly fuelled by biopellets started operation and increase significantly total Danish biopellet consumption [42]. Avedore generates electricity to the Nordic power grid and residential heating for Copenhagen metropolitan. There are two boilers in Avedore unit. The first boiler is fuelled 100% of straw [43]. The main boiler generates steam for the main steam turbine of the CHP block by firing the fuels shown in the Figure 2.11.

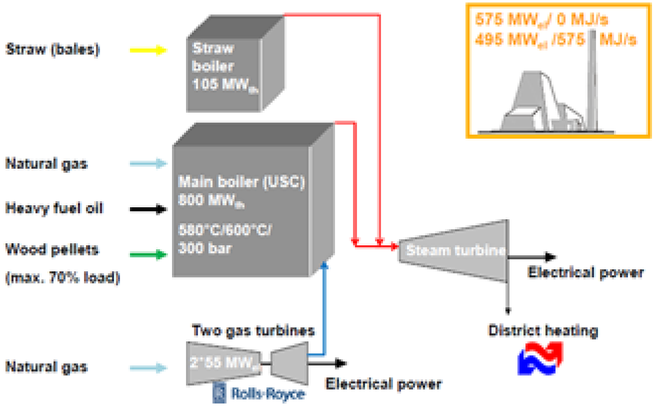

Figure 2.11: The multifuel concept of Avedore 2 [44].

Three units comprised by Avedore are an ultra-supercritical boiler plant, a gas turbine plant and a biomass plant. Avedore 2 unit has multiple fuel concept and different technologies such as ultra-supercritical boiler, steam turbines, and the largest straw-fired biomass boilers yet built and are derivative gas turbines for feed water preheating. Natural gas and heavy fuel oil is combusted in the ultra-supercritical boiler. The boiler is modified to burn 300000 tonnes of wood biopellets annually. Avedore 2 energy utilization can reach up to 94% of the fuel energy. Utilization of Avedore 2 unit and the closedown of many coal mine result 10% of CO_2 reduction in Denmark. Increasing interest in co-firing makes current usage of wood biopellets in coal fired dust burners. This resulted in a significant amount of wood biopellets being utilised mainly in the advanced Avedore 2 power plant located at south of Copenhagen [42-44].

Les Awirs

Contribution of solid biofuel for electricity generation is the result of the Green Certificate Scheme in Belgium. In order to provide sufficient fuel, biopellets are imported. The main biopellet consumer is Electrabel (GDF Suez) which has large demand with 80 MW and 100% biomass usage [37].

Les Awirs coal plant is modified to consume biopellet. Biopellets are pulverised and burned in dust using dedicated burners in the former pulverised coal boiler. Biomass is used from recycled forestry/wood conversion waste which otherwise would be lost and create greenhouse gas emissions. Fuel is provided from worldwide suppliers but the main focus is Belgian industry to reduce the transportation cost and emissions. The process flow of the Les Awirs is indicated in Figure 2.12.

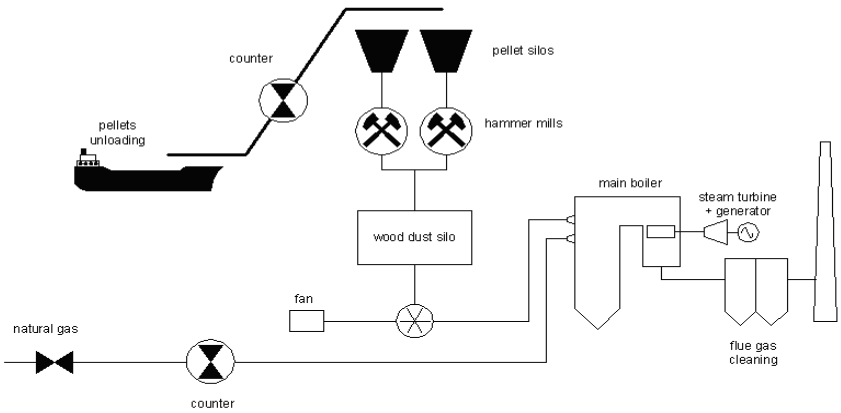

Figure 2.12: Process flow diagram of CHP from biopellet in Les Awirs [45].

Net electricity efficiency of the plant is 34%. Also it is not a cogeneration plant that would have required getting access to a potential customer for the residual heat [46].

2.2.5. Case studies of wood chips applications

Scharnhauser Park in Stuttgart is an example of the wood chip CHP. Scharnhauser Park is working basically for district heating system is based on organic Rankine Cycle (ORC) CHP [47]. This plant is a pilot project in order to getting practical experience about ORC and biomass furnace. Heat for 584 consumers (8000 in habitants) is provided by it. Plant supports 80% of heat demand and 50% of electricity demand in the region. 4,000 MWh of fossil fuel energy is saved by the biomass based CHP plant [48]. In Figure 2.13 district heating network of the Scharnhauser Park is illustrated.

In Netherland there is a wood chip CHP called Vink Sion. This plant provides 5 MW thermal powers by burning wood chips from pruning bushes and shelterbelts. Plant consumes 160 m^3/h wood chips. Electricity produced from plant is sold to the grid [49].

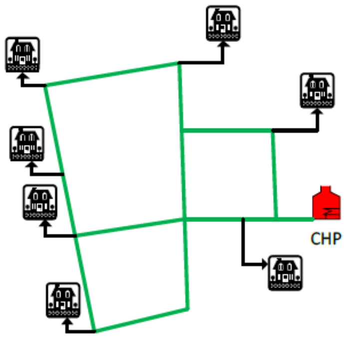

Figure 2.13: The DH network in Scharnhauser Park [47].

In Finland, BioNear plant is based on wood chip gasification CHP technology. It is an example of small scale CHP with 1 MW of thermal energy. CHP provide high efficiency [22].

In Italy, Castel d'Aiano school has a CHP system with wood chips gasification and Stirling engine. Electricity and heat demand of school campus, sport or recreational facilities and small settlements is provided by the CHP. System work almost 6,000 h and consumes 450 t/a wood chips. Annual electricity and heat production of the CHP are 210 MWh/a, and 480 MWh/a respectively [23].

2.3. Renewable-Based Electricity in Turkey

In this part renewable-based energy situation of Turkey will be mentioned on following subjects: renewable-based energy profile, bioenergy profile, bioelectricity, current laws and legislations, wood availabilty and biopellet in Turkey, respectively.

2.3.1. Turkey's renewable-based energy profile

Energy can be considered as one of the most important key player for countries in order to reach sustainable development. Population and economy of the Turkey grow parallelly. Energy demand increases correspondingly due to developing country conditions. This demand should be supported in order to keep sustainable development in economy and living conditions [50]. Turkey has energy diversity such as hydro, biomass, geothermal, coal and etc. but it has not enough available fossil energy resource. More than half of its energy is provided by imported fossil energy. Primary energy resources of Turkey can be listed as hydropower, geothermal, lignite, hard coal, oil, natural gas, wood, animal and plant wastes, solar and wind energy [50-51]. There is virtually all kind of energy resources available in

Turkey. However, these resources except for lignite and hydraulic energy are not enough to meet the energy requirement of the country: hence the renewable resource usage should be promoted [13].

Economic growth forces energy a rapid action to supply energy demand. Turkey has not enough fossil fuel reserve for its demand, but it has an abundant renewable energy resources potential. Turkey has to take up seriously new long-term energy strategies to reduce the share of fossil fuels in primary energy consumption [5]. In 2008, the renewablebased energy had 9 % share in Turkey's primary energy supply. The energy production from renewables is 9.319 million ton equivalent petrol (MTEP) [5]. Biomass such as wood, agricultural and animal based residues have the biggest share in renewable primary energy supply with 51.64 % share. The primary energy consumption is presented in Figure 2.14 [5]. More than half of the renewable-based energy produced as primary energy supply is obtained from bioenergy, which is used to meet a variety of energy needs, including generating electricity, heating homes (traditional use), fuelling vehicles and providing process heat for industrial facilities [52]. Renewable-based energy has 9.8% share in Turkish total primary energy consumption in 2009. Wood and waste based energy is the major renewable-based energy component in primary energy consumption [53].

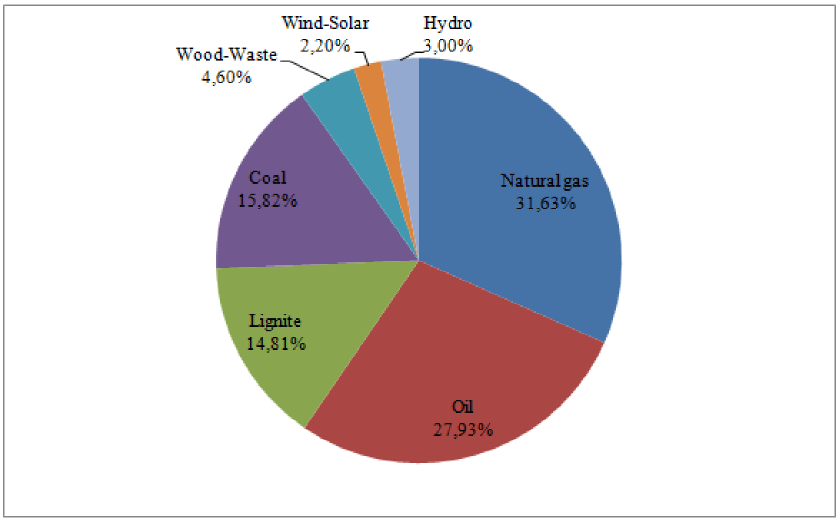

Figure 2.14: Energy resource distiribution of Turkey's primary energy consumption (2009) [53].

In Table 2.2 the potential of renewable-based energy in Turkey is given [13]. The values that are not defined is symbolized with line. Economic, natural and technical potentials of the renewable-based energies are presented in the table.

Table 2.2: Renewable-based energy potential of Turkey [13].

Renewable resources	Usage of energy	Natural potential	Technical potential	Economic potential
Solar	Electrical energy(TWh/year)	977,000	6,105	305
	Heat (mtoe/year)	80,000	500	25
Hydropower	Electrical energy(TWh/year)	433	216	127
Wind				
Direct terrestrial	Electrical energy(TWh/year)	400	110	50
Direct maritime	Electrical energy(TWh/year)	–	180	–
Sea wave	Electrical energy(TWh/year)	150	18	–
Geothermal	Electrical energy(TWh/year)	–	–	1
	Heat (MW_{th})	31,500	7,500	2,843
Biomass	Fuel (classic) (mtoe/year)	30	10	7
	Fuel (modern) (mtoe/year)	90	40	25

According to Table 2.2 the technical solar energy potential with an amount of 6,105 TWh/year is very high in terms of electricity production by the cause of the solar belt which Turkey is located, followed by the wind energy potential with an estimated value of 290 TWh/year and the hydro technical potential with 216 TWh/year. In order to realize the importance of this potential electricity generation in value 2009 can be compared. In 2009, 194,063 GWh Renewable except hydraulic and waste, have only very minor shares in power generation in Turkey. Total share of renewable in total primary energy supply has declined, owing to the declining use of non-commercial biomass and the growing role of natural gas in the system. Turkey has to take up seriously new long-term energy strategies to reduce the share of fossil fuels in primary energy consumption [13, 54].

2.3.2. Turkey's bioenergy profile

Biomass is the major resource of energy in rural area of Turkey. Biomass potential includes wood and agricultural and animal wastes. Available bioenergy resources for Turkey are various agricultural residues such as grain dust, crop residues and fruit tree residues [55-56]. The evaluation of the majority of biomass is achieved in rural parts to support heating and cooking needs of rural people. Traditional biomass use in stoves and fireplaces in order to cook meals and heating residences is very common. Almost 6.5 million residences consume wood as the primary heating fuel [51]. Some small scale industries realize use of agricultural waste, however there is no large scale application. Bioenergy potential for one year is indicated in the Table 2.3 Annual crops comprise the largest amount of Turkey's bioenergy potential [55]. Most of the biomass potential comes from annual crops and forest residues. Total energy generation potential of biomass is around 32 million tonnes of oil equivalent (Mtoe).

Table 2.3: Annual biomass amount and bioenergy potential of Turkey [55, 57].

Type of biomass resources	Annual potential (million tons)	Energy potential (Mtoe)
Annual crops	55	14.9
Perennial crops	16	4.1
Forest residues	18	5.4
Residues from agro industry	10	3.0
Residues from wood industry	6	1.8
Animal waste	7	1.5
Other	5	1.3
Total	117	32.0

The influences of selection of biomass are availability, resource and transportation cost, competing uses and prevalent fossil fuel prices. Biomass becomes attractive for developing countries with advantages such as using local feedstock and labour. Like other developing countries, biomass is an energy alternative for fossil fuel import [56].

Comparing other bioenergy resources, fuel wood has the major proportion with 21% of the total energy production of Turkey. Also energy production route does not require sophisticated knowledge. Annual fire wood production of General Directorate of Forestry (GDF) is about 6 million m^3 [58]. Biomass can be categorized into two parts traditional and modern biomass. Classic biomass comes from traditional resources and methods. Modern biomass is generated from conversion methods. Table 2.4 presents the classic and planned modern bioenergy production in Turkey. It is estimated that in the future modern biomass will have an increment. During the 25 year period total biomass increment is expected as 13% of total biomass in 2005.

Table 2.4: The present and planned biomass primary energy production (ktoe) in Turkey [56].

Years	2005	2010	2015	2020	2025	2030
Traditional biomass	6,495	5,754	4,790	4,000	3,345	3,310
Modern biomass	766	1,660	2,430	3,520	4,465	4,895
Total biomass	7,261	7,414	7,320	7,520	7,810	8,205

Traditional biomass utilization in Turkey is direct combustion of fuel wood, animal wastes, agricultural crop residues and logging wastes. Traditional biomass is not commercial energy resources comparing other primary energy resources in Turkey.

However it is widely used in rural and urban poor districts as the one of the main primary energy supplier [56].

The existing policy and market instruments are observed for analysing the adequate of them. Moreover, the existing policy/market instruments are not sufficient yet to take interest the private sectors investments to biomass and waste fuelled energy plants. By the way the financial and technical barriers to bioenergy as well as current oil and gas prices are also important player in the low private sector attention [58].

In the coming years, biogas, which is a modern biomass, will play an increasingly significant role for producing green-power. Last decade licenses of biogas plants are increased, 13 facilities have been licensed and total capacity reached 54.68 MW in 2009. Dung gas comprises the 85% of Turkey biogas potential and the remaining part comes from landfill gas. Animal waste based biofuels should compete with agricultural fertilizer sector [51-52]. Turkey can produce an important energy requirement from abundance renewable resources, however technical and economic conditions prevent sufficient utilization.

2.3.3. Bioelectricity in Turkey

Electricity production from biomass is a promising way for renewable-based energy generation in Turkey. Turkey has been working on laws and policies about renewable and biofuel according to European Union adaptation process. The Energy Market Regulatory Authority (EMRA) explanation on the license about electricity production and renewables situation in Turkey clarifies that renewables proportion are growing by many investments. The landfill gas energy plants own 50 MW_e electricity generation capacities in 2011. Moreover, there is a 49 MW_e capacity for biomass. The licenses from EMRA can easily show the situation for renewables in Table 2.5 [6, 59].

Table 2.5: Electricity generation situation of renewable in Turkey 2011 [6].

Electricity Generation	Capacity under construction (MW)	Capacity in operation (MW)	Capacity (MW)
Hydroelectricity	13,875	15,439	30,162
Wind-based electricity	3,523	1,402	4,929
Geothermal-based electricity	217	94	327
Landfill gas-based electricity	31	50	84
Biomass-based electricity	27	24	49

If the usable biomass is utilized, there is a net impact of $4.4 billion in personal and corporate income and represents more than 160,000 jobs [55]. Availability of required fuel, fuel prices and financing and the construction of the plant are important points for feasibility of a biomass plant.

The biogas use in energy generation is a new and popular topic for Turkey. In Turkey the biogas production has a rapid increment in recent year especially in municipal waste treatment plant. Turkey's first solid waste power project is in Adana province with an installed capacity of 45 MW. Another waste-to-power plant is in Izmit with an installed capacity of 5.4 MW. Two others, at a total capacity of 30 MW are at the feasibility study stage in Mersin and Tarsus provinces. A US firm will establish a 10 MW capacity power plant in Ankara-Mamak, which will use landfill gas generated from waste. Similar potential exists in large municipalities such as Istanbul, Izmir, Bursa, Adana and Antalya [56].

The bioelectricity generation occurs parallel to biogas production. Some municipals such as Adana, Istanbul, Ankara, and Gaziantep built up biogas and electricity generation unit in their municipal waste purification unities. This plants capacity is enough to provide whole or nearly %80 of process electricity need. Adana Municipal is built up first biogas and electricity production from municipal wastes in 2004. After water treatment the slurry process in biogas digestion system, then biogas is treated and is combusted in gas engine. The electricity production from waste is 803 kW in Adana. Ankara municipal treatment facility produces 92% of its process electricity requirement. Bursa, Kayseri and Isparta are the other cities that have biogas production facility. However they do not have electricity generation unit in yet and it is planned to build up in 4-6 years [60-62].

The commercial companies are encouraged by governmental policies for energy efficiency. Companies steer for producing own energy by effluent and waste with bioenergy conversion technologies. Europe has more biomass application than Turkey. In 2008 General Directorate of Electrical Power Resources Survey and Development Administration (EIEI) organize an event that is called Energy Efficiency in Industry 9th (SENVER) that courage efficient energy usage in industry. Turkey most of the important 14 industrial corporate create 35 projects for this organization. There are three categories in that competition and Cargill Food Company's 'Bioelectricity Production by Using Biogas' project is rewarded in

Energy Efficient Industrial Plant (EVET) category. The 25% of this project is supported by TÜBİTAK. The industrial firm Cargill describes the project, ‘The Company must treat its wastes in order to discharge at acceptable limits. The company produce foods and its wastes are organic as a result of this the effluent materials are derived into efficient biogas. This gas is converted into electricity and heat by using micro turbines.’ Finally the gain from that project is 198.8 ton equivalent petrol electricity and thermal energy for a year. This project is one of the important samples for bioelectricity production in industry. The results are a good example for encouraging the companies [63]. To sum up, meeting energy demand is essential for being able to continue development in the economy and improving the living conditions of humankind [6, 59].

2.3.4. Current Turkish legislation on bioenergy

Existing Turkish law and regulation with relevance to the use of renewable-based energy is limited. First law for renewable-based energy is accepted by in 10 May 2005. This law is updated in December 2010. The law is called as Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy (Law no. 5346). As indicated by the titles, this legislation has been developed for the electricity sector. In both regulations, biomass is included in the definition of renewable energy resource [52].

By “Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy” law, purchasing guarantee of a feed in tariff has been given to the electricity generated from renewable and so that investments on electricity generation by private sector has been facilitated. The Environment and Forestry Ministry of Turkish Republic is encourage the using of renewable resources and clean energy technologies for climate change mitigating purposes. The importance of air pollution reduction and carbon accumulation functions of forests is stated in the Turkish National Forestry Programme which is supported by a Food and Agriculture Organization (FAO) project [58].

In law with number 5346 feed in tariff is determined for renewable. Renewable-based electricity feed in tariffs are listed in the Table 2.6. Electricity feed in tariff for biomass resource is 13.3 US$cent/ kWh. Feed in tariff can be increased depending on the used technology. In this law there are supplement prices on feed-in tariff depending on the technology. For instance if a bioelectricity plant has cogeneration technology, feed-in tariff will be 13.7 US$cent/ kWh instead of 13.3 US$cent/ kWh (0.4 US$cent/ kWh comes from CHP technology). Feed-in tariff supplements are mentioned for a different type of renewable-based electricity specified in this law [64].

Table 2.6: Feed in tariff for renewable-based electricity in Turkey [6, 64].

Renewable-based electricity	Feed-in tarifff (US $ cent/kWh)
Hydroelectricity	7.3
Wind electricity	7.3
Geothermal electricity	10.5
Bioelectricity	13.3
Solar electricity	13.3

Moreover, another important point in law with number 5346 is purchasing electricity. Feed-in tariff in Table 3.6 is applied for 10 years. However feed-in tariff supplements are applied for 5 years [64].

Additional payment to feed in tariff for bioelectricity is given in the Table 2.7.

Table 2.7: Additional feed-in tariff for bioelectricity [64].

Renewable based electricity	US $ cent/kWh
Fluidized bed boiler	0.8
Liquid and gas fuelled boiler	0.4
Gasification and gas treatment	0.6
Steam or gas turbine	2.0
Internal combustion engine and stirling engine	0.9
Generator	0.5
Cogeneration	0.4

According to the Climate Change Strategy Document of the Prime Ministry High Planning Council (10 May 2010) Using wood biopellets instead of coal will be promoted [58].

The policy options for wood energy of the General Directorate of Forestry Bioenergy Application Program are [4]:

- Encouraging increased production and/or use of energy derived from woody biomass resources through GDF policies, information dissemination, and state and regionally funded research and demonstration projects to establish
- Spreading small scale power generators which are use wood in rural areas.

One piece of legislation is the Electricity Market Licensing Regulation. Electricity Market Licensing Regulation, promotion of renewable-based energy in the electricity market has been assigned to the Energy Market Regulatory Authority (EMRA). The incentives brought into existence based on the Electricity Market Licensing Regulation are given below:

- Only 1% of the total licensing fee will be paid by companies that apply for licensing of construction and operation of a natural resource or renewable energy resource [52].
- Renewable-based energy generation plant shall not pay annual license fees for the first 8 years following the facility completion date indicated on their respective licenses [52].
- Turkish Electricity Transmission Company (TEIAS) and/or distribution companies shall assign priority for system connection of generation facilities based on domestic natural resources and renewable resources [52].

If native energy resources like biomass are evaluated sufficiently and efficiently, energy dependence on foreign countries will decline dramatically [50]. There is no special legislation or law for heating.

2.3.5. Wood availability and distribution

Turkey forest residues produced from forest thinning activities, silviculture activities and harvesting activities. In Figure 2.15 forest biomass frequency of Turkey is shown [65]. Distribution of forest is presented in the Figure 2.15 with different colours, depending on the density of forest. On the other hand, wood processing industries create wood residues which are not common in energy sector usage [65].

Figure 2.15: Distribution of forest potential in Turkey [65].

Mediterranean Region of Turkey has the maximum firewood, forest residues and shrubs vegetation production. Turkey annual forest residues capacity is mainly 5 million tonnes. Some of the examples are that Muğla Forest District Directorate has got about annual 750,000 tonnes potential production of forest residues and Adana Forest District Directorate has got about 550,000 tones potential production of forest residues. Roots, pinecones, wood briquettes, and woodchips are consumed in some sub district chieftaincies of Bolu, İzmir, Kastamonu, Çanakkale Forest District Directorates for heating. Energy potential from wood residues: installed power generation capacity of Turkey is 40835.7 (MW). Turkey can produce approximately 5,000,000 MW of electricity from forest residues. Forest residues can meet the 3% of total energy consumption of Turkey [4, 65].

The forest industry in Turkey is increased 35% in 4 years. This results that industrial wood production become 10 million m^3 and fire wood is 4 million m^3. When the wood is harvested almost 50% percentage of it is not suitable for industrial production. 4 million m^3 of 10 million m^3 industrial wood comprises residues [4].

2.3.6. Biopellet in Turkey

The most common biopellet feedstock is wood all over the world [35]. Although, Turkey has available wood resources, biopellet generation is not common. A medium density fiberboard (MDF) producer Akdent generates 40 tonne biopellet from sawdust per day since 2008. Some private facilities trying to built biopellet plant and attempt to production. At the same time some governmental investments on biopellet are supported. Governmental projects are partner projects with countries that are more advanced on biopellet. Although people in rural regions use wood as primary energy resource, industrial wood energy sector has not developed yet [58].

Some factories produce wood briquettes and some big forestry use wood chips for heating purpose. Legislations promote the commercial biomass usage for energy production. Commercial wood removals are 16 Mm^3, annual increment is approximately 36 Mm^3. Turkey's forest potential is shown in Table 2.8 [58, 66]. Total growth is about 28,000 thousand m^3 of wood and total forest resource is about 936,000 thousand m^3 of wood.

The total forest potential of Turkey is around 935 millionm^3 with an annual growth of about 28 million m^3.The average annual growth rate of the forests is about 3%.

Around 90% of this potential includes highly productive forests and other woodlands, the others being low productive forests and other woodlands [66].

Table 2.8: Turkey's forest potential and annual growth [66].

Forest Potential	Resources (thousand m^3)	Annual growth (thousand m^3)
High productive (total)	847,032	25,605
Forest	88,300	4,813
Other woodlands	758,732	20,792
Low productive (total)	88,479	2459
Forest	34,129	1115
Other woodlands	54,350	1344
Total	935,511	28,064

In recent years, Turkey has invested significantly in its improved forest information systems and forest management in general. There are projects cooperated with Netherlands aimed improved forest information systems and forest management planning. Fire protection activities produce residues that are suitable for biopellet production. Fire line construction and deadwood clearance leave the significant volumes of woody biomass [4].

Biopellet is low-cost resources for regional wood processing industries, stimulating regional economic development. The first biopellet project of Turkey is integrated forest fire protection and sustainable wood biopellet production. The financial partners are from Netherland BioCandeo Group International B.V and Biyokor from Turkey. The research support will be done by Suleyman Demirel University and the supporter stakeholder is GDF. In this project the aim is to establish an initial capacity for the production of certified wood biopellets in the Muğla Forest District Directorate, logistic export chain for wood biopellets, local supply chain initial biopellet production capacity of 15.000 ton/month [65, 67]

With this project an infrastructure to serve both local and export markets in a balanced approach will be developed. In recent times similar application will be applied in other forest regions of Turkey [67].

Forestry product sector can be divided into seven different application areas: furniture, timber and pulp mill have the biggest wood consumption. In last four years forestry industry increased 35%, industrial wood production is 10 million m^3 and firewood production is 4 million m^3. Most of the wood residues are existed in Marmara Region. Timber industry is developed in Cide (Kastamonu), Düzce, Etın, Devrek, Yenice, Ayancık, Bafra, Rize, Ordu, Ardeşen, Borçka and Demirköy (Kırklareli): furniture industry takes place in Manisa, Karabağlar (İzmir), Siteler (Ankara), inegöl (Bursa), Düzce, Dudullu (İstanbul) and pulp mill industry is developed in Aksu (Giresun), Paşaköy, Çaycuma ve Bartın, Dalaman (Muğla), Taşucu, Bolvadin (Afyon), İzmit, Balıkesir. Some of these industries utilize their residues such as Oyka paper and packaging company generates 32 MW heat and 12 MW electricity by wood fuelled CHP. An Indian firm Abellon will construct a facility that generates 250 ton/day capacity wood biopellet [4].

2.4. Methods of The Study

In this part, general information about the methods of the study will be explained. These methods are LCA, mass and energy balance and economic assessment.

2.4.1. Life Cycle Assessment

In this thesis, life cycle assessment based on International Organization of Standards (ISO) 14040 is implemented to the electricity and heat generation system from wood biopellet and woody biomass.

LCA observes whole life cycle comprised processes from cradle to grave. LCA evaluates the potential environmental impacts and resources used throughout a product's lifecycle, i.e., from raw material acquisition, via production and use phases, to waste management (ISO, 2006a) [68]. Product concept comprised both goods and services. All attributes or aspects of natural environment, human health, and resources might be considered and assessed comprehensively [69]. The uses of LCA can be classified as general and particular:

General:

• Compare alternative choices.
• Identify points for environmental enhancement.
• Count on a more global perspective of environmental issues, to avoid problem shifting.
• Contribute to the understanding of the environmental consequences of human activities.

• Establish a picture of the interactions between a product or activity and the environment as quickly as possible.

• Provide support information so that decision-makers can identify opportunities for environmental improvements [69].

Particular:

• Define the environmental performance of a product during its entire life-cycle.

• Identify the most relevant steps in the manufacturing process related to a given environmental impact.

• Compare the environmental performance of a product with that of other concurrent products or with others giving a similar service [69].

The LCA concept first appear in 1960s and developed since the 1970s. However 1990s is a new age for LCA because of increasing attention from individuals in environmental science fields. Several name is offered for this study for instance eco-balancing (Germany, Switzerland, Austria and Japan), resource and environment profile analysis (USA), environmental profiling and cradle-to-grave assessment [70]. Many organizations works ended with a consensus about LCA framework and inventory methodology is defined well. According to ISO 14040 and 14044 standards LCA includes four interrelated components. These four phases are goal and scope definition, inventory analysis, impact assessment and interpretation [71]. These steps are showed in Figure 2.16.

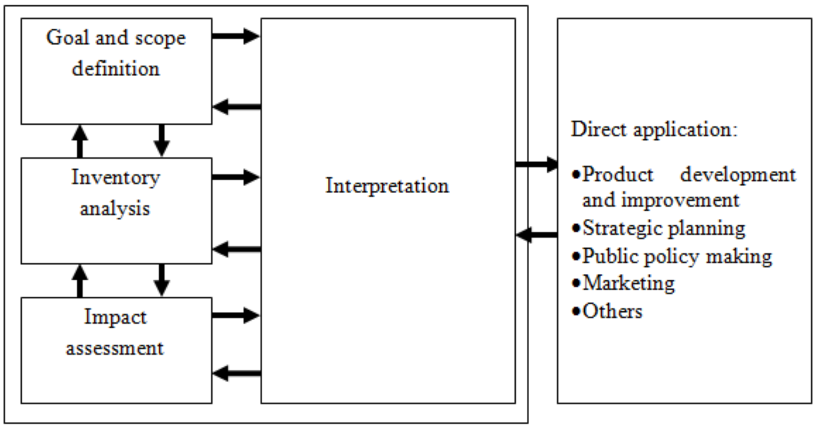

Figure 2.16: The LCA framework [70].

Interrelated steps make LCA an iterative process. These steps are explained in this chapter and the application of the system will be given in the progressive parts.

2.4.1.1. Goal and scope definition

The most significant part of LCA can be defined as goal definition and scoping step which determine the statement shaping the study infrastructure of study and defines purpose of the study. Furthermore, the expected product of the study, system boundaries, functional unit and assumptions are defined in this section [70]. Choices regarding system definition and boundaries are more or less accurate due to the goal and scope of LCA. The goal may be process design-, operation- or policy-oriented [73].

A general output and input flow diagram is generally suitable for designating the system boundaries. Inside the system boundaries, all operations that contribute to the life cycle of the product, process, or activity are included. Analyzing more properly the system can be separated into small systems [68, 70].

The quantitative measure of the functions providing the goods are called functional unit [69]. Definition of proper functional is most significant part since different functional units could lead to different results. For instance in biomass systems the results should be stated on a per unit output basis to be independent of the biomass feedstock and be able to properly compare several of them, or per unit input basis to be independent from the conversion process and compare different conversion systems for a given biomass resource [74].

2.4.1.2. Life cycle inventory analysis

Life cycle inventory (LCI) step includes the identification and quantification of raw materials and energy inputs, air emissions, water effluents, solid waste and other life cycle inputs and outputs. Comparing the other sections of LCA this parts required more intensive work and are time consumption because of proper data collection [70-72].

General data required for LCA can be combined together with an existing LCA databases and software. Non-specified data about a product for instance the production of electricity, coal or packaging that are not specified for product can be used for processes [70].

Therefore, inventory analysis concept includes schematic of the whole system in the way of the inputs (energy, water, raw materials,) and the outputs (products, co-products and emissions). Combination and relation of materially and energetically operations (e.g. manufacturing process, transport process, fuel extraction process) for the purpose of specific function constitute a system. A basic system schematic is illustrated in Figure 2.17. In the inventory analysis methodology any product or service needs to be represented as a system [70]. As seen in the figure all the steps of a product: material production, manufacturing use and energy requirement are taken into consideration in LCA study.

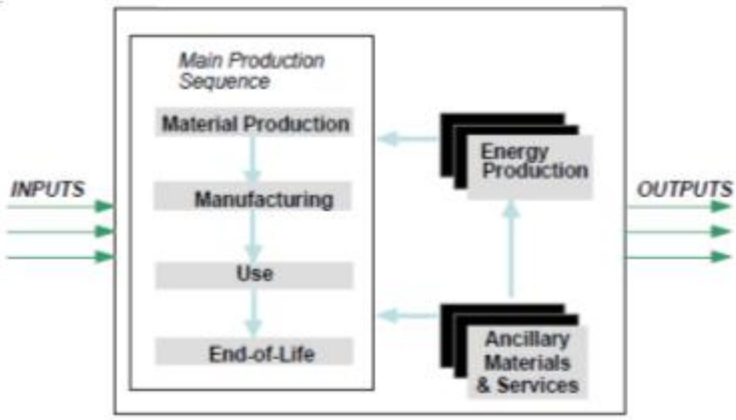

Figure 2.17: Simplified illustration of a generic process within a process flow chain analysis [75].

When the system boundaries are described, it is more systematic to analyze all the flows of materials and energy across the system boundary either into or out of the system itself [76].

If the output of the system is more than one (e.g. electricity and heat), it is necessary to distribute the environmental burdens [71]. In order to distribute burdens there are some allocation procedure on substitute methods in the ISO 14044. By-products or scientist by-product handling choices lead to the varied allocation methods from study to study [77].

Bioenergy systems comprise several energy products such as electricity and/or heat. Moreover several material products can be produced and compostable matter from biogas production: in such cases the emissions and offsets generated by the system must be estimated and allocated among products and co products [78].

System expansion approaches to the system effect-oriented, by the way economic allocation approach cause-oriented [79]. Weight basis allocation associate products and co-products using a physical property that is available and easy to interpret. It is possible object to energy allocation approach in the case where the co-products are not meant for energy purposes. In the inappropriate physical properties case ISO has some recommendations: the use of other basis for allocation such as the economic value of the products. A justification for economic allocation can be explained like that allocation according to the share on sales value is applicable for environmental burdens of a multifunctional process because the main driving force of production system is demand. The implementation problems can be caused by price variation, subsidies, and market interferences [73]. The most suitable allocation method for bioenergy system is still undefined issue. When a bioenergy process has multiple products such as heat and power in the same unit or animal feed from liquid biofuels production, it is especially hard to decide the best allocation method [74].

2.4.1.3. Life cycle impact assessment

In life cycle impact assessment (LCIA) inventory analysis are used in order to understand and evaluate environmental impacts according to defined framework in goal and scope of the study. LCIA assigned the inventory results into different impact categories due to the expected types of impacts on the environment [70].

LCIA should construe the inventory results into their potential impacts on what is referred to as the ‘‘areas of protection’’ of the LCIA, i.e., the entities that we want to protect by using the LCA. Protection areas of LCA are human health, natural environment, natural resources, and man-made environment [69].

In this thesis global warming potential (GWP) will be taken into account for environmental assessment. In order to calculate GWP CO_{2eq} of the total emission should be calculated. Furthermore, the most important greenhouse gas in this content is CO_2 which gives reference to calculate the global warming potential. Other gases, which are contemplated gases into this, are CH_4 and N_2O [77]. Although there are more GHG gases, three gas is observed and the effect of rest is ignored. Global warming potential is a measure of the future radioactive effects of a substance relative to the emission of the same amount of CO_2 integrated over a chosen time horizon [77]. All contemplated greenhouse gases and their influence are shown in Table 2.9. The result of the programmes will be mentioned in form of CO_{2eq}.

Table 2.9: CO_2 equivalent factors for some greenhouse gases [77].

	GWP (100)
CO_2	1
CH_4	23
N_2O	296

2.4.1.4. Life cycle interpretation

The main reason for applying LCA is to achieve a result in order to use in decision support or to provide a readily understandable result of an LCA. All the outcomes of the inventory and impact assessment are discussed together. After the discussion identification of the environmental issues is expressed for conclusions and recommendations consistent with the goal and scope of the study. LCI and LCIA results are identified and quantified with a systematic technique. Also checking and evaluating information is done and all of them are communicated effectively. Quantitative and qualitative measures of improvement can be comprised in this assessment for instance changes in product, process and activity design: raw material use, industrial processing, consumer use and waste management [70].

All the LCA steps have life cycle interpretation. When comparisons of the two product alternatives are evaluated and one of them has higher consumption of each material and of each resource, an interpretation purely based on the LCI can be conclusive. If the comparison based on impact categories is managed, there should be trade-offs between product alternatives or in a single lifecycle study if it is desirable to prioritize areas of concern [69-70].

2.4.3. Mass and energy balance

Material and energy balances are very important in an industry. Material balances are fundamentals to the control of processing, particularly in the control of yields of the products. The first material balances are determined in the exploratory stages of a new process, improved during pilot plant experiments when the process is being planned and tested, checked out when the plant is commissioned and then refined and maintained as a control instrument as production continues [81].

When any changes occur in the process, the material balances needs to be redetermined. The increasing cost of energy has caused the industries to examine means of reducing energy consumption in processing. Energy balances are used in the examination of the various stages of a process, over the whole process and even extending over the total production system from the raw material to the finished product [80].

Material and energy balances can be simple, at times they can be very complicated, but the basic approach is general. Experience in working with the simpler systems such as individual unit operations will develop the facility to extend the methods to the more complicated situations, which do arise. The increasing availability of computers has meant that very complex mass and energy balances can be set up and manipulated quite readily and therefore used in everyday process management to maximise product yields and minimise costs [80-81].

2.4.4. Economic assessment

Economic assessment is the last analysis of this thesis. Although for economic analysis there is some methodological analysis exists such as life cycle cost assessment, these methodological analysis is not used. All the costs are calculated except the disposal of the system, because there is not enough information about disposal and it can be a done in another study.

Economic analysis is important while it provides costs of all the items in a chain during its whole life and identifies all the relevant cost and measuring them [82-83]. Economic analysis estimates the value of all relevant costs regarding to the study period, comprising construction costs, maintenance, repair, and replacement costs and energy costs [8].

To achieve the most optimal design it is usual to minimise the expected value of the discounted costs for economic analysis. Economic assessment is suitable for implementing current and new systems. If the analysis on ‘do nothing’ is comprised by an analysis, current system can be evaluated with economic analysis. It makes current system comparable with the other systems to give decision on leaving the existing system unchanged [82]. General application of the economic assessment is determining the future operational savings justify higher initial investments [8].

Economic analysis has some limitations. It is important to minimise the economic assessment limitations in order to increase the practical use. The result of the economic analysis can vary from study to study and the results are called neither wrong nor right, only reasonable or unreasonable. Accuracy of the inputs and the interval of estimate is better than the accuracy of the results because of it depends on supposition. It is a particularly true analysis. It is difficult to figure outing errors in accuracy and the variances are often larger found by statistical methods. Most details require extensive extrapolations and obtaining facts is difficult [83].

Economic analysis is useful for affordability studies, resource selection studies of competing systems, warranty pricing and cost effectiveness studies. Identifying costs drivers and ranking the comparison of competing designs and support approaches can be done with economic analysis by suppliers [83].

Economic analysis provides change provincial perspectives for business issues with emphasis on enhancing economic competitiveness by working for the lowest long-term cost of ownership. Generally economic view is useful for long term decisions. Consider these typical events observed in most companies. Determining capital is important for the engineering. As a result engineers avoid specifying cost effective redundant equipment needed to accommodate expected costly failures.

2.5. Literature Review

In this part other studies about woody fuels and biomass CHP systems results will be given. Some of the researches about woody fuel-based systems are used observed in the literature. General contents of these studies are clarified.

First of all, Fantozzi and Buratti (2010) evaluated wood biopellet from short rotation coppice using data measured on real plant in Italy by using Simapro7. Biopellets are combusted in a 22 kW boiler for residential heating. They focus on human health, ecosystem quality and resources [84].

Mani (2005) investigates biomass densification process and system analysis. In that study, biopellet production steps are observed and LCA is applied for the densification (drying, size reduction and biopelletizing) on the gate to gate basis. Coal, dry sawdust, wet sawdust, wood biopellet and natural gas are used for comparison. Energy, environment impacts, economics and fuel quality are the main criteria of his study for Canadian industry [85].

Margelli et al (2009) assess environmental effects of biopellets from Canada to Europe. Their analysis starts from harvesting and continues sawmill residues transportation, biopellet production, biopellet ground transportation and biopellet ocean transportation. Total emission over entire life is observed and assessed regarding to total energy consumption and environmental impacts on global warming, acid rain formation, smog formation and human health [86].

MacLean, McKechnie and Zhang investigate LCA of wood biopellet use in Ontari's generating plants. Their objective is determining greenhouse gas (GHG) reduction of the use of wood biopellets from biofibre from the forest region for electricity generation. Production of the biopellets is also investigated. Air pollutant emissions according to life cycle basis are compared to reference electricity pathways coal and natural gas [75].

Jungmeier (2008) makes a research on contribution of increased biopellet use for the climate protection. It focuses on LCA based GHG analysis of the biopellet for heat and electricity generation. It evaluates heat and electricity production as separate operations. Heating and electricity generation with biopellet provide 91% and 85% emission reduction compared to light oil heating system and natural gas power plants respectively [87].

Another study is done by Hagberg et al (2009) is titled as LCA calculations on Swedish wood biopellet production chains. Calculations are done for biopellet production from wet raw material, dry raw materials and round wood. Also production plants that are integrated, CHP, district heating or a saw mill are observed. Total CO_{2eq} of the systems are determined as results [88].

On the other hand chipped based studies are also available in the literature. Raymer presents a paper on comparison of avoided greenhouse gas emissions using different kinds of wood energy [89]. Johansson et al. has a study on wood chips which is based on called transport and handling of forest energy bundles advantages and problems. Chipping system and its energy requirements are observed [90]. Özdemir (2011) also studied LCA of the chipping process in Germany. GHG emission of the system is determined [91].

Moreover, economic analysis of biopellet plant is done by Campbell (2007) for agricultural biopellet plants. The capacity of the observed plants change from 2t/h to 14 t/h. All the production steps are observed capital investment cost and operational cost in a detailed way. Biopellet production cost varies from 110 $\$_{2007}$/t to 180$\$_{2007}$/t depending on water content of the materials [92].

Obernberg and Thek (2002) also observed biopellet production in Sweden and Austria. Their results changes between 79.6 $€_{2001}$/t and 94.6 $€_{2001}$/t depending on country influenced raw material and production cost [93].

In Turkey, General Directorate of Forestry (GDf) has a project cooperated with Netherland. This project is based on biopellet production from forest residues. Another study of GDF is producing wood chips from forestry residues as well. The economy of the woodchips usage for heating purpose is examined. Comparing coal fuelled heating chips are relatively economical [4].

Economic assessment of the biomass fuelled CHP is studied by Obernberg and Thek (2004) for Denmark and Austria. Biomass fuelled Stirling engine process, organic Rankine cycle process, steam turbine process based CHP systems are observed. In Danish conditions, electricity generation cost is 0.1068 $€_{2003}/kWh_e$ in steam turbine CHP. The specific electricity generation cost for Austrian market conditions are 0.1082 $€_{2003}/kWh_e$, 0.1248 $€_{2003}/kWh_e$, 0.1418 $€_{2003}/kWh_e$ for steam turbine, ORC and Stirling engine respectively. According to this result steam turbine based CHP seems to be the most economical system [94].

All in all, for an integrated consideration for potential of wood fuels in a Turkish context, the available studies are not nearly sufficient. An investigation of wood fuel evaluation in Turkey is necessary. There are serious studies in Europe and America as some of them given above but local values for Turkey should be evaluated.

3. APPLICATION PART

In this chapter LCA analysis, mass and energy balance and economy analysis is applied three cases using woody biomass. A brief information about the cases, LCA application, mass and energy balance results and economic asessments are presented on following subjects, respectively:

- Information About the Cases
- Life Cycle Assessment Regarding Electricity Generation from Combined Heat and Power Plants Using Woody Biomass in Turkey
- Mass and Energy Balance Regarding Electricity Generation from Combined Heat and Power Plants Using Woody Biomass in Turkey
- Economic Assessment Regarding Electricity Generation from Combined Heat and Power Plants Using Woody Biomass in Turkey

3.1. Information About the Cases

In this chapter three cases will be observed. Two of these cases are fuelled by woody biopellet and one is fuelled with wood chip. Energy conversion is processed in the same CHP technology: however pretreatments process of fuel shows difference. Pellet and chip production pathways validate according to selected technology and selected plant orientation.

First case, which has integrated pellet and CHP plant, is named as Case A. Case A uses wood biopellet from locally generated sawmill residues which are collected from three cities and derived into biopellet. Biopelletizing plant and CHP plant are combined systems at the same location and there is no transportation between two plants. In Case A, residues are collected from wood operating industries such as timber, furniture and plywood. The emissions and energy consumption during the sawmill operation is not taken into consideration. Then, the shavings and sawdust are carried into biopellet production facility. After some required steps: drying, grinding, biopelletizing, cooling and screening, biopellets are formed. The wood biopellets are combusted in CHP plant in order to produce heat and electricity. As mentioned before biopellet plant and CHP plant are combined systems as a result of this, CHP provides energy for drying sawmill residues instead of natural gas drying. Then, produced power is given to the electricity grid and rest of heat provides heat demand of a residential area with 290 houses via district heating system. Details of the district heating will be explained in the further section. District heating system ends after residential heat station. The flow diagram of Case A is displayed in Figure 3.1 to have a more detailed view to the whole cases.

Secondly, next biopellet fuelled pathway is called Case B. It is showed in Figure 3.2. In case B sawmills and biopellet plants are close to each other: but the CHP plant is far from them. It is close to consumers so that biopellets are carried by trucks to the CHP plant. General structures of the two cases are close to each other with some exceptions. Differences between Case A and B can be determined as follows: in Case B natural gas is used for drying process instead of heat from CHP and in Case A sawmill residues are carried rather than biopellets as in Case B. District heating in Case B is different than case A as well. Case B can provide space heating for 460 households but Case A supports heat for only 290 households.

Finally, the third woody fuel-based pathway is wood chips fuelled case (Case C). It is based on chipped forest residues as showed in Figure 3.3 In this supply chain, forest residues are processed into wood chips. Trees are harvested from the forest and then transported to the lumber mill. The rest of the timbers remain in the forest as residues, including both shavings and sawdust is combined with other forest residues (cultivation, civil culture residues etc). Then they are collected, chipped and transported by trucks for using in a CHP plant. Products of electricity and heat are used like Case A and B. District heating system and numbers of heated residents are similar to Case B.

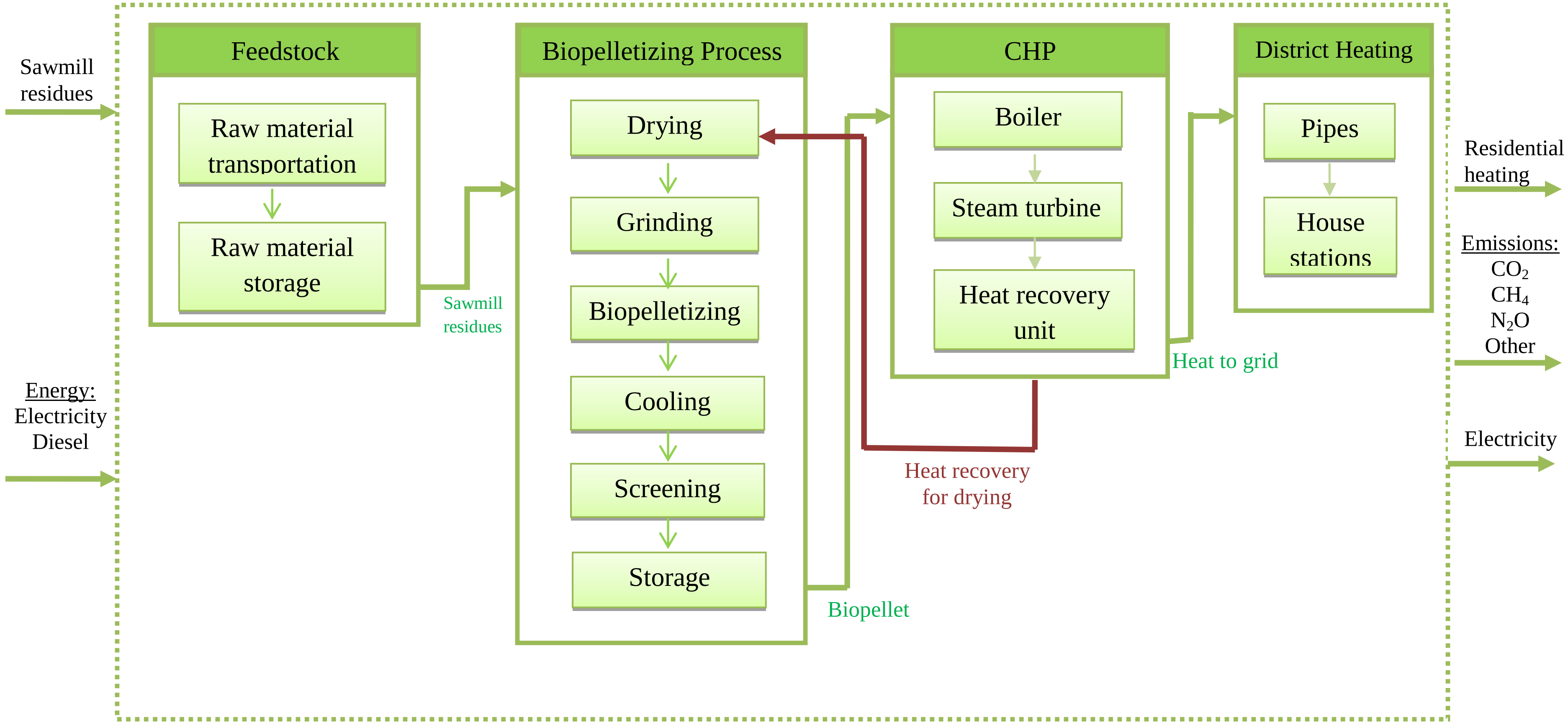

Figure 3.1: Flow diagram of all steps in Case A.

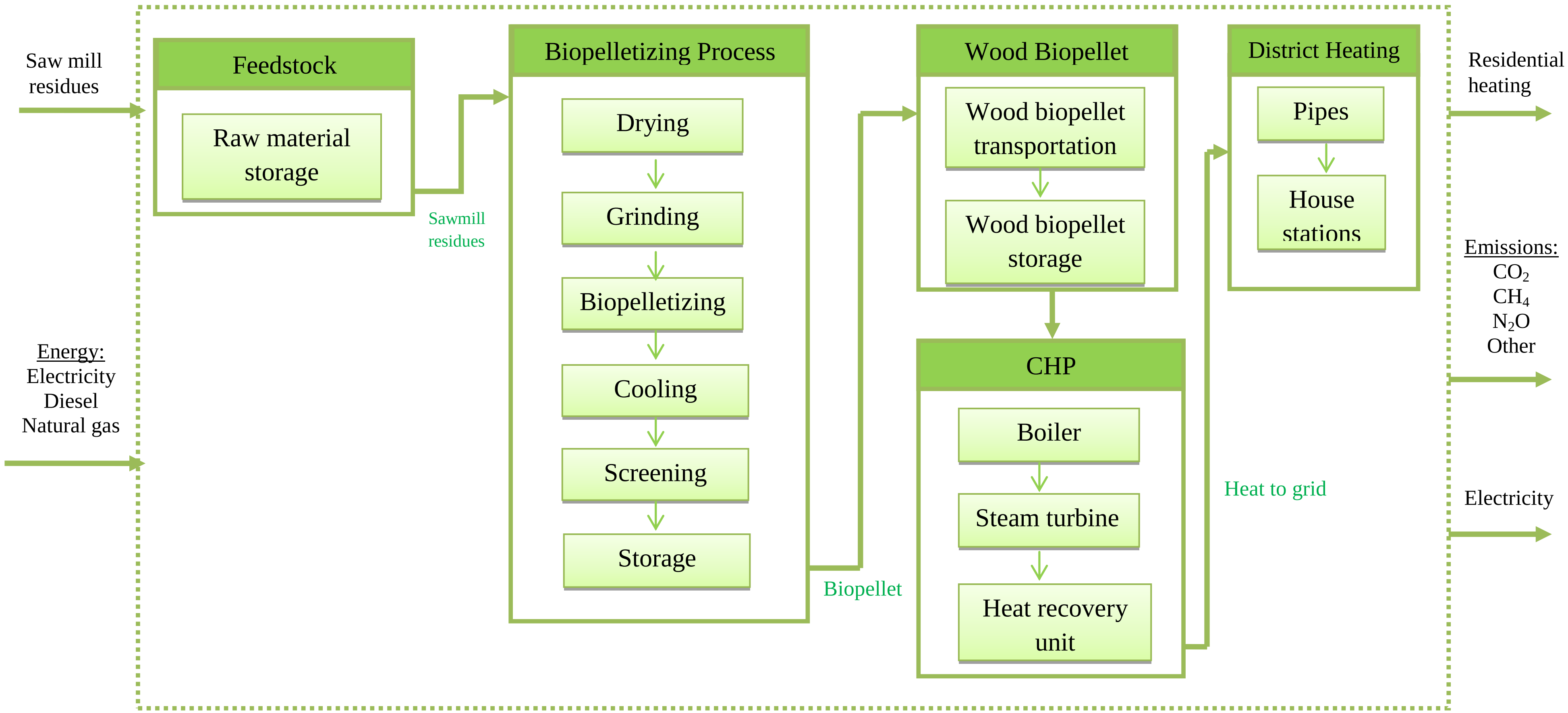

Figure 3.2: Flow diagram of all steps in Case B.

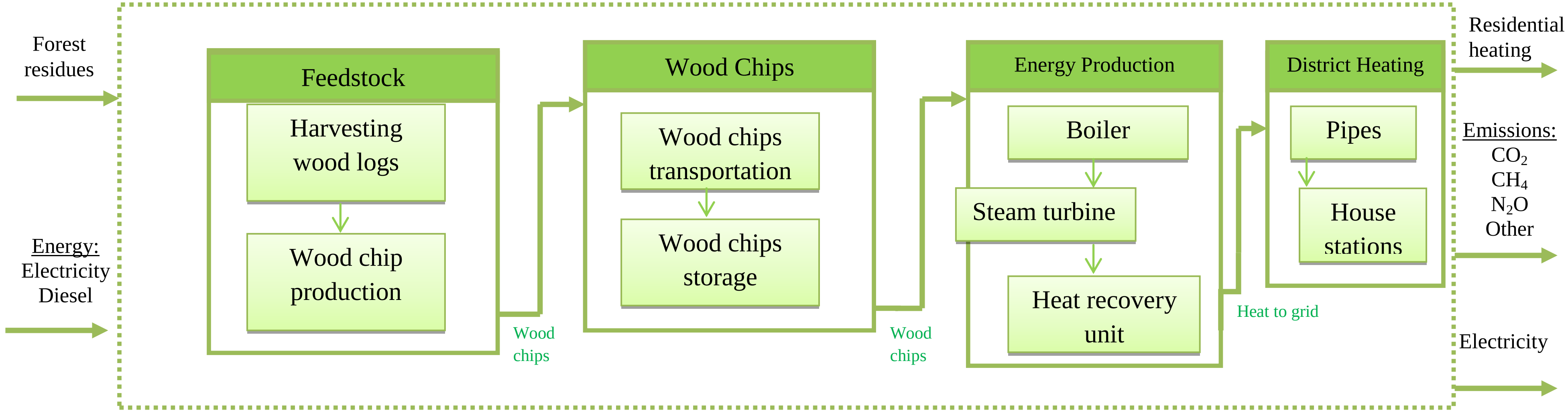

Figure 3.3: Flow diagram of all steps in Case C.

3.2. Life Cycle Assessment Regarding Electricity Generation from Combined Heat and Power Plants Using Woody Biomass in Turkey

In this study LCA according to ISO 14044 methodologies will be applied to show the applicability wood biopellet production systems and biopellet fuelled CHP in Turkey. During LCA assessment LCA software tool GaBi is used. GaBi programme file exists but in order to access the programme it is necessary to have the dungle of GaBi which is kept in Institute of Energy Economics and the Rational Use of Energy (IER) in University of Stuttgart.

GaBi is a commercial LCA tool which has a flow oriented tool and allows process modeling, balance calculations, analysis and interpretation. Data on the life cycle inventory, the life cycle impact assessment and the weighting models are separated from each other. GaBi structure is based on plans, process and flow. Different processes such as conversion, production are linked to each other by means of flows. Plans contain flow and process relationships and processes among each other. Figure 3.4 shows the interface of the software [95].

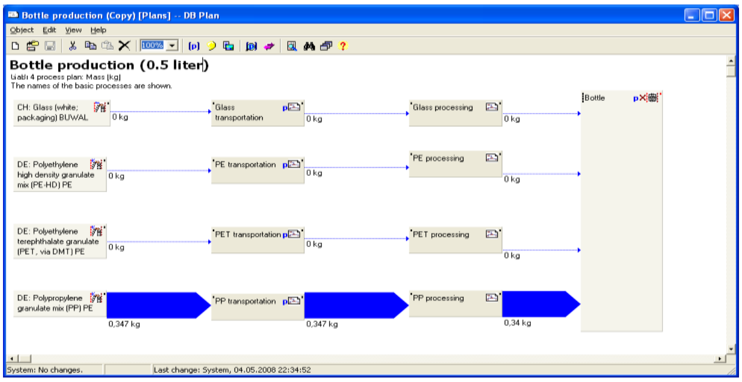

Figure 3.4: User interface of GaBi [95].

3.2.1. Goal and scope definition of systems

The goal of this study is defined in the aim of this study section properly. In this LCA analysis, it will be determined: environmental effects of wood biopellets, wood chip production and use for electricity generation in CHP system with Turkish conditions. These systems will be observed with respect to GHG emission reduction results. Finally results will be compared to reference energy generation pathways for Turkey. Moreover, economic feasibility of electricity generation from wood biopellet will be observed.

3.2.1.1. Functional unit

The reference functional unit of inventory analysis and impact assessment is energy content expressed as 1 of kWh_e electricity delivered to the main grid in Turkey. However the CHP units produce also heat. During the calculations all the mass and energy flows are normalized according to the functional unit [84, 88, 96].

3.2.1.2. System boundaries

According to ISO standards, system boundaries for biopellet fuelled case are defined after sawmill residues (from the by-product) to heat and power generation and heat distribution by district heating until residences for the biopellet based scenarios. For the chip fuel based pathway, system boundaries begins after wood harvesting (collecting of forest residues) and continues until electricity and heat output and heat distribution by district heating until residences like biopellet systems.

First of all, the first biopellet fuelled chain called Case A is explained. It starts from sawmill residues and continues with biopellet plant and CHP plant. Then electricity is given to the existing grid and heat is consumed in the district heating which is built on purpose of this system. The pathway A is illustrated in Figure 3.5. First of all, the process can be observed in four sections, feedstock collection, biopellet plant operation, CHP plant and district heating. After sawmill operation, residues collection and biopellet production steps are applied to the sawdust and other residues. In the drying step recovered heat from CHP is used instead of natural gas. Therefore an energy efficient process is achieved. System boundaries of Case A are presented in the Figure 3.5 with red line.

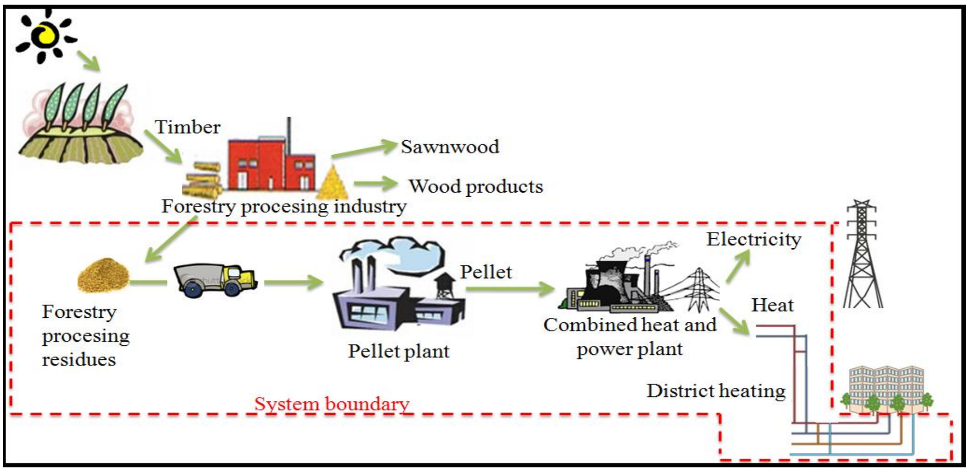

Figure 3.5: Schematic of CHP using biopellet - Case A.

System boundaries for Case B are presented in the Figure 3.6. It is similar with Case A because only the biopellet preparation processes have diversities. Pellets are transported to the CHP plant.

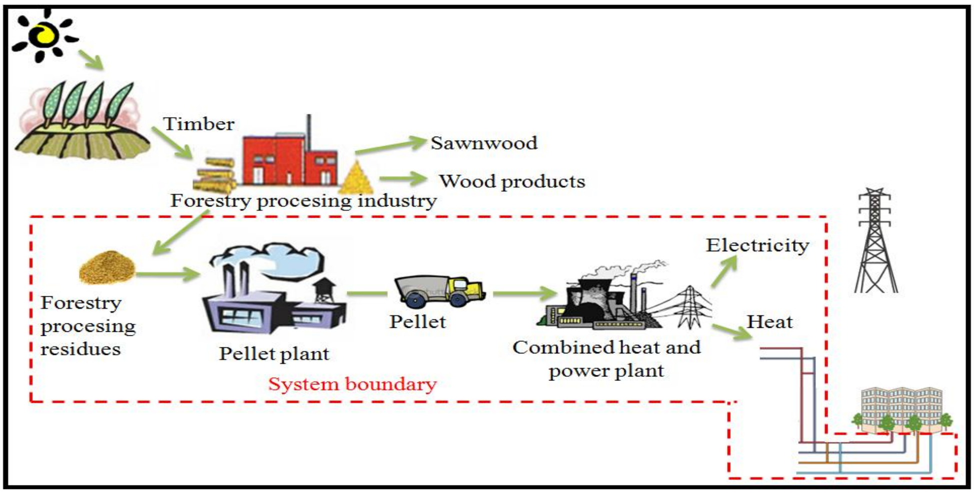

Figure 3.6: Schematic of CHP using biopellet - Case B.

Thirdly, system boundaries for wood chip fuelled case are shown in the Figure 3.7. System boundaries start from the collection of forest residues and ends like other cases at the residential heating system. Red dash lines refer to the limits of Case C as well as seen in Figure 3.7.

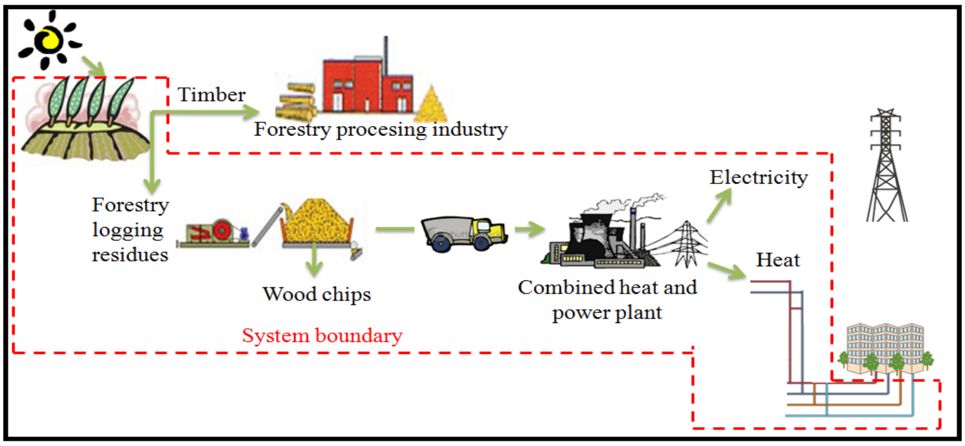

Figure 3.7: Schematic of the CHP using wood chips - Case C.

General parameters of the biopellet plant, chipping process and CHP plant are given in the Table 3.1. Annual biopellet production of biopellet based systems is 12,000 tons of biopellets. Wood chip production of the chip based system is 19,300 tons. 4.2 MW heat and 2.1 MW of electricity is generated in the CHP plant. Table 3.1 mentions general information about feedstock, annual working hour, energy capacity and CHP efficiency of the three cases.

Table 3.1: General feedstock comsuption and CHP operation data of three cases [94, 97-101].

Parameter	Unit	Value
Biopellet Plant		
Annual biopellet production	t	12,000
Annual sawdust consumption	t	21,500
Full load operation hours	h/a	8,000
Chipping operation		
Chips amount	t	19,300
CHP Plant		
Fuel power input	MW	7.3
Electric production	MW_{el}	2.1
Heat production	MW_{th}	4.2
Full load operation hours	h/a	8,000
Electricity efficiency	%	29
Total efficiency	%	87

3.2.2. Inventory analysis for Case A

Inventory analysis of Case A is explained in this part. Goal and scope definition is valid for three cases but inventory analyses are different. Therefore, inventory analysis of three cases is observed as separate part for the cases.

3.2.2.1. General data and assumptions for Case A

Usually, wood based raw materials have difficulties about accuracy in terms of energy content calculations. Volume and moisture content of wood residues has significant variations which cause the differences in energy calculations. Assumption of this study is that moisture content, density and wood based material properties are considered as homogeneous. The variations of these properties are assumed as negligible. Feedstcoks from different suppliers are harmonized [96].

Furthermore, it should be specified that sawmill residues are considered as waste (with zero emission up to collection) or by-product. In that case, it is not obvious how the emissions from sawmill should be allocated between sawn wood and the by-products. For this purpose sawmill residues are assumed to have no greenhouse gas emissions up to the collection of these materials, therefore they are considered as waste residues from saw mill process [88].

Moreover, in this study it is assumed that all produced biopellets are used in CHP plant for substitution of Turkey's electricity mix with electricity produced. When the CHP is operated the produced heat displaces the heat generated by household boilers fed with natural gas but all of the heat cannot be used for residential purpose. The reason of this will be determined in district heating part [102].

Additionally some chemicals which are consumed in very small amounts are assumed as having negligible emissions. Different kinds of engine oils can be example of these chemicals. Regarding to biopellet plant data from the literature, the amount are considered as small and having a negligible impact on the results and thus left out in the calculations [88].

Another point is to determine the operation duration of the plants. System needs to produce electricity without time dependency. Also there is no meaning to operate biopellet plant discontinuously because a daily start-up and shut-down of the dryer cannot be recommended. The optimum operation is 7- days per week as 3 shifts per day. Plant operates continuously for 8000 hours. One month is for vacations and maintenance [93].

Life time of the whole system is assumed as 20 years of operation. All the payment of capital investment will be paid at the end of the first year. During the calculations different life time of the machines are taken into consideration. Operational entire life of the supply chain is considered as 20 years [97].

In order to determine the efficiency of the CHP plant, some of the existing plants are observed. Considering all studies, the electricity efficiency and total efficiency of the system is assumed to be 29% and 87% respectively [103].

For district heating system, pumping, pipe installations and house final station construction material constructions and deconstructions are calculated: therefore energy and material requirements for the assembling of the items considered were not taken into account [84].

Electricity generation in 2010 data are estimated as similar to 2009 data, because 2010 data is not available during preparation of this thesis. Even the emission values of the 2010 are existed for Turkish electricity mix in 2008, these values are assumed the same for the 2008 emissions.

In conclusion, plant construction materials are assumed as concrete and steel even there are other materials such as plastic, aluminium, glass, cooper and etc are used. This assumption is valid since concrete and steel proportion in construction are higher than other materials as a result this assumption is made. In order to make more detailed analysis other material can be added to LCA. The effect of construction is quite small, adding other materials cannot affect the results or can have small effect. More detailed study can be done for further studies. Also, the energy necessary for assembling and production of the items during machine construction is not considered in the calculations.

Lifetime of the equipments in Case A is listed in the Table 3.2. Lifetime of the equipments changes between 10 to 25 years. Lifetime of the whole system is assummed as 20 years. As a result, all the calculations are done by taking into account equipment and system lifetime.

Table 3.2: Lifetime of the equipments in Case A [84,88,93-94, 101].

Life time for biopellet plant	Unit	Value
Plant building	a	20
Drying	a	15
Grinding	a	10
Biopelleting	a	10
Cooling	a	15
Screening	a	20
Storage	a	20
Conveyor, tanks, etc	a	10
Transport vehicle	a	12
Lifetime for CHP plant	Unit	Value
Fuel storage unit	a	20
Weighbridge	a	25
Furnace and boiler	a	15
Flue gas cleaning	a	15
Ash container and conveyor	a	15
Heat recovery	a	15
Fuel conveyor	a	15
Electric installation	a	20
Hydraulic installation	a	20
CHP module	a	15
Planning	a	20
Lifetime for district heating	Unit	Value
Pipe system	a	20
Pumping system	a	15
House station	a	15

Electricity mix is an important and country specific value for the calculations. In order to apply LCA to the system, electricity mix of Turkey should be determined. The electricity generation distribution is indicated in Table 3.3. The shares of electricity for natural gas, coal, hydroelectricity, fuel-oil and renewable-based electricity in 2009 are 48.6%, 28.3%, 18.5%, 3.4% and 1.1% respectively. Although there are also other energy resources such as wind, biomass and geothermal, their capacity comprise the minor share of electricity generation. As a result of this it is assumed that electricity is generated from coal, natural gas, hydro and oil for this study.

Table 3.3: Electricity mix of Turkey in 2009 [98].

Energy Type	Share %
Natural gas	48.9
Coal	28.6
Hydro	18.8
Fuel oil	3.7

The greenhouse gas emission data for electricity generation in Turkey are presented in Table 3.4. Coal has the biggest emission comparing the other energy generation methods. Total CO_{2eq} of Turkish electricity mix is about 524 $gCO_{2\text{-}eq}$/kWh.

Table 3.4: GHG emissions of Turkish electricity mix 2008 [66, 99, 101].

	Mix	Natural gas	Hydro	Coal	Oil
CO_2 [$gCO_{2\text{-}eq}$/kWh]	495.279	349.786	10	1036.704	714.281
N_2O [$gCO_{2\text{-}eq}$ /kWh]	4.977	0.339	0.065	9.067	2.931
CH_4 [$gCO_{2\text{-}eq}$ /kWh]	23.682	16.405	0.118	7.847	21.281
Total [$gCO_{2\text{-}eq}$ /kWh]	523.938	366.191	10.183	1053.614	764.876

Heating mix for Turkey is not mentioned clearly in national corporations. Recent years, the natural gas consumption increased for heating purpose especially Northwest of Turkey. In all cities of Northwest of Turkey natural gas is used for district heating [102]. Therefore it is assumed that woody fuel (in CHP) combustion substitutes with natural gas space heating.

3.2.2.2. Feedstock inventory analysis for Case A

A biopellet plant must obtain a resource of proper feedstock in order to make wood biopellets. Biopellets are generally manufactured from forestry processing industry residues especially sawdust. Other biopellet feedstock are shavings, grinding dust, bark and finely reduced wood waste, some of which comes from further processing of wood chips. The future expectation of biomass is that increasing demand will make all kinds of biomass waste as raw material [20]. Sawdust generation of sawmills are more than cutter shavings because if cutter shavings are preferred to make biopellets then transport distance will increase. Therein, the capacity of sawdust based biopellet plants is larger than cutter shaving based ones. Though, biopellet plants with drying equipment often use both of these raw materials [103]. In this study like the important producer countries sawdust and shavings are used as feedstock for biopellet production. In Turkey, wood processing industry comprises timber, particle board, coating, plywood, furniture and, pulp mill semifinished production systems. Timber, furniture and pulp industry have production facilities. However other production systems' size varies [104].

Turkey has almost 6 million m^3 wood processing industry residues as seen in the Figure 3.8. USA is the leader of the wood processing residues. Turkey is in the 16^{th} place and has more production than developed countries for instance Spain and England [42].

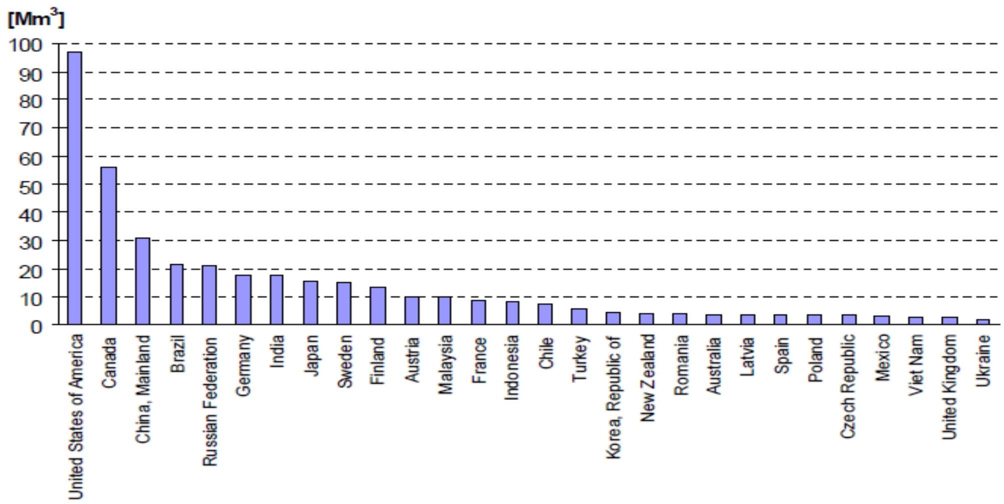

Figure 3.8: The largest producers of by-products from sawmills and plywood mills,2006 [42].

The production capacities of some plants are collected in Yalova, Kocaeli and Sakarya and explained in Appendix A.1. Also these cities are selected because they are the participants of MARKA. That means government promotes the investments in these cities. Due to increased production in sawmills, the amount of sawmill residues has increased, which would have resulted in a surplus of sawdust in the region without any biopellet manufacturing plant [105].

Yalova is selected to build both biopellet and CHP plants: because it is close to big cities and industries [106]. Yalova is available for marine transport which means if the biopellet facility expends capacity: the biopellets can be transported to other cities by sea. Distance calculations are done in the Appendix A.1. Although Sakarya has favourable logistic conditions, Yalova is preferred to build the whole change because of its strategic location.

In one study, for sawmills 47% of solid wood input is under bark as wood products from sawmills [103]. According to observations wood residues of some industries can be given, in furniture 30%-60% and plywood 50% of total raw material. A timber plant residue has 60% yield and sawdust share between 14% and 16% depending on the diameter of timber which means that, even if they are small, sawmills produce large quantities of by-products suitable for processing into biopellets [42, 107-108].

In this study, it is assumed that capacity of the sawmill residues are considered as 27% of the total amount of used wood [108]. Also it is assumed that all the residues in those plants is used only for biopellet production instead of using heating, recycling and other sawdust Considering these assumptions and the existing wood processing capacity data from three cities, total capacity and wood residues capacity including sawdust and shavings are calculated as in Table 3.5. Feedstocks from three cities are harmonized together. The total feedstock capacity of these cities is more than stated value in the table. However in this study it is assumed that the feedstock comes from selected facility in the region. The detailed information about facility data are explained in Appendix A.1.

Table 3.5: Total wood use and wood residues capacity for selected raw material suppliers (see Appendix A1).

Facility	Total capacity (m^3/year)	Wood residues (m^3/year)
Wood processing industry	310,000	83,000

In 2010, the amount of sawmill produced at the selected sawmills were about 83,000 m^3 (solid), which equals about 12,000 tons of biopellet. This calculation is based on the assumption of the drying of sawdust going from a moisture content of 50% to 10% [107]. The density of the residues is taken as sawdust, and then mass calculations are done. According to this calculation 6.3 MW power can be generated efficiently in CHP plant. Properties of sawmill residues are stated in the Table 3.6. The sawmill residues are considered as wet sawdust as generally used in biopellet producer countries such as Sweden [36]. Water content of the residues is assumed as 50% of the residues even it shows variation sample to sample.

Table 3.6: Properties of sawmill residues [35, 93].

Raw material parameters	Value
Water content % (wet base)	50
Bulk density wet base (kg/m^3)	267
Lower heating value (MJ/kg)	10

3.2.2.3. Transportation of feedstock for Case A

Transportation of the feedstock is important because of economic and environmental reasons. Transportation is directly related to location of sawmill and biopellet production plants. There are some influence factors to choose while choosing the biopellet facility locations: distance between feedstock and biopellet plant and distance from biopellet plant to CHP plant location final use. In this study raw material supplier and final biopellet user are taken into consideration while determining the transportation distances and plant locations.

Renström indicated that the economic feasible sawmill carrying distance is up to 100 km to the biopellet generation: otherwise carrying cost will be unreasonable. The transport distance of biopellets from biopellet plants and sawmill to end use consumers are assumed to be 100 km and 20 km respectively [4]. In Magelli and friends study sawdust are transported by trucks for an average distance of about 27 km to biopellet plant [86]. According to Selkimaki transportation costs of raw materials can be very high as distances are often very long. For small/medium scale producers, the profitable biopellet delivery radius is about 300 km [109]. Thek and friends take an average transport distance as 50 km. Hansen and friends also set the transportation of the raw material is based on a distance of 50 km between the factory and the wood processing industry that delivers the raw material [110]. The economical carrying distance for chipped wood is less than 50 km to power generation plant. If it is carried more than this distance the cost will be increase reasonable. According to Hagberg et.al biopellet plants situated adjacent to large saw mill can have very short transport distance for most of the raw material and fuel, even though some materials must be transported from other places. However average transport distance are generally longer (70-85km) since raw materials must often be collected from couple of different saw mills [88].

The idea that supports the assumption of the raw material transportation to the plant is basically economic production and the energy content. It is not reasonable to transport low energy residues for a longer distance that is more costly [77]. Taking all of the remark into consideration the suitable plant location is defined between three cities. The distance between biopellet plant and raw material are presented in Figure 3.9.

Figure 3.9: Locations of raw material suppliers [111].

In order to calculate the distance, the capacities of each feedstock providers are determined. The amount of sawdust that is needed to guarantee full capacity is calculated. Linear programming methods are used in order to find the suitable place for biopellet plant taking consideration the distances and feedstock capacities.

The average distance tranported by truck for each tonne of sawdust or wood biopellet is calculated as the sum of the distance multiplied by the fraction of raw materials used in each plant. The average distance that each tonne of raw material has to be trucked in Yalova from sawmill to the plant is thus found to be around 58 km [86]. The calculated average distance 58 km is considered as a suitable distance. All the feedstock will be carried by trucks from sawmill to biopellet plant. To study the environmental impact and the total transportation cost, it is necessary to have the information about the fuel consumption, the emission factors and the energy consumed for each kilometer of transportation by truck [86]. Properties that are used in LCA study is summarized in the Table 3.7 below. Capacity of the truck is 20,500 kg of biopellets.

Specific fuel consumption and emissions factor for a full and empty lorry is increased approximately linearly with heavier load [77]. Truck load is assumed as 50% in average depending on the assumption that the truck brings material with 100% load and goes back without any. When the feedstock is delivered to the biopellet plant, the biopellet generation requires drying, grinding, biopelletizing, cooling and screening steps. The inventory analyses based on these steps are presented in the following part.

Table 3.7: Spesification of transportation truck data [77,91, 112].

	Unit	Value
Diesel consumption (unloaded)	l/km	0.30
Diesel consumption (loaded)	l/km	0.55
Diesel consumption (average)	l/km	0.43
Average speed	km/h	40-60
Life time	a	12
Yearly carrying distance	km/a	55,165
Diesel consumption	l/vkm	26.7
Diesel calorific value	MJ/l	35.9
Capacity (mass)	kg	20,500
Capacity (volume)	m^3	80
Load capacity	%	50
Average distance	km	58

3.2.2.4. Drying of feedstock for Case A

In order to produce biopellet, drying is the first step where wet sawdust is dried in a drier. The energy demand for biopellet drying is about 10–12% of the heating value of wood fuel biopellets. Due to this energy requirement, costs are increased as well [107].

In Case A there is no need for external heating equipment since: the heat output of the CHP is used as drying resource. All the drying unit equipment will be defined in the drying section of the second system. The electricity usage will be defined in part 3.2.3.3. The CO_2 emissions from solid biofuels are assumed to be zero during combustion. The emission of the biofuels is called biogenic CO_2 emission. CO_2 in the atmosphere is consumed by trees. In the calculations, the CO_2 used by trees is not taken into account, as a result CO_2 is resulted from wood combustion is not taken into consideration in calculations. However other emissions from combustion such as CH_4 and N_2O are accounted in the calculations [88].

In Case A the sawmill residues enter the dryer with 50% moisture content. Redidues go to a combined dryer from the heat output of the CHP. This moisture content is reduced to about 10% by drying [86]. Moisture content is an important point for pelletizing because it affects the quality of the final product if it is higher than 10%. It is difficult to biopelletize materials with more than 15% of water content [110]. When materials have moisture content lower than 15%. They present the bacteria to be active. Having moisture content lower than 10% provides a significant advantage storing indefinite amount of time without being decomposed by microorganisms for biopellets. The raw materials are usually carried by a conveyor, feed screw, pneumatically or with loading shovel to the biopellet production line [109].

3.2.2.6. Grinding of feedstock for Case A

The dried material is brought to the grinding process by feed control. Grinding of residues is often necessary, as a finer and more homogeneous material is needed to produce biopellets with high durability. If the material is homogeneous is sieving machine can be used for grinding. In this system residues are used and there is no homogeneity in the feedstock so that grinding is necessary. While coarse fractions are homogenised in the grinder, small fractions are directly used in biopellet plant. It is common to have a hammer mill operation for homogenization in biopellet producers, even though raw material is only sawdust. Consequently grinding is important because of feedstock delivery in heterogeneous size [93, 110]. A grinder is seen in the Figure 3.10.

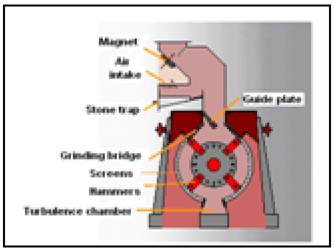

Figure 3.10: Scheme of grinding machine [110].

The most common grinding equipment is the hammer mill, but roller mills are also used. Hammer mill powered by an electric motor is common to use in general for the size reduction of wood residues [113]. The grinded material is transported through a cyclone where the air/hot gas is separated from the sawdust. This is called biopellet plant and it is going to be explained in the next section [107].

In this study dried materials are ground in a hammer mill and milled into smaller particle sizes. Milled materials are thereafter fed into the buffers for each individual biopellet press [41]. Grinding system data is indicated in Table 3.8. electricity consumption and installed power values are 37.7 $Wh/kg_{biopellet}$ and 202 kW respectively.

Table 3.8: Installed power and electricity consumption of grinding in Case A [84, 114].

Grinding	Unit	Values
Installed Power	kW	202.0
2 screw extractors	kW	3.6
2 feed screws	kW	4.4
2 hammer mills	kW	150.0
2 volume pumps	kW	44.0
Electricity consumption	$kWh/kg_{biopellet}$	0.03770
2 screw extractor	$kWh/kg_{biopellet}$	0.00067
2 feed screws	$kWh/kg_{biopellet}$	0.00082
2 hammer mills	$kWh/kg_{biopellet}$	0.02800
2 volume pumps	$kWh/kg_{biopellet}$	0.00822

3.2.2.7. Biopelletizing for Case A

After the grinding, the dried and uniformed raw material is transported to the biopelletizing machine, usually by means of a screw feeder. Six conditions affect the quality of biopellet production:

- The relation and correlation of raw material quality, machine compressing capacity and the compressing process.
- The friction capacity of the die block.
- Properties of the surface and the material of the die block and the rolling press.
- Die block holes diameters and lengths.
- The thickness of the material that is pressed into the block and the thickness of the layer of raw material above the die block.
- Compression frequency for instance the speed of rotation [110].

Biopellet properties for the produced biopellet in this plant are listed in Table 3.9. Biopellet production rate of plant is 1.5 t/h. During one year operation biopellet plant produces 12,000 tonnes of biopellets.

Table 3.9: Characteristic properties of biopellet [35, 93].

Biopellet data	Unit	Value
Biopellet production rate	t/h	1.5
Water content	wt%	10
Bulk density of biopellets	kg_{wb}/m^3	650
Diameter of biopellets	mm	10
Lower heating value	MJ/kg	17.5

Moreover, dried materials are fed into biopellet press from buffers. Buffer levels are adjusted automatically and then dried sawdust is pressed inside the matrix with many holes by the help of temperature and pressure, as displayed in the Figure 3.11. Inside the matrix there are rolls that press out raw material through the matrix. Also knifes at the outside of the biopellet chamber shave off the biopellets from the matrix [41]. Biopelletizing mechanism is displayed in the Figure 3.11.

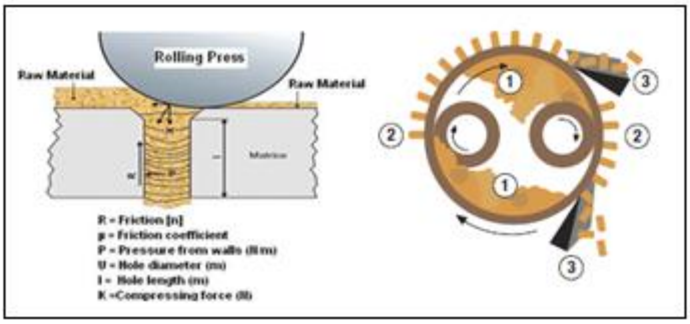

Figure 3.11: Scheme of biopelletizing machine [114].

Two main technologies are available for biopelletizing, ring die and flat die biopellet plants. Leader biopellet producers prefer die biopellet plants because they have lower investment cost. Furthermore, based on experiences of several biopellet producers, ring die biopellet plants show higher equipment availability [93].

After biopelletizing operation outputs left the machine around 70-90^{o}C, as the consequence of the frictional heat generated during extrusion and material pre-heating [93]. Rhén et al. also point out some advantages of using higher temperatures during biopelletizing. The compression strength and the dry density of the biopellets is raised by the effect of high temperatures and a low initial moisture content of the raw material [107]. Characteristic properties of biopelletizing unit are mentioned in Table 3.10. Installed power and electricity consumptions of the biopelletizing operation is 16 kW and 3 Wh/kg$_{biopellet}$ respectively.

Most important step in transformation of wood into biopellet is biopelletizing mainly due to usage of diesel and bio-additives [84]. Bio-addictives provides increment in biopellet throughput, if the suitable one is selected, it act as a lubricant in the biopellet plant [93].

Table 3.10: Installed power and electricity consumption of biopelletizing in Case A [84, 93, 115].

Drying	Unit	Values
Biopellet plant type		Ring die biopellet plant
Steam consumption for per ton biopellets produced	wt%	4
Bio-additive demand of corn starch	%	0.1
Utilisation period biopellet mill	a	10
Diesel consumption	$g/kg_{biopellet}$	4.788
Installed Power	kW	16
2 feed hoppers	kW	4.4
2 conditioners	kW	8
2 screws conveyor	kW	3.6
Electricity consumption	$kWh/kg_{biopellet}$	0.0030
2 feed hoppers	$kWh/kg_{biopellet}$	0.000822
2 conditioners	$kWh/kg_{biopellet}$	0.001504
2 screws conveyor	$kWh/kg_{biopellet}$	0.000674

Additives substances such as starch, lignin and others with advantageous characteristics could be used to improve the quality of the biopellets. On the other hand, addictives can cause unwanted substances that could lead to higher ash content for the product, as well as higher production costs. Thereby addictives such as corn starch are useful for improving the durability of the biopellets significantly [107]. Therefore, corn starch is assumed to be used in the biopelletizing plant. As a result of this corn starch is used in this study.

3.2.2.8. Cooling of biopellets for Case A

The next step after biopelletizing is the cooling of the biopellet cooling is refused after biopelletizing some biopellets are still warm and elastic after the process. They should be cooled around 25^{o}C to harden and stabilize the wood biopellet and to maintain the quality of the product during storage and handling. After cooling biopellets are transported to the screening and storage units with mechanical or pneumatic conveying systems [93].

Generally counter flow coolers are preferred by the users. If the capacity of the biopellet plant is small, a subsequent cooler is optional [93]. Biopellets and the cooling air moved different directions. As a result, warm air is used to cool the warmest biopellets and vice versa. There is a reduction in the amount of heat stress that the biopellets are exposed to (which may decrease the quality of the product) by the consequence of gradual cooling of the biopellets with counter-current cooling

[110]. Cooling unit characteristics of LCA are indicated in Table 3.11. Installed power and electricity consumption for screening is relatively low than other steps.

Table 3.11: Installed power and electricity consumption of cooling in Case A [84, 115].

Cooling	Unit	Values
Cooler type		Counter flow cooler
Installed Power	kW	4.8
Screw extractor	kW	1.8
Cooler	kW	3
Electricity consumption	$kWh/kg_{biopellet}$	0.0009
Screw extractor	$kWh/kg_{biopellet}$	0.000676
Cooler	$kWh/kg_{biopellet}$	0.001052

The hardness of the biopellets depends on quick cooling procedure. Therefore, a cooling process that is too quick could prevent the biopellets from being sufficiently cooled, especially on the inside [107]. It is really important to cooled biopellet sufficiently before storage: otherwise there will be temperature increase in the warehouse which can cause technical accidents [107].

3.2.2.9. Screening and storage for Case A

After the cooling process, the biopellets are screened to minimise the amount of fine particles, and these particles are brought back to the process. Fine materials are recycled to the system to make certain that there is no material waste. Screening is applied to support clean and dust free materials as much as possible. After screening biopellet operation is finalized and the final good is ready for energy generation [41, 42].

To decide the capacity of the storage, several existing plants are observed. For example in Austria the storage capacity is generally less than the annual biopellet production capacity [93]. Characteristic information about storage and screening is indicated in Table 3.12.

Storage of the biopellet and the biopellets differs from each others for example the moisture content of these material is different as a result the growth of microorganism is different.

Table 3.12: Installed power and electricity consumption of screening and storage in Case A [84, 115].

Storage	Unit	Values
Kind of storage		Silo storage
Installed Power	kW	2.95
Vibrating screen	kW	0.75
Cup elevator	kW	2.2
Electricity consumption	$kWh/kg_{biopellet}$	0.0006
Vibrating screen	$kWh/kg_{biopellet}$	0.0003
Cup elevator	$kWh/kg_{biopellet}$	0.0009

3.2.2.10. Construction of biopellet plant for Case A

In the previous parts biopellet production steps, properties of equipments and electricity consumptions are determined. Some of the equipments are taken into the Ecoinvent data base for instance truck, however all the equipments have available data in the literature and market are used to design systems in GaBi. Summary of the material need for biopellet production equipment is listed in Table 3.13**.** Materials that used in the construction of the units are aluminium, steel, iron, concrete, glass fibre and their variations. More materials are required for am plant production but only the major materials are used in calculations.

3.2.2.11. Transportation of biopellet for Case A

In the Case A biopellet plant and CHP plant are integrated. Therefore transport between two facilities is done by conveyors, pneumatic systems or small carrying machines [115]. Finished biopellets require gentle handling. However, low-speed belt conveyors are used in the final stages [92].

3.2.2.12. Energy production for Case A

In this study steam turbine based CHP system is modelled because it is the most established technology. Other factors for preferring steam turbine are different applications are reliability, variable speed operation and possibility of energy savings. Rankine cycle is used as the CHP in this case. The principle of the Rankine cycle is that high-pressure steam at predetermined parameters is produced in the boiler by fuel consumption. Then, mechanical power/ electricity and a low-pressure steam are generated with steam expansion through a steam turbine [116].

In general, large scale users of biopellets are districts heating plants and CHP plants whose boiler size is >2 MW [109]. However in this thesis electricity production is the main aim. Heat produced is also used in district heating for improving the system efficiency [103]. According to Perry, biomass based CHP plants based on electricity can have a ratio of 2.2 for produced heat to electricity, this ratio is taken as 2.0 [117].

Table 3.13: Summary of the material requirement for construction of biopellet production equipment [84, 95].

Sections	Infrastructures Type	Materials	kg	Lifetime (years)
Drying	Rotary drum	Aluminium wrought alloy Aluminium sheet rolling	640 640	10
	Exhaust fan	Aluminium Steel low-alloy	1,000 1,000	50
	Cup elevator, screw conveyor	Steel low-alloy	700	50
Grinding	Cup elevator, screw conveyor	Steel low-alloyed	700	50
	2 hammer mills	Reinforced steel Steel sheet rolling	2,500 2,500	10
Biopelletizing	2 presses	Steel low-alloy Sheet rolling	4,000 4,000	10
	2 feed hoppers, 2 screw conveyor	Steel low-alloy	700	50
Cooling	Screw extractor	Steel low-alloy	200	15
	Cooler	Steel low-alloy	210	50
Storage	Vibrating screen	Aluminium Steel low-alloy	107.5 107.5	50
	Silo (100 m3)	Glass fibre Cast iron Reinforcing steel	3,800 500 500	25
	Cup elevator	Steel low-alloy	350	50
Plant	Building	Concrete Steel	1,161,000 218,000	20
Raw material storage	Building	Concrete Steel	142,000 3,000	20

Input biopellet energy capacity is around 7.2 MW. Electricity generating efficiency and heat transmission efficiency and overall cogeneration efficiency are 29%, 58% and 87% respectively [103]. The system can produce 2.1 MW of electricity and 4.2 MW of heat with 7.2 MW of biopellet input. Efficiency is calculated with the Equation 3.1.

$$\text{Total Efficiency} = \frac{E_{\text{CHP electricity}} + E_{\text{CHP heat}}}{E_{\text{Biomass,input}}} \quad \textbf{(3.1)}$$

The construction of the CHP plant is considered from literature and market values. Market values and literature values are improved with scaling factor to build plant. Detailed information about scaling factor and calculations are given in Appendix A.2. Construction material requirement for the CHP plant is given in the section 3.1.2.14. Energy consumption value of the CHP plant is taken from the literature, steam turbine based biomass CHP system. It is indicated in Table 3.14. Electricity consumption during the CHP operation is 30 kWh/ MWh_{th}. CHP is based on steam turbine cycle.

Table 3.14: Characteristics of CHP unit in Case A [94].

CHP	Unit	Values
Electricity consumption	kWh/ MWh_{th}	30
Input biopellet energy capacity	MW	7.2
Total output energy capacity	MW	6.3

In order to decide the efficiency of the CHP plant some of the existing plants are observed. The plants are chosen in Europe because there are no examples in Turkey. One example in Sweden is that in Hässelby, the system's electrical efficiency is better than the average efficiency of existing conventional biofuelled CHP plants, which have electrical efficiencies between 20 and 30%. Total efficiency is, however, somewhat lower compared to the existing CHP plants' 80-110% (based on lower heating value). In another study about Swedish power plant Skelleftea system electrical efficiency is changes 24% to 27% depending on seasonal operating conditions. The overall efficiency of the plant is distributed 86% to 87% [112]. In Denmark biomass fired CHP plants efficiency changes from 16% to 35% and overall efficiency 83% to 91%. In a wood chip fuelled 8MW CHP plant the efficiency is 12% for electricity and 52% for thermal. The technology of the CHP also effects the efficiency the electrical efficiency for Rankine cycle is 10-20% however 30-38% for internal combustion engine. Thermal efficiencies for the same systems are 70-80% and 45-50 %. According to Biomass Power Association eleven existing plants were in the United States and Canada was reviewed. The average efficiency for a biopower generation project is 23%. Considering all studies, the electricity efficiency of the system is assumed as 29%, and total efficiency 87% [103].

3.2.2.13. Ash disposal for Case A

When wood biopellets are combusted the amount of ash generated is lower comparing coal [110]. Only 0.5-1 % of a wood biopellet is non-combustible. If the quality of the ash is low, more ash will be produced. Amount of impurities such as sand or other inorganic material results quality problems in the biopellet [110]. In this study the share of mass of ash in mass of biopellet is assumed as 0.5% [118]. After combustion of biopellets only a little ash in the shape of a fine, grey powder is left, which is easy to remove [110].

Ash disposal is done by collecting and transporting to landfill or for utilizing them as a fertilizer. Actually, ash is not the only waste produced from biopellet production and energy chains. Therefore, ash and waste generated in a biopellet plant is not more than 2-3 kg per ton biopellets of which 80% are ash [88, 110]. When the LCA of the systems is taken into account, the emissions of the ash are at negligible level. As a result it is assumed that emissions from transport of the waste and even these are negligible compared to other emissions in the biopellet production. During the calculations emission caused by transport and treatment of the waste are not considered [88].

3.2.2.14. Construction of CHP plant for Case A

The specifications of CHP systems are taken from literature data and scaling is applied, if required. In the Table 3.15 all the components of the case are listed. Values of some of the real plants are used by applying scaling factor. All the scaling factors are given in the Appendix A.2 [122]. A GaBi program is developed as a flexible system with those scaling factors. When the capacity of the system is changed, required building material also changes by the effect of these scaling factors. All of the components in the Table 3.15 are supposed as steel, because when the Kanan's study is observed the mass share of the iron is 0.33% and aluminium is 0.21%. Kanan's study is for 250 MW steam turbine system, when is scaled with direct proportion for 2.1 MW_e and 4.2 MW_{th} system total steel requirement is 315 ton steel, it is closed the calculated in Table 3.15 310 ton steel. The iron and aluminium values are 3.9 ton and 2.6 respectively and calculated by using scaling from 250 MW steam turbine plants [119].

Table 3.15: Equipment weight calculation and material requirement for the construction of the CHP unit [119-123].

Component	Weight (kg)	Real value	Calculated for system (2.1 MW_e& 4.2 MW_{th}) (kg)
Turbine engine	5,200	3.4 MW_e	4,108
Gearbox	5,000		3,950
Auxiliaries	3,000		2,370
Steel skid base frame	12,300		9,717
Alternator	17,000		10,540
Condenser	6,000		7,411
Boiler	8,770	2.12MW_e	26,000
Pump	2,250	3.4 MW_e	1,389
Plant Building			218,000
Total steel			283,485
Iron	155,000	250 MW_e	3,900
Aluminium	105,000	250 MW_e	2,600

3.2.2.15. District heating for Case A

To start with heat produced from CHP, it is given to the district heating system. However there is no existing district heating system in Yalova. Therefore a fictive district heating system is constructed for a new settlement area in Yalova. In order to calculate optimal residence number, annual heating curve of a house in Yalova is used [124]. Annual heat requirement of a residence is showed in Figure 3.12 in terms of m^2. Between June to September, there is no residential heat requirement in the region. Detailed information about heating is given in the Appendix A.3.

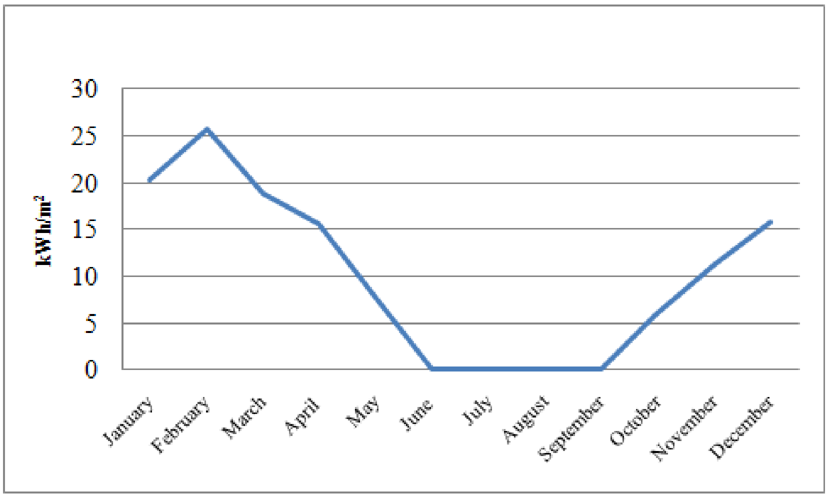

Figure 3.12: Annual average specific heating curve in Yalova for a residential building [124-126].

Area of the houses assumed as 200 m^2 and system can support heat of 290 residences for whole year without any back-up system. 10% of the existing heat is used for heating purpose of the biopellet plant and offices [127]. According to Obernberger and Thek in a steam turbine based biomass CHP heat distribution loss is assumed 10%. As stated before 26% of the heat is used for drying wood biopellet. Only 54% of the heat can be sold for Case A. However in summer conditions heat cannot be sold due to absence of heat demand. Therefore, 33% of the heat is wasted. The 10% of the saleable heat is used for space heating in the CHP and biopellet plants and offices. Table 3.16 defines the heat proportion of Case A. 26% of the total heat is used for drying biopellets in the pelletizing plant. Only 21% of the heat is used for residential heating.

Table 3.16: Proportions of heat evaluation areas of Case A.

	MW_{th}	%
Heat used in drying	1.09	26
Heat used in plant heating	0.42	10
Heat used in district heating	0.88	21
Heat loss in the system	0.42	10
Waste heat	1.39	33
Total	4.20	100

District heating system is build for the system for a new residential area, the illustration of this area and calculations are given in the Appendix A.3.

For the LCA pipe length, diameter and material parameters are required. District heating system can be built in three ways: radial, ring or mesh network [128]. Radial network is applied for the 290 of residents. One apartment includes 5 floors with two flats, totally 10 flats comprise one apartment building. 29 buildings are settled in to a 13,175 m^2 area.

General information about the district heating system is mentioned in Table 3.17, the calculations explained in the Appendix A.3. Double district heating pipes are used in the system: in the fourth column of the Table 3.17 total diameter of the double district heating is given. One pipe is for hot water pipes from CHP plant to houses and other pipe is for cold water from houses to CHP plant. Mass calculation is done based on double pipe diameter and insulated weight. In the third column the diameter of the internal pipes are given. Figure of the double pipes is displayed in Figure 3.13.

Figure 3.13: Schematic of double diameter pipe of district heating [129].

Table 3.17: Characteristic of district heating pipes of Case A [130].

	Length (m)	Diameter (mm)	DN diameter of double pipes	40 mm isolated weight (kg/m)
Primary pipes	547.5	148	300	23
Secondary pipes	372.5	83	200	13
Tertiary pipes	72.5	40	100	8

Primary pipes are settled from CHP plant to the settlement. Secondary pipes are used in transferring heat from primary pipes to building. Tertiary pipes are the last pipes that connect secondary pipes to the households.

During the GaBi programming pipes are assumed to be made of steel and isolated weight value is used only for steel, emission contribution of the isolation material is ignored. Therefore, calculated diameters values are given in the table, DN size is selected for the pipes [130]. Isolation thickness is selected as 40 mm: different thickness can be used as well. After the secondary pipes, heat comes to the tertiary pipes and at that stage some equipment such as heat station is needed. Residential installation is not taken into consideration: the system boundaries do not comprise the materials beyond heat station. Heat station is required for district heating but residential installation will be required in any case also for natural gas heating. Case A is not responsible of the residential installation. Weight of the house final heat station is 38 kg and assumed made of steel [131]. A house final station is showed in Figure 3.14.

Figure 3.14: Schematic of house final heat station [131].

3.2.3. Inventory Analysis for Case B

In the second biopellet fuelled CHP system (Case B), biopellet plant is located near sawmills. The assumption is that sawmill in one region can provide enough sawdust for as the same amount of biopellet production as Case A.

Transporting wet sawdust is an expensive method because of the high water content and the high distance between the suppliers. Sawmill residues are collected in the close sawmill to biopellet plant without bulk transportation then biopellet production steps are applied and finally biopellets are transported to CHP. One of the differences from Case A is transportation which is between biopellet plant and CHP plant. The CHP plant is close to the last consumer electricity grid ant district heating. On the other hand it is a reasonable way to carry densified wood fuel instead of carrying high water content wood fuel [77]. In this part some information about differences between biopellet fuelled systems A and B will be given because most of the operations and conditions the same both processes. Only different parts will be clarified to be avoided repetition.

Common parts of Case A and B are general assumption and Turkish electricity mix, feedstock, grinding, biopelletizing, cooling, screening and storage, construction of plant, energy production and ash disposal. All the values related with these sections of Case A is assumed as the same with Case B.

3.2.3.1. Drying of feedstock for Case B

Biopellet production units may have different drying technologies and systems for instance standalone process or integrated with, for example, district heating network, pulp mill, sawmill or combined heat and power (CHP) plant [132]. In Case B, drying is different than Case A (CHP integrated drying) because it is a standalone drying system set with natural gas fuel.

Standalone drying system requires high cost so that the capacity of the plant becomes important for feasibility of the plant. According to many studies 12,000 tonne throughput per year can be the lower limit of the biopellet plants that has economic use of a dryer. It is not recommended to use standalone dryers in the small scale biopellet manufacturing plants [93]. The biopellet plan in this study operates 12,000 ton/a so that a dryer system is adapted to process.

Dryer type is selected depending on the general use in Europe. The most common technology used by the important biopellet manufacturers in Sweden, Austria and North America for the drying of sawdust is a rotary drum dryer with a co-current or counter-current flow of drying gases [93]. Rotary- dryers represent the most commonly used technique because of their flexibility to handle small and large capacities, their reversibility and their ability to handle a wide assortment of feeds. The flue gas rotary dryers are relatively cheap and easy to install and run. They can also dry a variety of materials of different sizes [107]. In Turkey, there is no information about biopellet drying as a result of this the inventory analysis for drying is done based on European countries data.

Determination of the drying fuel is as important as drying technology. In order to decide the suitable fuel for Turkey, European data from biopellet producers are taken into consideration. Mani analyzed a typical densification process for several scenarios using different fuels. In order to evaluate the total energy consumption, environmental emissions and cost of biopellet production, using different alternative fuels for the drying process is observed. The fuels compared are natural gas, coal, dry and wet sawdust, and ground wood biopellets. The environmental burden is the highest if coal is used as a fuel among all other alternative fuels. Biopellet production cost is high if natural gas or wood biopellets is used as a fuel. The results showed that wood biopellet or dry sawdust might be the best alternative when compared to natural gas followed by coal and wet sawdust, if all the criteria were weighed equally [85].

Table 3.18: Installed power and electricity consumption of drying in Case B [84, 85, 115].

Drying	Unit	Values
Dryer type		Rotary drum dryer
Heat demand (per ton vaporised water)	kWh/t_w	1000
Natural gas	$kWh/kg_{biopellet}$	0.722
Installed Power	kW	100.9
Feeding tank	kW	7.5
Rotary drum	kW	10
Exhaust fan	kW	75
Star valve	kW	2.2
Cup elevator	kW	2.2
Screw conveyor	kW	4
Electricity consumption	$kWh/kg_{biopellet}$	0.0188
Feeding tank	$kWh/kg_{biopellet}$	0.0014
Rotary drum	$kWh/kg_{biopellet}$	0.0019
Exhaust fan	$kWh/kg_{biopellet}$	0.0140
Star valve	$kWh/kg_{biopellet}$	0.0004
Cup elevator	$kWh/kg_{biopellet}$	0.0004
Screw conveyor	$kWh/kg_{biopellet}$	0.0007

In the past, natural gas was the most common fuel resource for dryers. However, with a rise in fossil fuel costs, many producers have been switching to waste wood. In contrast to using natural gas, waste wood is cheaper and provides the opportunity to market environmental advantages associated with greenhouse gas emissions.

These environmental benefits can be important when selling to markets with significant environmental regulations like the European market [42]. Even though there is a new trend in biofuel use, in Case B, natural gas which has been commonly practiced in the industry will be considered as fuels in rotary drum dryer [86]. The drying system of this study is determined in the Table 3.18.

The natural gas consumption for Case B is as stated in the Table 3.18. The electricity consumption is valid for both systems A and B. Total installed power and electricity consumption values are 100.9 kW and 0.0188 $kWh/kg_{biopellet}$ respectively.

Construction of the biopelletizing plant is stated in the part 3.2.2.10, however drying unit shows difference as a result drying unit is mentioned in that part. In the first plant there is no standalone boiler, but there can be one for the case of start up and potential breakdown in CHP heat recovery system. The natural gas boiler in the first system the size is not big as the second system. The information about the spare boiler is not taken into calculation because it has a limited use and the emissions can be assumed negligible. In the Table 3.19 drying unit with natural gas boiler is indicated below. Natural gas boiler requires more material than other parts of drying.

Table 3.19: Summary of the material requirement for the construction of biopellet production equipment difference for Case B [84].

Section	Infrastructures Type	Materials	Lifetime (years)
Drying	Rotary drum	Aluminium wrought alloy: 640 kg aluminium sheet rolling: 640 kg	10
	Exhaust fan	Aluminium: 1000 kg, steel low-alloy: 1000 kg	50
	Natural gas boiler	Refractory: 70 kg, cast iron: 4200 kg, chromium steel: 230 kg Steel low-alloy: 190 kg, rock wool: 40 kg	20
	Cup elevator, screw conveyor	Steel low-alloy: 700 kg	50

3.2.3.2. Transportation of biopellet for Case B

In Case B, biopellets are transported to the CHP by trucks. The properties of the truck are as the same as the Table 3.5. But the emission and the cost are different than biopellet feedstock transportation. In Europe bulk deliveries are loaded from the silo storage to pneumatic trucks or with loading shovel to normal trucks [109].

For feasibility of the biopellet transportation some information is useful. Transportation of the biopellets more than 300 km is not reasonable for the small and medium scale producers [109]. Regarding to another study distance of biopellets from biopellet plants and of split wood to end user consumers is assumed to 1000 km and 20 km respectively [133]. Additionally data about wood transformation is mentioned before for different fuels. The transportation distance between biopellet plant and CHP is assumed as 20 km.

3.2.3.3. Construction of CHP plant for Case B

Construction of the system CHP plants are the same, however the only difference from CHP of Case A is storage. There is biopellet storage in this system because storage of biopellet plant cannot be common for both plants because of the distance. Construction of the CHP is given in section 3.2.2.14. The biopellet silo construction is explained in Table 3.20.

Table 3.20: Equipment weight calculation and material requirement for the construction of the CHP unit difference for Case B [84].

Infrastructures Type	Materials	Lifetime (years)
Silo (100 m3)	Glass fibre: 3800 kg, cast iron: 500 kg, reinforcing steel: 500 kg	25

3.2.3.4. District heating for Case B

In Case B, there is more heat than Case A because drying is done by natural gas. Case B can provide heat of 460 flat each with 200 m^2 area. Although Case B provides heat for more residence than Case A, it loses 52% of heat. In Case A, there is 26 % of stable heat demand for drying and 10% for plant space heating, but in Case B only CHP plant heating demand is quarantined (5% of heat production), biopellet plant is far for heating. Table 3.21 explains the proportions of the produced heat usage distribution. Comparing Case A more heat is used for residential heating.

Table 3.21: Proportions of heat evaluation areas of Case B.

	MW	%
Heat used in plant heating	0.21	5
Heat used in district heating	1.39	33
Heat loss in the system	0.42	10
Waste heat	2.18	52
Total	4.20	100

In order to calculate the number of heated house the same heating curves in Case A is used for the region. The settlement of the houses is given in the Appendix A.3. According to this settlement 18,375 m^2 area will be heated. One parameters of the district heating system pipes are given in Table 3.22 District heating part can be done more detailed in this study only pipe and house connections are taken into consideration to have a rough idea about district heating. For more detailed study emission from pipeline drilling, material transportation, pumping, item assembly and conductive equipment emissions can be observed. Calculations are done according to the double pipe diameter because of double pipe is also used in this system.

As stated before primary, secondary and tertiary pipe systems are made of steel and residential final stations have no diversity as well. Information about Case B pipe installation is represented in Table 3.22.

Table 3.22: Characteristic of district heating pipes of Case B [124].

	Length (m)	Diameter (mm)	DN diameter of double pipes	40 mm isolated weight (kg/m)
Primary pipes	592.5	148	300	23
Secondary pipes	775	83	200	13
Tertiary pipes	160	40	100	8

3.2.4. Inventory Analysis for Case C

The biomass utilization as renewable-based energy is widely discussed in present time. In this study, the other observed biofuel is wood chips which are heterogeneous material composed from parts of wood, bark, needles, leaves, small branches and undesirable non-wood adulterants. Most common chip production way is using harvesting residues, residua from commercial thinning and saw mill residues. In this study residua from forest operations are preferred as the feedstock of the chips [134].

Furthermore, chipping has some benefits for instance making acceptable fuel and simultaneously improving bulk volume, homogeneity and handling characteristics of fuel raw materials from the forest [90].

In Turkey, forest residues are left in the forest until the recent time because of the lack of technology and information, landscape structure and lack of investment [135]. Developed countries collect forest harvesting residues, firewood and forestry thinning practices in order to make chips. After collecting, saving, handling, chipping and transportation operations are done respectively to complete the forestry residues energy production chain.

Nowadays, there are some research and development activities go on, as well as forestry strategies and applications are improved for getting benefit from forestry biomass in different areas, but they are not finalized with an environment and economy friendly project yet [135].

Land clearing for highways, development, on tops left over from logging or firewood operations, or in forestry-thinning practice is major resource of wood residues for chips in Turkey.

Wood chip fuelled CHP system is taken into consideration as the third observed case in this study. In part 3.1 general information about the cases are explained and an illustration of Case C is displayed. In this topic inventory analysis and system details are indicated.

3.2.4.1. General assumptions for Case C

In this part, it is assumed that all produced wood chips are used in CHP plant for substitution of Turkey electricity mix with produced electricity. When the CHP is operated the heat displaces the same quantity of heat generated by household boilers fed with natural gas.

The cultivation process for the system is not taken in the consideration. The activities after cutting down wood are taken into account [86]. Wood log production, firewood operations and forestry thinning practices are out of this system only their residues are important. Because of it is difficult to allocate emissions for residues.

During wood chips energy generation chain there are some losses. General assumption about loss of the system is explained in Table 3.23. During the storage 4% of the material became loss.

Table 3.23: General loss of the biopellet chipping [136-137].

Material loss chipping	%	1
Loss of material transport	%	1
Material loss of storage	%	4

The values for the Turkish wood residues are showed in the Table 3.24. Chip generation efficiency is 93%.

Table 3.24: Forest residues information in Turkey [138].

Forest residues value	Unit	Values
Average weight of 1 ster forest residues	kg	255
Chip from 1 ster forest residues	kg	236
Efficiency transformation to chip	%	93

Wood residues data are taken from the Turkish Ministry of Environment and Forest studies. For the capacity calculations average wood residues in the forest are significant data, however it changes depending on, region, and climate and wood types. A general forest residues capacity value is given about wood residues in Marmara region forests.

3.2.4.2. Collecting forestry residues for Case C

On average, 100% of the annual fuel need of the CHP plant is supplied by wood chips from forestry residues. Wood residues such as twigs and branches left- over from cutting spruce trees, both forests thinning and final clear cutting are collected after forest operations [97].

When firewood, forest residues and fibre chip production is observed, İstanbul, Amasya, Bursa and Kastamonu Region Forest Management have biggest production proportion [138]. Yalova is connected Bursa Region Forest Management and also % 58 of its land is coated with forest. Additionally, as indicated before the final energy use and location influence the plant construction location as Yalova. Forest distribution of Yalova is displayed in Figure 3.15.

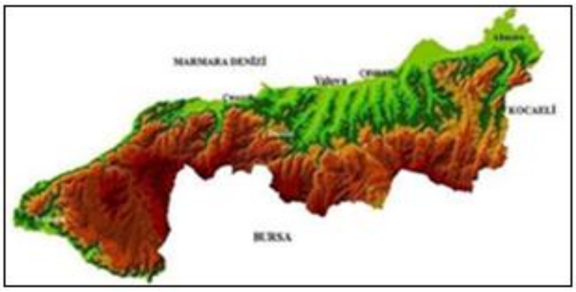

Figure 3.15: Geographical map of Yalova [106].

According to Ministry of Environment and Forest, Turkey has important wood residue potential that is not efficiently evaluated yet. Wood residues data about Yalova is given in Table 3.25, it is obvious that, fibre chip production capacities and wood resides are more than feedstock need of a 2.1 MWe capacity CHP plant. Total forest residues are 5000 stere and average chip production is about 35000 stere [4].

Table 3.25: Wood and residues production and capacities in Yalova [4].

Average firewood production stere	Firewood residues Stere	Forest rehabilitation residues potential stere	Average fibre chip production stere	Total stere
81430	3000	2000	35286	122716

The wood resource may be a natural forest or an established forest. In Yalova there is no established forest as a result of this, the forest in this study is assumed as natural forest. In this work, only harvesting residues of wood from natural forest will be analyzed, excluding the re-forestation [86]. Some information about tree cutting operation in Turkey can be useful for further studies, for instance wood harvesting is generally done by petrol fuelled saw machine and axes [139]. Unless, the cutting emissions of forest wood are not used in the calculations, this information can be important for future work. In order to collect wood residues wheeled loader is used, however the inventory data for wheeled loader is assumed as tractor data in Ecoinvent. During the wood residues collection it is assumed that 20 km road is travelled. Some parameter about the wheeled loader is given in Table 3.26.

Table 3.26: Properties of wheeled loader and feedstock collecting data [91, 118, 140].

Vehicle	Unit	Values
Average daily road	km	20
Diesel consumption	l/km	2
Mass of wheeled loader	kg	5300
Lifetime	h	7200
Diesel consumption wheeled loader	l/GJ_{wood}	0.5
Specific diesel consumption	l/h	33.3
Calorific value of diesel	MJ/l	35.9
Average speed	km/h	20
Daily utilization time	h	8

The average occupancy of the wheeled loader is assumed as % 50 as the assumption of this study. Also another machine is needed in order to collect and carry forest residues which is called carrier. Information about carrier is listed in Table 3.27. Its construction is also assumed as tractor in the Ecoinvent. Lifetime of the carrier is 7200 h.

Table 3.27: Properties of forest residues carrier [91].

Vehicle	Unit	Values
Mass of carrier	kg	5300
Lifetime	h	7200
Diesel consumption wheeled loader	l/GJ_{wood}	0.09

3.2.4.3. Wood chips production for Case C

Harvesting operations residues become chips by mobile chippers. Mobile chippers are used to turn diseased and other cull logs into chips, while most of the tops and branches stay in the forest to return nutrients to the soil. These chips are blown from the chipper into delivery trucks, which deliver them to bioenergy user. Chipping can be done in three ways, directly at the stand, on the roadside and on the central yard.

- Directly at the stand: it is done by using small machinery with lower engine output power but with higher terrain accessibility [134].
- On the roadside: it is a more robust, high power and middle size machinery than directly at stand method. However using adequate hauling technology is necessary for transporting material to the roadside [134].
- On central place: both mobile and stationary machines can be processed with high power. Transport of chipped materials requires more complicated machinery [134].

Selected method for chipping is on the roadside application. Feedstock is skidded to the roadside by using trailers and truck. Sometimes chips are at the roadside by waiting residues for 2-5 months or in the plant, if the season is suitable [134]. Moreover it is important to leave some of the wood residues inside the forest to protecting natural life [135]. Collected residues are chipped at the road side with chipper. Some useful data for LCA of chipping is listed in the Table 3.28. Like collecting equipment chipper is also modelled with the chipper module in Ecoinvent, energy requirement is added.

Table 3.28: Characteristic of chipper [91, 140-141].

Vehicle	Unit	Values
Tractor power requirement	kW	77.1
Diesel	kg/ha	25.1
Mass of chipper	kg	5300
Diesel consumption	l/GJ	0.24
Specific diesel consumption	l/h	26.7
Calorific value of diesel	MJ/l	35.9

When tree is cut, the moisture content is about 50% [138]. The data about the wet and dry chips are explained in Table 3.29. Calorific value mainly depends on sort, composition and humidity [134].

Table 3.29: Properties of wet and dry wood chips [136].

	Unit	Wet forestry residues	Dry forestry residues	Dry mass
Water content	%	50	35	-
Calorific value of wood	MJ/kg	8.13	11.30	18.70
Density of wood	kg/m^3	758.00	583.08	379.00

In order to produce chips mobile chipping machine collaborating with a carrier such as tractor is suitable because of cost, technologic availability and easy use. Chips are then delivered to the customer and combusted.

3.2.4.4. Wood chips transportation for Case C

The wood chips are fed directly into the truck trailer by the chipper. It is not reasonable to carry more than 50 km chips with 50% humidity [138]. In the study of Jungmeier, fuel wood is transported by a truck over a distance of 50 km to the CHP plant [97]. In the Heller and et al. study, preliminary modelling of biomass transport by 40 tonne diesel trucks [142]. In the Goglio and et al. research it is resulted that willow chips transportation up to distances of 38 km did not have significant impact on the net energy production and CO_2 emission. If the chips are transported more than 38 km, energy efficiency of the chain drops significantly [141]. According to this researches and the geographical structure of Yalova wood grows in the vicinity of the CHP plant over an average distance is assumed as 20 kilometres. Table 5.28 gives information about the wood chip transformation. In Table 3.30 wood chip transportation data is presented.

Table 3.30: Wood chip transportation data from forest to the plant [91].

Parameters	Unit	Values
Transporter type		Lorry 40t
Annual transportation	km/a	55,165
Lifetime in years	a	12
Lifetime	km/vehicle	661,980
Diesel consumption	l/vkm	26.7
Payload	t/vehicle	20.5
Utilization	%	50
Distance	km	20

3.2.4.5. Wood chips storage for Case C

Storing chips in metal silos provides clean and dry fuels even it is expensive and also, concrete based storages are useful choices. Before storage it is important to get rid of gravel and rocks which may be picked up when chips are scraped off the ground to load into the delivery truck. Moisture and foreign materials are the most important problems of the chip storage [21]. In this study a concrete storage building is used for storing woodchips. Table 3.31 shows the properties of the storage.

The storage has a capacity of 340 m^3 bulk cubic meter that enables autonomy of the plant of approximately 7 days. The storage is calculated as a cubic building with 7x7x7 dimensions. Also the thickness of the wall is taken into consideration as 20 cm. The wood fuel is fed through one mechanical shovel that discharges woodchips in silos. Then the system of feeding to pushing-feeds the boilers in an automatic sliding bars system [23]. Material loss during the storage is 4%.

Table 3.31: Characterisitc of wood chip storage [91].

	Unit	Values
Volume of storage	m^3	343
Dimensions of storage	mxmxm	7x7x7
Thickness of wall	cm	20
Concrete requirement	kg	142,000
Material lost	%	4
Lifetime of storage	a	20

3.2.4.6. The construction of the chipping system for Case C

When chipping system is modelled in the GaBi forest residues collection equipment are built as tractor. There is a module for biopellet chipper as a result this prepared module is used for the construction of the chipper.

3.2.4.7. Wood chips in CHP for Case C

Wood chips fuelled CHP operations has no diversity in biopellet fuelled systems so all the explanations and values in the section 3.2.2.14 are valid for Case B as well. Second system contains a storage unit as stated in part 3.2.4.5. The wood chips are taken in the furnaces by means of a hydraulic pushing system. The steam generated from the furnaces flows through the turbines and supplies the necessary energy for the conversion. The steam then goes out and flows in one exchanger steam/water for the feeding of the district heating [23].

3.2.4.8. Ash disposal for Case C

Forest residues ash can be used in re-circulation systems for maintaining a sustainable energy system. Large scale ash recirculation systems is so far not demonstrated and thus wood ash is considered to be used as landfill or left for use as construction material [96]. Farmers and foresters can remove ash from the plant at zero cost, and spread it on fields. However, since this takes some time to develop: in this study it has taken a more conservative approach: ash disposal is ignored comparing the emissions in the whole system [143].

3.2.4.9. District heating for Case C

District heating of Case C have similar properties with Case B. All the values and tables in part 3.2.3.5 is valid for this system.

3.2.5. LCA impact assessment of the cases

The impcat assessment categories are explained in part 2.4.1.3. In this thesis GWP is observed by characterization factors reported by the Centre of Environmental Science of Leiden University (CML baseline 2001 method), and the potential impact categories is analysed for 100 years. GWP assessment results are clarified in g of CO_2 equivalent for 1 kWh of electricity both including and excluding heating credits.

3.2.6. Life cycle interpretation and result of the cases

Last part of the LCA interpretation is done regarding to delivering results from previous parts. Previous steps are defining goal and the scope, drawing a conclusion, determining limitations and mentioning recommendations. Inventory analysis results of observed three systems are given as global warming potential GWP (100 years). Discussions of the LCA results are also mentioned in this part.

3.2.6.1. Life cycle interpretation and result for Case A

When biopellet fuelled Case A is observed regarding to GWP, CHP plant has significant emission compared to the other systems components. These emissions are due to the electricity consumption coming from Turkish electricity mix.

The other emission resources are process of biopelletizing, grinding and drying. In the biopelletizing, process the resulting emissions are result of the diesel and electricity use. Diesel is required for operating biopelletizing diesel motors which performs in the biopelletizing. Drying is done by heat recovery from the CHP plant, the emissions from drying process comes from electricity use of heat recovery case and peripheral equipments such as residues conveyors. The CO_{2eq} values for the operation are presented in Figure 3.16. When the results are summed up with heat credit, CO_{2eq} of 1 kWh of electricity production is calculated as -15 gCO_{2eq}/kWh_{el}. White column shows the total emissions of the system considering the heat credits.

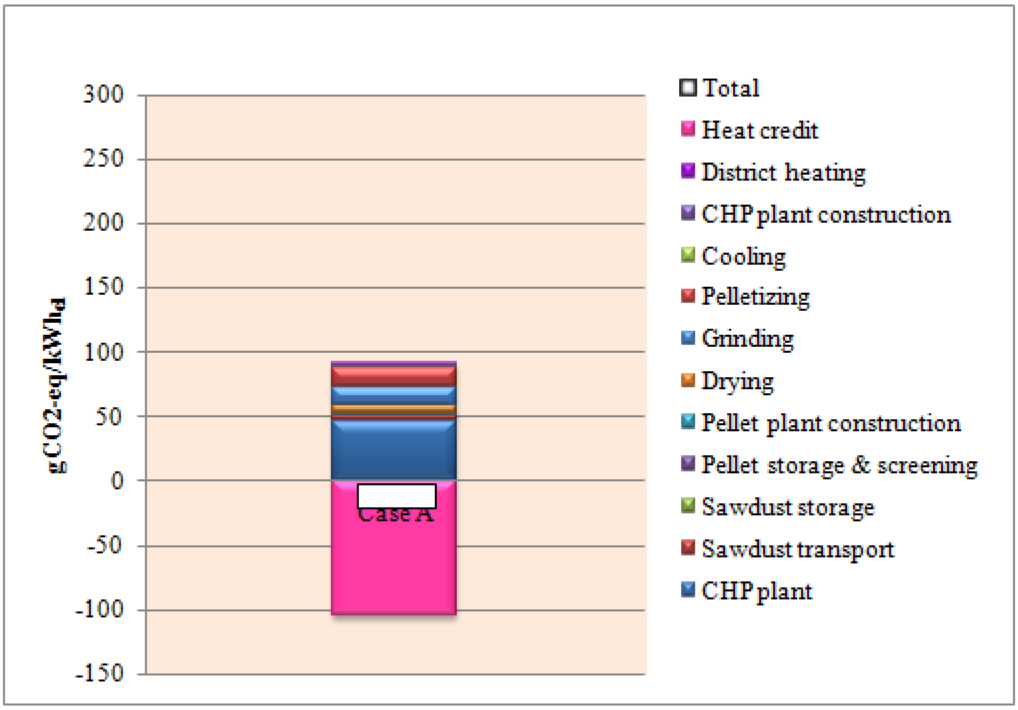

Figure 3.16: Global warming potential regarding operations for Case A.

Additionally, emission distribution of machine, plant construction and some of the other component can be showed in Figure 3.17 Electricity use in biopellet plant and CHP plant is responsible for the most of the system emissions. Machine construction emissions can be assumed as negligible compared to the other emission components. Corn starch use has negative effects on GWP. It is because of corn starch is a renewable material. Figure 3.17 shows GWP areas of the system for general structure such plant constructions and machine construction of the biopellet and CHP plant.

Moreover, heat credits are also important effects on the total emissions. It is assumed that if the sold of excess heat emissions are given into the system, the total emission is belong to the electricity. CO_{2eq} for the 1kWh electricity producing system is at Table 3.32. To sum up, in Case A total emission for the electricity can be calculated as -15 g CO_{2eq}/kWh_{el}. This value is expected because of both biomass and CHP use.

When the total emission is considered system gives negative CO_{2eq} to the environment. It means that the CO_{2eq} emission gain is higher than emission produced current methods. Thus, it is shown with a negative sign.

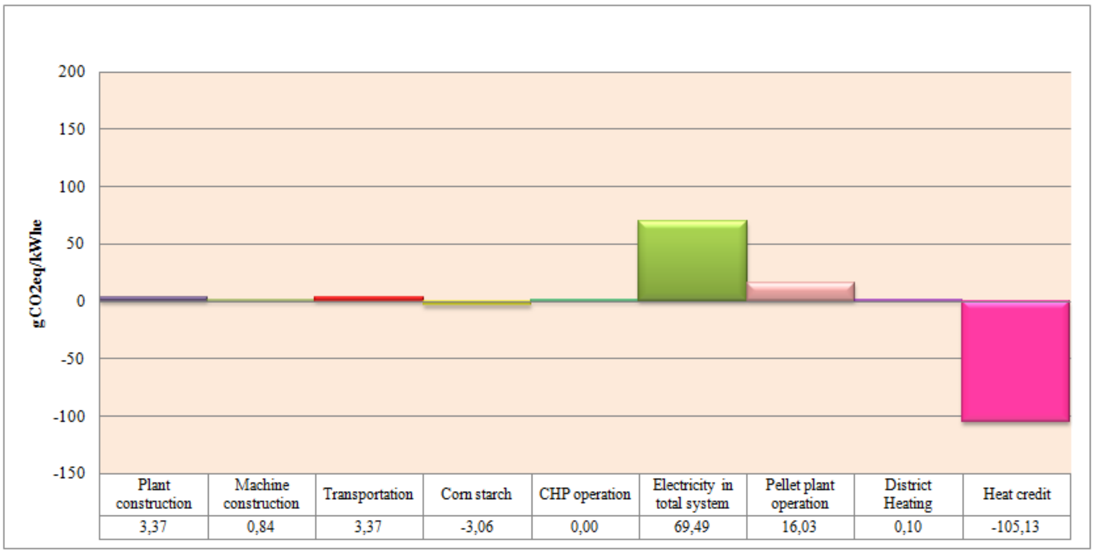

Figure 3.17: Global warming potential regarding general structure for Case A.

Table 3.32: GWP_{100} summary of Case A.

	g CO_{2eq}
System without heat credit	90.1
Heat credit	-105.1
Total system (for 1kWhe)	-15.0

3.2.6.2. Life cycle interpretation and result for Case B

Case B also consumes biopellet like Case A but the GWP is different than Case A. The use of the natural gas for drying is resulted with increment in the GWP. As clearly seen from Figure 3.18 almost 74 g $CO_{2\text{-}eq}$ is emitted during 1kWh of electricity. The main emissions are coming from the natural gas drying. Emission distribution is mentioned in Figure 3.18 for the system. Total of the emission regarding to heating credit is showed with white bar.

In this pathway, the drying process has the highest fossil energy consumption during the whole process. Use of natural gas causes this high amount of CO_2 emission. Comparing other process in Case A and B there are no obvious difference in CHP plant, grinding and biopelletizing operation. Emissions are due to electricity use in all the unit process and diesel use in biopelletizing.

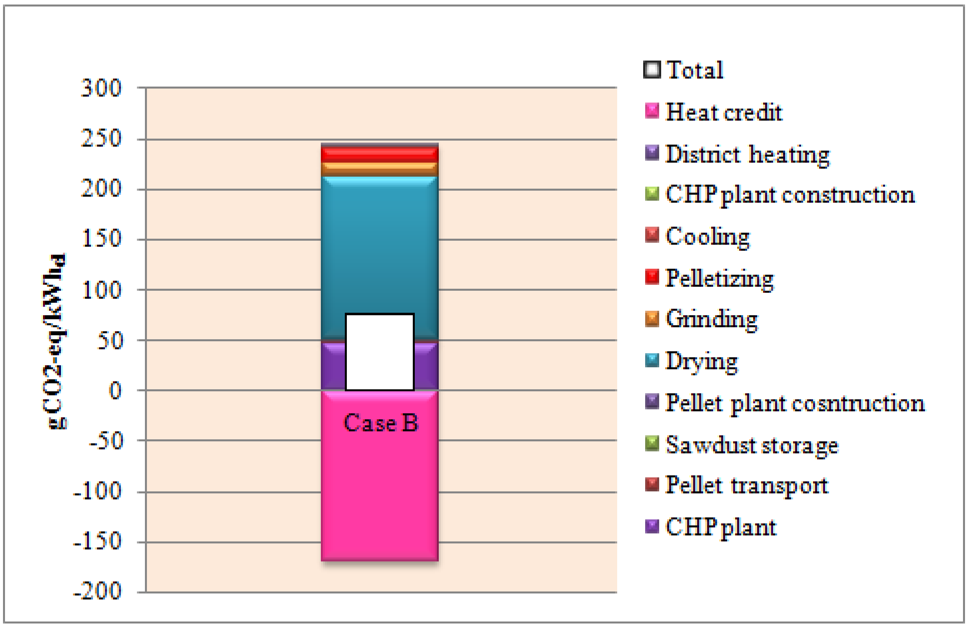

Figure 3.18: Global warming potential regarding operations for Case B.

Fossil fuel is responsible from around 70% of the overall impact. Use of natural gas, diesel and electricity use is responsible from 97% of the emission. All in all, it is obvious that rest of the components take the lowest influence on the GWP. The production stage also consumes large amount of energy. Both the drying and biopelletizing of wood residues consume a very large amount of energy, although these are essential steps for wood densification in order to transform the bulky wood residues into a useful and clean energy resource and to ease long-distance transportation for the production of wood biopellets mainly lie in the increased quantity of greenhouse gas emissions and cost when natural gas is used.

Furthermore, another representation of the emission areas is showed in Figure 3.19. Biopellet plant and CHP plant operations produce major emission of the system depending on natural gas, electricity and diesel use in unit operations. Corn starch is showed separately from biopellet operation in order to show its negative value. Construction of machine and plant has a minor effect as expected like in other studies. Heating credit comes from district heating has a major effect on the whole case as understood from the graph. This advantage comes from CHP technology, if the electricity is generated without CHP, the electricity generation emissions would be different.

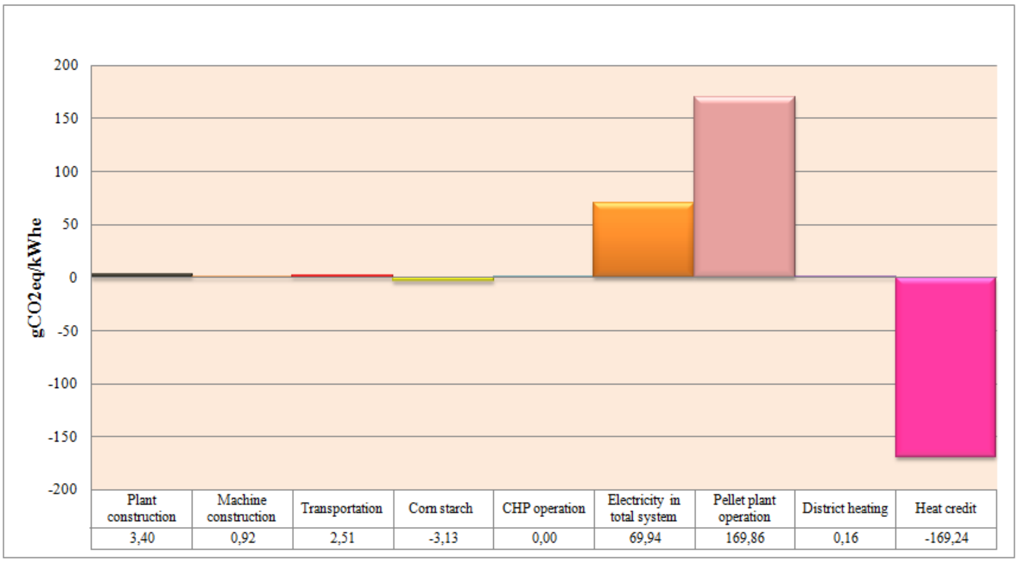

Figure 3.19: Global warming potential regarding general structure for Case B.

To sum up, one can assert that in Case B drying process has the highest energy and emission influence. An optimized use of fuel for drying can reduce the energy and emission balance significantly. At the same time different fuel alternatives such as biomass can be used for drying due to increasing usage over the world.

When the contribution of heat to district heating is added to the system, the GWP result is 74.4 g CO_{2eq}/kWh_e. In the Table 3.33 emission values regarding heat credit and other situations are given.

Table 3.33: GWP_{100} summary of Case B.

	g CO_{2eq}
System without heat credit	243.6
Heat credit	-169,2
Total system (for 1kWhe)	74.4

Consequently, heat credit is higher in Case B because it provides heat to more residence, but in Case A significant part of the heat is used for drying, it result is negative 15 gCO_{2eq}/kWh_{el}.

3.2.6.3. Life cycle interpretation and result for Case C

Wood chip fuelled system has different structure than the other systems. Chip collection, transportation, CHP plant emissions and district heating are general emission areas. During the chip production diesel is used for forest residues collecting equipments convey emissions and the minor emissions comes from equipment construction. During the chipping process diesel resourced emission occurs. While the collection equipments go through the forest, they consume more diesel than chipping. Moreover, it is clear that more than half of the emission of Case C is the result of CHP operation. As indicated before CHP electricity consumption causes the high emissions. Figure 3.20 shows the total CO_{2eq} for the system with heat credits. Total emission of producing 1 kWh of electricity is displayed with white column.

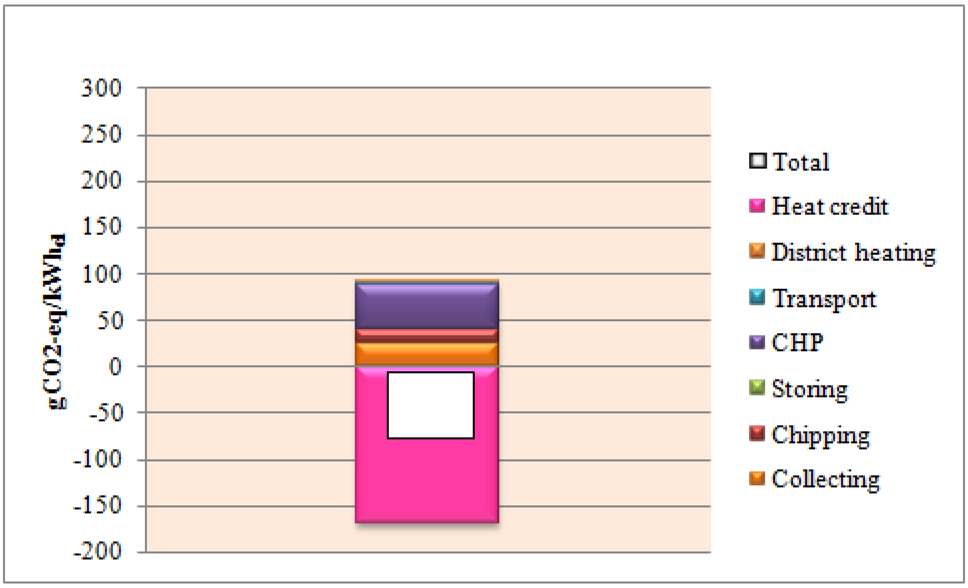

Figure 3.20: Global warming potential regarding operations for Case C.

To point out the global warming effect constructions the results are presented in Figure 3.21. It is obvious constructions of plant building and equipments have only minor responsibility about emissions.

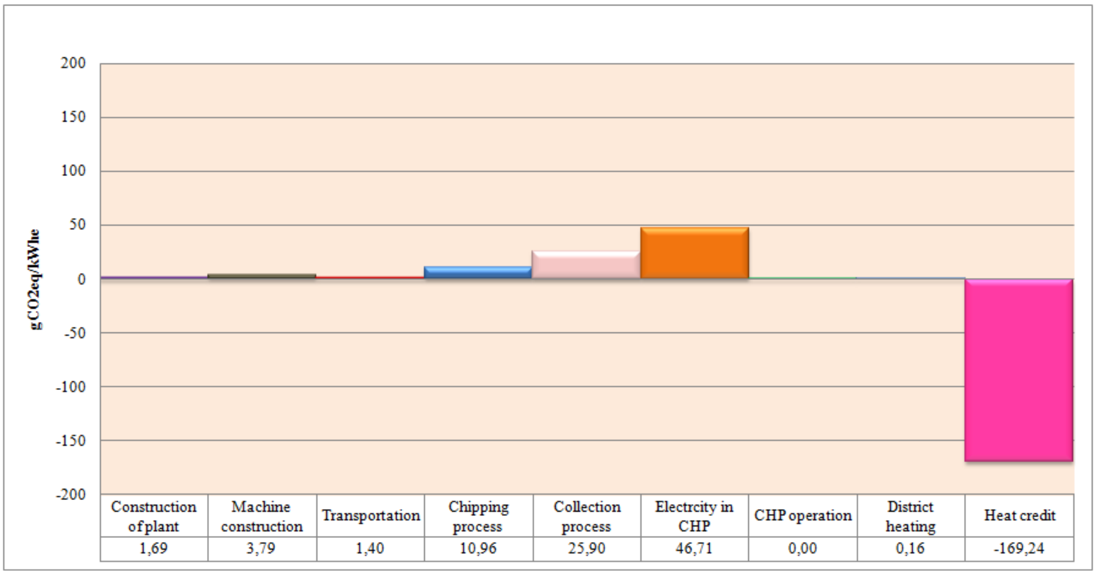

Figure 3.21: Global warming potential regarding general structure for Case C.

In conclusion, Table 3.34 shows the GWP emissions for the chips fuelled system which gives the better CO_{2eq} values. According to calculations producing 1 kWh of electricity involves -78.6 g CO_{2eq}/kWh_{el}. Surplus heat is assumed to feed the built district heating system, this means that in total the electricity generation is conveys negative GWP emissions. The CO_2 emission during combustion is assumed conveys no CO_2 emission because the CO_2 released in the combustion process is bound by the next generation of wood [144]. Its emission is negative like Case A.

Table 3.34: GWP100 summary of Case C.

	g CO_{2eq}
System without heat credit	90.6
Heat credit	-169.2
Total system (for 1kWhe)	-78.6

3.2.6.4. Life cycle interpretation and result discussion for the cases

Without heat credit it is clearly seen that, there is no a significant emission difference between Case A (biopellet without natural gas drying) and Case C (chipping). It can be seen in the Figure 3.22 without heating credits.

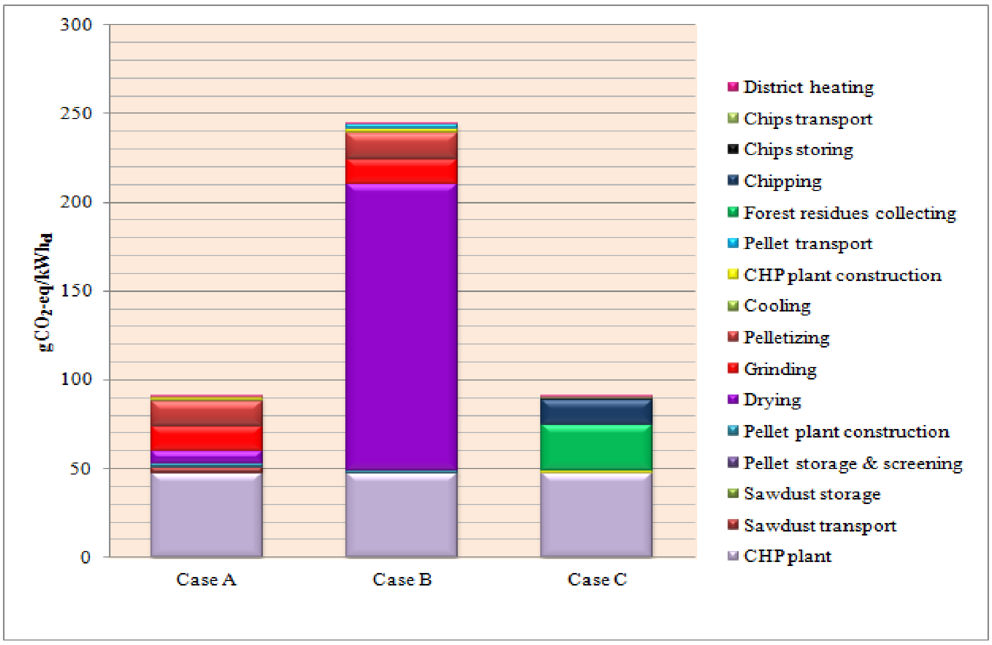

Figure 3.22: Comparision of systems for GWP without heat credit.

In fact LCA result of Case A and Case C shows a negative amount of GWP corresponding to avoided emission in comparison with fossil fuels. The result of Case C is better than Case A. On the other hand, Case B emissions are positive because of higher fossil fuel use and complex operations than Case C.

Heating credits are mentioned in Figure 3.23 for three systems as well. Case A has the lowest heat credit due to utilizing heat for drying unit of biopellet production plant. Heat credit of Case B and C is the same. However Case C has lower emission due to lower fossil energy consumption in the life cycle.

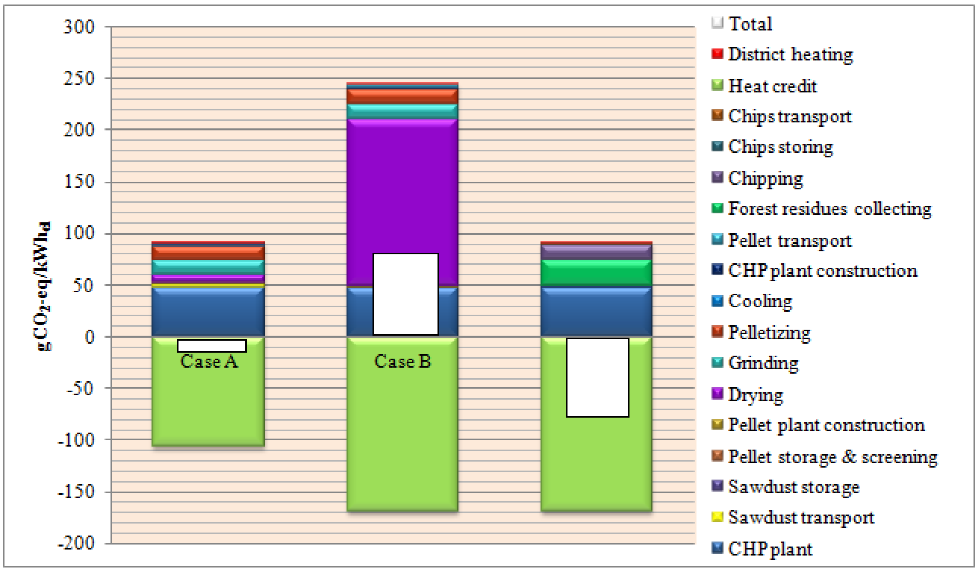

Figure 3.23: Comparision of systems for GWP with heat credit.

Figure 3.24 indicates the comparison of general Turkish electricity mix, electricity generation from fossil fuels such as natural gas, coal and oil and observed systems in this study. Turkish electricity mix has 523.94 g CO_{2eq}/kWh$_e$ emission: in section 5.2.2 detailed information is given about the mix.

If electricity generated by using biomass and CHP, the resulting emission are significantly lower than Turkish electricity mix and other conventional electricity production process. Although Case B has the highest GHG emission in three systems, comparing the Turkish general electricity mix. The effect of heat credit cannot be disregarded. The overall GWP savings due to biomass use in Turkey can be assessed using the LCA results and the information on the amount of biomass actually utilized.

Finally, the evaluation of GHG emissions show that forest and sawmill residues seems to be preferable compared to fossil energy use. To decide the feasibility of these systems economic values should be calculated.

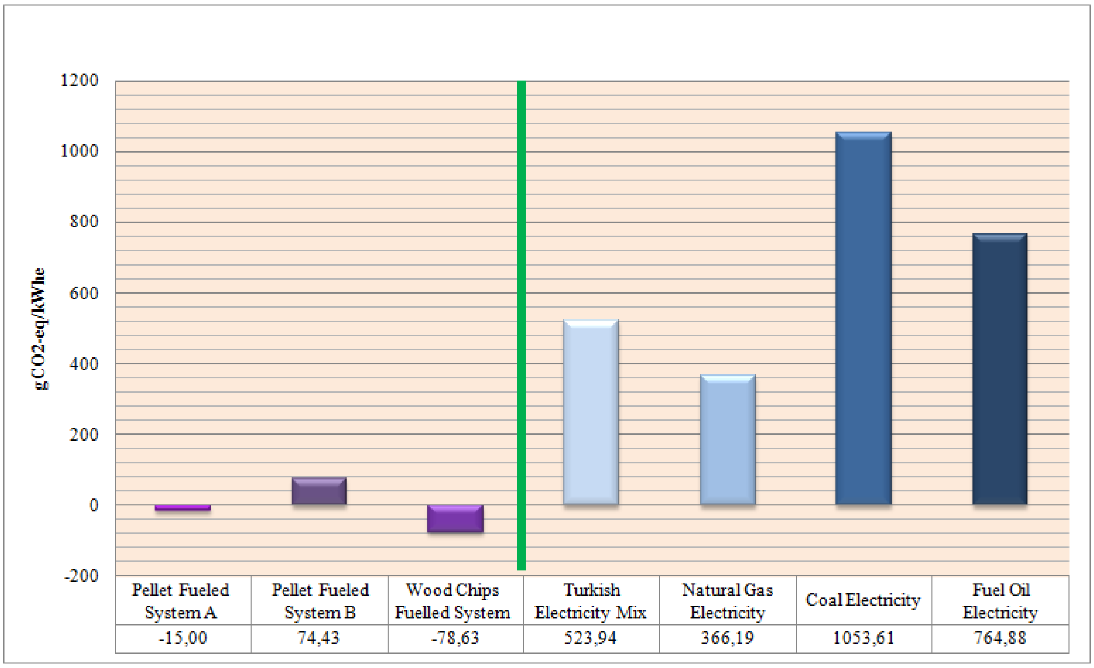

Figure 3.24: Comparison of GWP results including heat credit with Turkish electricity production [100].

3.3. Mass and Energy Balance Regarding Electricity Generation from Combined Heat and Power Plants Using Woody Biomass in Turkey

For the mass balance of fuel biopellet and wood chips, Figures 3.25-27 are a base for mass calculation of case A, B and C respectively. There are loss materials between inlet and outlet of the operations because of operation conditions. For instance inlet of the feedstock storage there is 1.29 kg sawmill residues for 1 kWh of electricity generation however t the outlet 1% of the material became loss. In Case A pellet transport input and output is showed with line because it is not exist in Case A. Operational loss percentages are explained previous sections.

In Case B, sawmill residues input is more than Case A because of the material loss during operation. Case B contains more steps such as pellet plant storage and pellet transportation. Woody material mass balance is given in Table 3.35 for biopellet fuelled cases. Base condition for the calculation is 1 kWh of electricity generation. Fossil fuel inputs are not presented as a material input: they are presented in energy balance. For Case A and Case B, GaBi interfaces are presented in the Figure 3.25 and Figure 3.26 respectively.

Table 3.35: Material input and output of operations for Case A an Case B.

Inlet	Material type	Case A (kg)	Case B (kg)
Feedstock storage	Sawmill residues	1.29	1.32
Drying	Sawmill residues	1.28	1.31
Grinding	Sawmill residues	0.72	0.74
Pelletizing	Sawmill residues	0.71	0.73
	Cornstarch	0.007	0.007
Cooling	Biopellet	0.71	0.73
Storing of pellet	Biopellet	0.71	0.73
Pellet transport	Biopellet	-	0.72
CHP storage	Biopellet	-	0.71
CHP plant	-	0.70	0.70
Outlet	Material type	Case A	Case B
Feed stock storage	Sawmill residues	1.28	1.31
Drying	Sawmill residues	0.72	0.74
	Vapour	0.56	0.57
Grinding	Sawmill residues	0.71	0.73
Pelletizing	Biopellet	0.71	0.73
Cooling	Biopellet	0.71	0.72
Storing of pellet	Biopellet	0.70	0.71
Pellet transport	Biopellet	-	0.70
CHP storage	Biopellet	-	-
CHP plant	-	-	-

In order to produce 1 kWh of electricity from wood chips, 1.76 kg raw material is required. This amount is 1.29 kg and 1.32 kg for Case A and Case B respectively. Major mateial loss of Case C is in the forest and wood chip storage sections.

Case C material balance is explained separated than other cases. There is a weight loss during chipping: however there is no thermal operation during chipping. GaBi interface of Case C is given in the Figure 3.27.

The reason of decrease in forest residues water contenet is that residues are waited in the forest for drying. It has advantage of carrying more dry wood chips. Also during the storage there is 4% of material loss. Wood chips are not dry as pellets as result storage losses are higher than pellet storage. Material balances for Case C are presented in the Table 3. 36.

Energy balance of the three cases are presented in the Table 3.37 This balance is calculated according to the 1 kWh of electricity generation. CHP system requires 3.59 kWh, 3.63 kWh and 3.98 kWh of raw material for Case A, Case B and Case C in order to produce 1 kWh of electricity and 2 kWh of heat respectively. According to whole life cycle Case A has the biggest total efficiency. The worst efficiency is belong to Case B because of natural gas consumption. Total efficiency of the system is calculated with that equation 3.2.

Table 3.36: Material input and output of operations for Case C.

Inlet	Material type	Case C (kg)
Forest residues collection	Wet forest residues	1.76
Chipping	Wet forest residues	1.73
Chip transportation	Dry forest residues	1.15
Chip storage	Dry forest residues	1.14
CHP plant	Dry forest residues	1.10
Outlet	Material type	Case C
Forest residues collection	Wet forest residues	1.73
Chipping	Wet forest residues	1.15
	Vapour	0.58
Chip transportation	Dry forest residues	1.14
Chip storage	Dry forest residues	1.10
CHP plant	Dry forest residues	-

$$\text{Total Efficiency} = \frac{E_{\text{CHP electricity}} + E_{\text{CHP heat}}}{E_{\text{Biomass,input}} + E_{\text{Fossil}} + E_{\text{Electricity}}} \quad \textbf{(3.2)}$$

Table 3.37: Total energy balance of three cases using woody biomass for 1kWh of electricity.

Inputs	Case A	Case B	Case C
Sawdust (kWh)	3.59	3.63	3.98
Diesel fuel(kWh)	0.15	0.10	0.51
Natural gas (kWh)	0.00	0.53	0.00
Electricity (kWh)	0.13	0.14	0.32
Total fossil energy consumed (kWh)	0.27	0.74	0.77
Total fossil primary energy (kWh)	0.29	1.91	0.98
Total fossil primary energy incl. credits (kWh)	-0.07	1.33	-1.11
Outputs	Case A	Case B	Case C
Heat (kWh)	2	2	2
Electricity (kWh)	1	1	1
Heat for district heating (kWh)	0.18	0.29	0.29
Total chain efficiency (%)	78.00	68.00	71.00
CHP efficiency %	87.00	87.00	87.00

Total annual energy balance is also important in order to observe the three cases. During one year operation sawdust and wood chip consumptions are 60.29 GWh, 60.90 GWh and 66.87 GWh for Case A, Case B and Case C respectively. Total primary energy consumption requirement of Case B is the biggest. Annual energy balance of the system is presented in the Table 3.38.

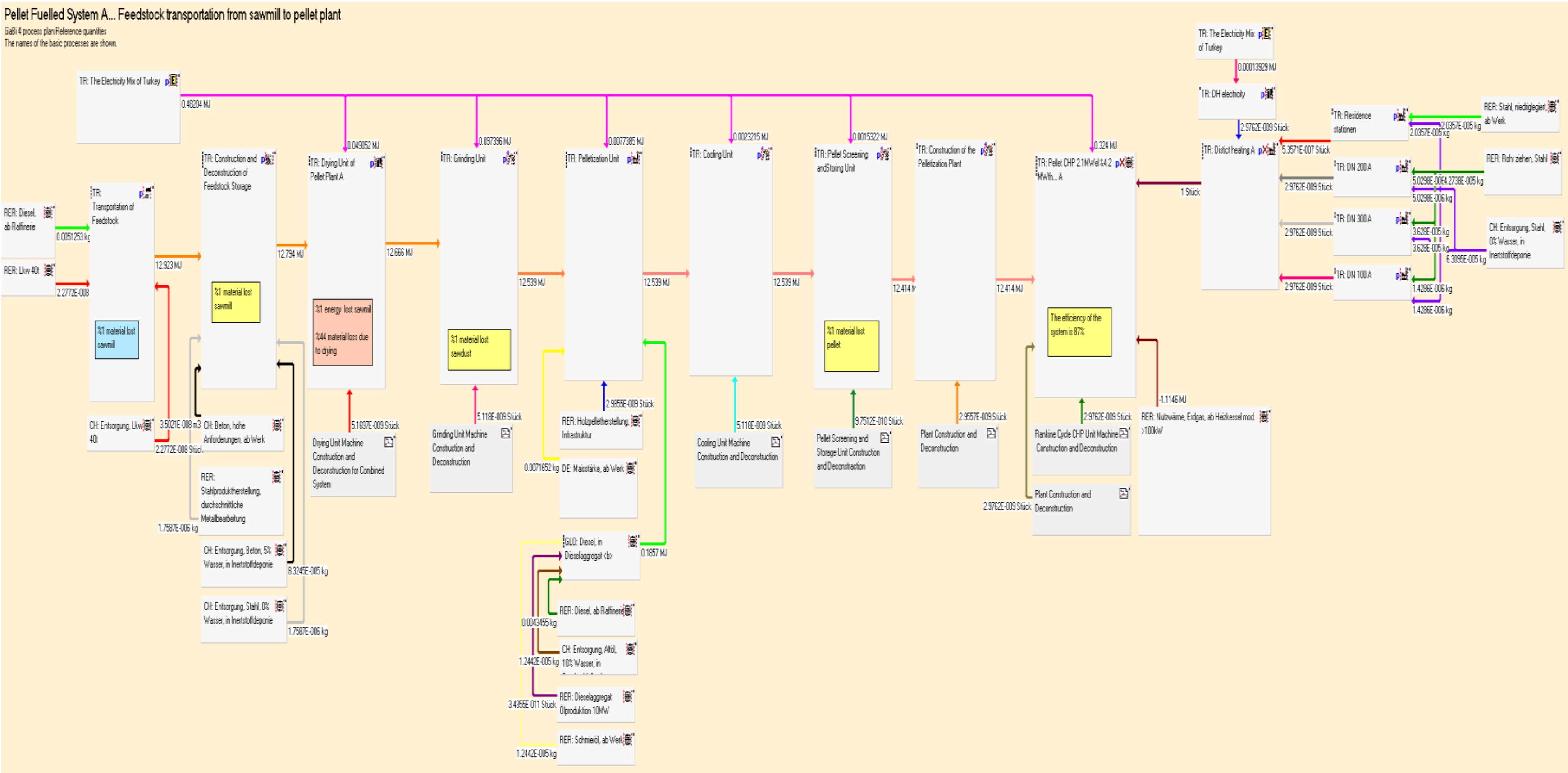

Figure 3.25: GaBi interface for Case A.

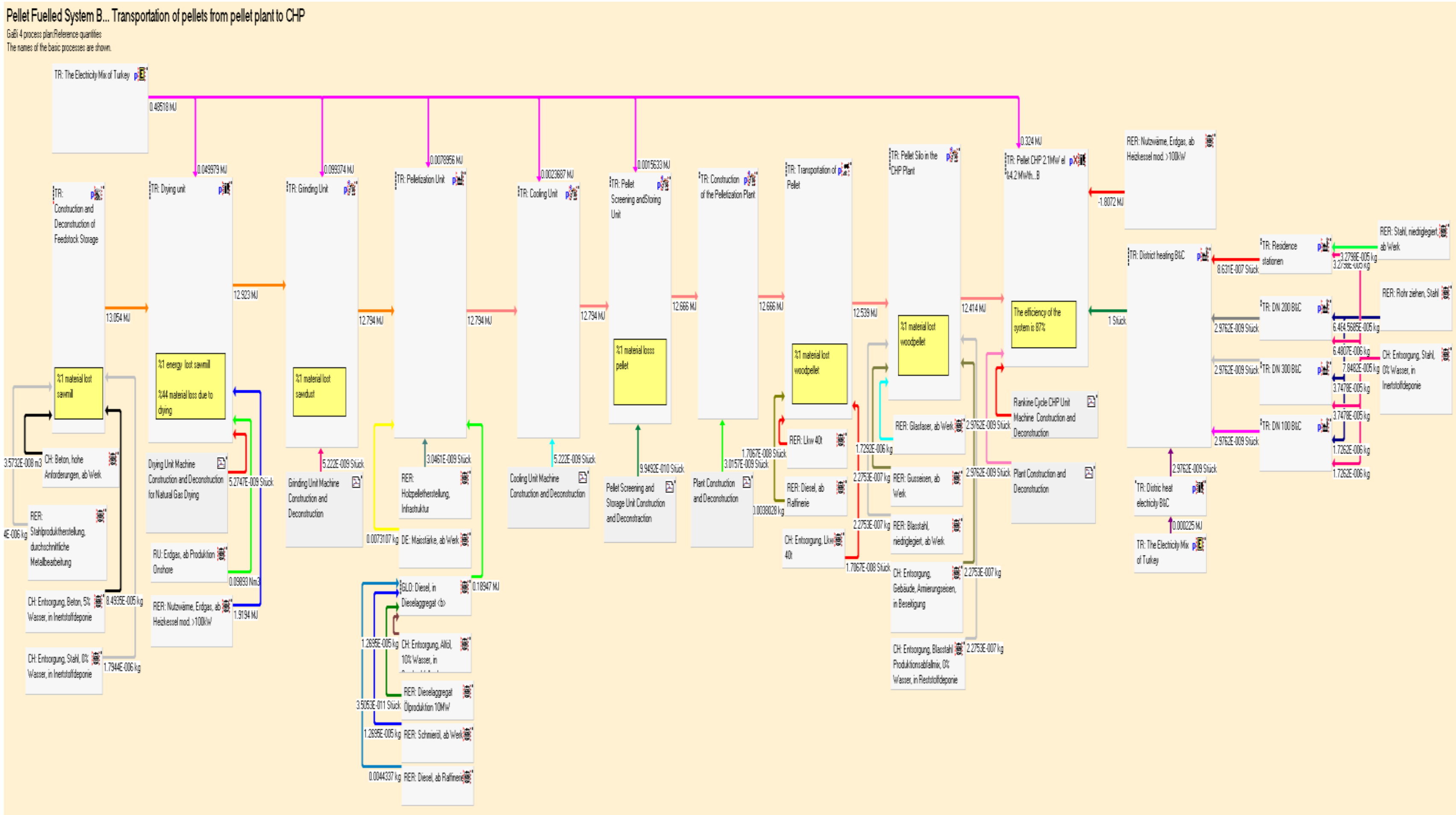

Figure 3.26: GaBi interface for Case B.

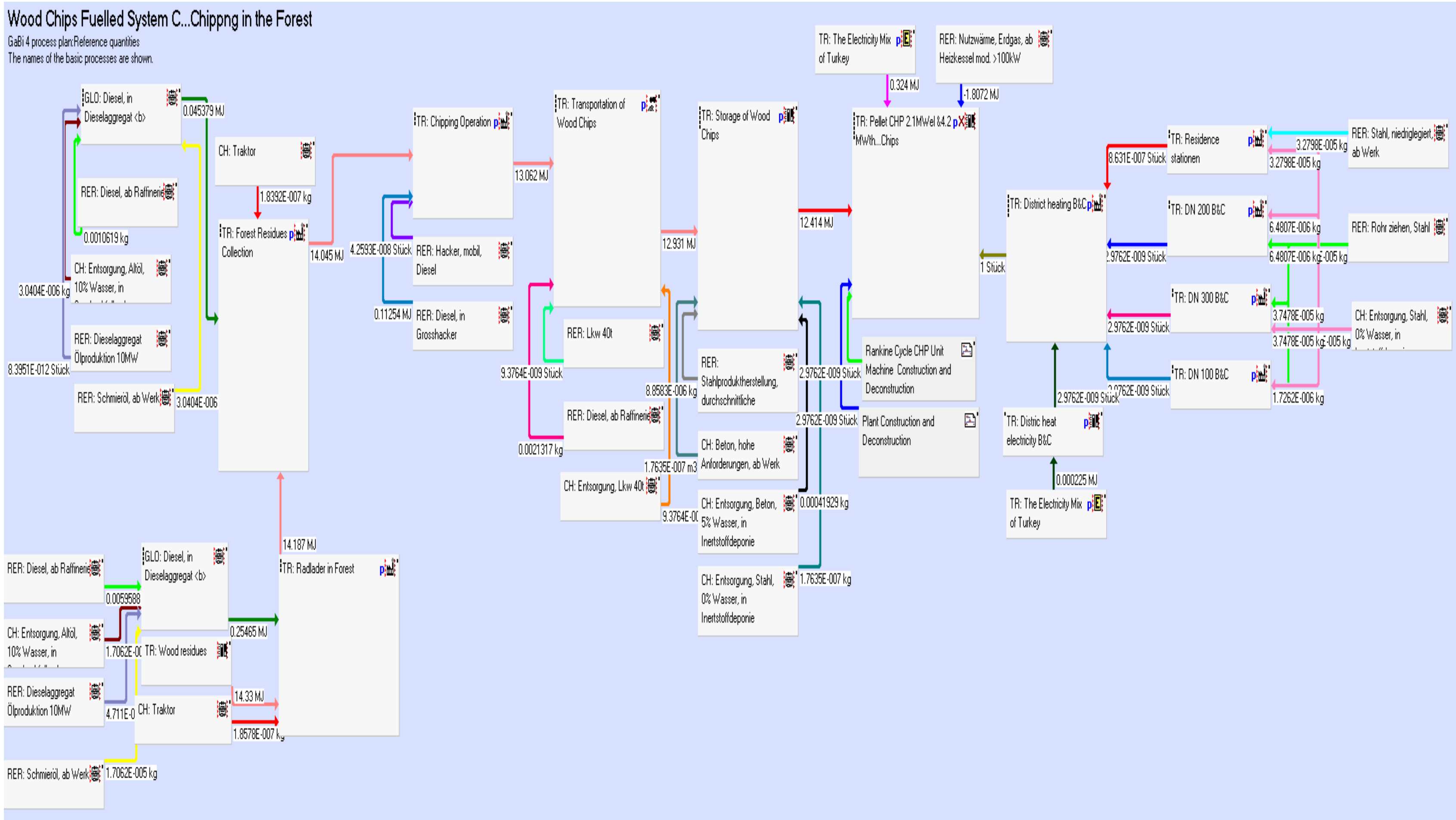

Figure 3.27: GaBi interface for Case C.

Table 3.38: Annual energy balance of three cases using woody biomass.

Inputs	Case A	Case B	Case C
Sawdust (GWh)	60.29	60.90	66.87
Diesel fuel (GMWh)	2.47	1.63	2.38
Natural gas (GWh)	0,00	8.96	0,00
Electricity (GWh)	2.24	2.28	1.49
Total fossil energy consumed (GWh)	4.57	12.46	3.59
Total fossil primary energy (GWh)	4.85	32.06	4.57
Total fossil primary energy incl. credits (GWh)	-1.12	22.26	-5.18
Outputs	Case A	Case B	Case C
Heat (GWh)	33.6	33.6	33.6
Electricity (GWh)	16.8	16.8	16.8
Heat for district heating (GWh)	3.08	4.90	4.90
Total chain efficiency%	78,00	68,00	71,00
CHP efficiency %	87,00	87,00	87.00

3.4. Economic Assessment Regarding Electricity Generation from Combined Heat and Power Plants Using Woody Biomass in Turkey

One way of considering the profitability of plant is on the basis of its complete economic analysis. The main cost influencing factors can be listed as: acquisition costs (capital cost, installation cost and time, commissioning cost and time), operation cost (production cost, maintenance cost and fuel cost), output parameter (useful life, plant availability) and outside management control (product demand, product price).

Result of the economic assessment gives the specific electricity generation cost of the whole cycle. The specific investment cost, as well as the electricity generation costs, can significantly be reduced by a reduction investment cost or by the investment subsidies [145]. As mentioned before, Yalova is a MARKA city. It means investment of this city is supported by funding. In 2010 MARKA funding for east Marmara is up to half of the project investment but the upper limit of funding is 300,000 TL [105]. In these calculations two cases investigated governmental supports, used and not used. During economic calculations cost of disposal of the plants and equipments are not considered. Additionally the profits margins of plant operation are not included in the calculations. All the system related costs are defined in the next sections and specific electricity generation costs are derived for three systems.

An economic evaluation of the steps of the manufacturing process was made using the full costing method based on the study of Thek [145]. According to this, the different types of costs are divided into two cost groups. These are:

- The costs based on capital
- The operating costs

Capital costs include machine investment, plant area, factory building, freight, installations, engineering, planning and tax. Labour, maintenance, raw material and energy resources constitute operating costs [146].

3.4.1. Economic assessment for cases using biopellets

During economic analysis capital investment and operational costs will be defined. Specific electricity cost will be calculated for each system considering annual investment cost, lifetime of the system, sold heat and governmental incentives. General technical information about Case A is mentioned before [94].

The analysis was carried out for the different sections of the biomass plant over their entire life cycle 20 years of operation. This means that the operational lifetime of all stages and their different parts of the biomass fuel cycle is assumed to be 20 years [97]. Characteristic information for the economic assessment of the biopellet and CHP units are given in Table 3.39 Furthermore utilization period of the equipments which are used in calculations are also summarized in Table 3.39. General electricity selling price is 14.07 TL_{2010}/kWh in Turkey.

Table 3.39: Economic specifications for biopellet and CHP plant [94, 97-101].

General conditions of systems A&B	Unit	Value
Price of electricity	TL_{2010}/kWh	14.07
Interest rate	%	6.25

To sum up district heating system is also included into economic analysis. Utilization period of the district heating can be seen in the table above.

3.4.1.1. Estimation of capital cost of Case A

Capital cost pertains to the costs associated with the construction of a new plant or modifications to an existing manufacturing plant. The capital cost for plant is taken into consideration many costs other than the purchased cost of equipment [81]. Capital cost of CHP system is more expensive than other processes. The most expensive equipment is CHP furnace and boiler. The capital cost of different equipment has been collected from equipment suppliers, biopellet manufacturer and the literature. Initial purchase cost is affected by the quality of the equipment.

Table 3.40: Fixed capital investment cost for biopellet and CHP plants of Case A [92, 101, 148-153].

Parameters	Unit	Values	TL_{2010}
Biopellet Plant			
Land Cost	TL_{2010}	536,000	53,6000
Building	$€_{2009}$	250,000	316,000
Sawdust storage	$\$_{2007}$	280,000	213,000
Grinding	$\$_{2007}$	31,200	27,400
Biopelleting			
Conditioner	$\$_{2007}$	43,900	35,000
Boiler	$\$_{2007}$	45,000	36,000
Biopellet mill	$\$_{2007}$	125,000	86,000
Cooling	$\$_{2007}$	31,800	28,500
Screening	$\$_{2007}$	18,300	16,000
Conveyor, tanks, etc	$\$_{2007}$	200,000	151,000
Biopellet Storage	$\$_{2007}$	280,000	213,000
Freight of equipment	$\$_{2007}$	79,000	60,000
Transport machinery	$€_{2008}$	200,000	167,700
Engineering	$\$_{2007}$	20,000	31,700
Project Management	$\$_{2007}$	10,000	15,800
Mechanical installation	$\$_{2007}$	40,000	63,300
Electrical installation	$\$_{2007}$	30,000	47,500
Tax of equipment	TL_{2010}	41,300	41,300
CHP Plant			
Land Cost	TL_{2010}	440,000	440,000
Building	$\$_{2008}$	280,000	231,000
Furnace and boiler	$€_{2002}$	4,900,00	3,726,000
Flue gas cleaning	$€_{2002}$	510,000	388,000
Ash container and conveyor	$€_{2002}$	120,000	75,300
Heat recovery	$€_{2002}$	Included	Included
Fuel conveyor	$€_{2002}$	800,000	608,300
CHP module	$€_{2002}$	4,100,00	3,177,000
Steelworks	$€_{2002}$	Included	Included
Planning	$€_{2002}$	720,000	655,700
Weighbridge	$€_{2002}$	100,000	76,000
Electric installation	$€_{2002}$	670,000	610,275
Hydraulic installation	$€_{2002}$	40,000	36,400
Tax of equipment	TL_{2010}	71,900	71,900
District Heating System			
Pipe system	TL_{2005}	120,300	163,000
Pipe assembly	TL_{2005}	75,600	98,000
Pumping station	$€_{2009}$	19,500	41,500
Residential installation	$€_{2009}$	406,000	860,000
Planning	TL_{2010}	52,245	52,245

In Case A, there is no natural gas boiler in the case and there is one storage unit for biopellets and one storage unit for sawdust. Transportation of biopellet does not exist because the close location of biopellet plant and CHP. Transportation equipment assumed to be two trucks. Literature values are used with scaling factor for the equipments. Also the taxes for the equipment are not included in the price as a result tax is taken as 4 % of capital investment [147]. For the CHP plant tax is taken as 0.9% of capital investment regarding to Thek [94]. All equipment prices are adjusted to 2010 Turkish Lira (TL_{2010}) value by using inflation factor. Price from literature and TL_{2010} equality by means of scaling factor is showed in Table 3.40.

The base cost for equipment according to price in resource year is explained in the second column of Table 3.41. Values in original resources are located in third column and fourth column gives the prices for 2010 in terms of Turkish Liras (TL).

Table 3.41 gives the scaling factors of the system. Biopellet plant equipment prices are generally taken for biopellet plants capacity between 2t/h and 4t/h depending on the resource.

Table 3.41: Economic scaling factors for biopelletizing and CHP plants [143, 147].

Equipment	Scaling Factor
Dryer	0.99
Grinding	0.60
Feeder	0.57
Boiler	0.70
Biopellet mill	0.85
Biopellet cooler	0.58
Screener	0.60
Conveyor, tanks, etc	0.75
Storages	0.75
Total power plant	0.75

For CHP, the heat and power production is considered separately in the study of Thek. CHP values are mentioned for a plant based on steam turbine with 4.7 MW_{el} and 14 MW_{th} as nominal capacity. The values are calculated by using the scaling factor as 0.75 in order to make suitable for observed system.

Moreover, the average land price in Yalova is 160 TL/m^2 [148]. For biopellet production plant total area is estimated according to the average area of European biopellet production factory buildings [148-150]. A summary of the land area requirement is showed in the Table 3.42.

Table 3.42: Land area requirement of the plants [149-150].

Plant	Unit	Area
Biopelleting Plant		
Factory Building	m^2	750
Land for development	m^2	2600
CHP plant		
Factory Building	m^2	750
Land for development	m^2	2000

District heating system calculations are done based on equipment from CHP plant to residential buildings. For the planning of district heating 5% of the capital investment is taken into consideration [101].

3.4.1.2. Estimation of operating cost of Case A

To estimate the manufacturing costs, raw materials, utilities, waste treatment and operating labour costs are calculated [81]. Technical data about the CHP plant based on a steam turbine process is described in Table 3.43.

Table 3.43: Energy consumption data of Case A[6, 154-155].

Parameter	Unit	Value
Specific electricity consumption of CHP plant	kWh_e/MWh_{th}	30
Electricity consumption biopellet plant	$kWh_e/kg_{biopellet}$	0.0629
Diesel consumption	$g/ kg_{biopellet}$	9.9
Electricity specific cost	TL/kWh	14.07
Diesel specific cost	TL/l	3.3
Specific sawdust consumption	$kg/ kg_{biopellet}$	1.79
Sawdust cost	TL/kg	105

Raw material cost is taken as 105 TL_{2010}/t due to average data from the market. Feedstock transportation is not included to that price [155]. Besides, transportation calculations are done in Appendix A.4.

Annual operating cost of the system is declined in Table 3.44 regarding to the point explained in this part.

All biopellet plant equipment needs electricity, which is a significant part of biopellet production cost. All of the equipment required for biopellet production, the most of the electricity is consumed by grinding, followed by the dryer if the dryer is used. Size of the unit should be proper otherwise overly large unit will waste electricity. Power need is related with the feedstock species, particle size, biopellet size and moisture level [147]. Average electricity sale price for Turkey is used in the calculation as explained by EMRA 0.1407 TL_{2010}/kWh [6].

Quality and reliability of the equipments affects the maintenance cost significantly [147]. The annual maintenance cost of the equipment in this study is taken as 2.5% of the capital cost of equipments except for the hammer mill and biopellet mill. In this study, the annual maintenance cost of the hammer mill and biopellet mill are assumed to be 18% and 10% of the installed equipment capital cost, respectively [93, 147]. For CHP and district heating sections annual maintenance cost value is also calculated as 2.5% of capital investment cost.

Another major cost component is the employee cost, which includes the cost of personnel in production, marketing and administration. There are two types of employee in the biopellet plant permanent employee and hourly-wage employees. Maintenance operators are generally hourly wage employees [147].

Many biopellet plants run with two production employees per shift and have a separate bagging operation that employs two to four people depending on volume processed and level of automation. Usually maintenance work is performed by another one to two persons. Total plant operational personnel are five to six people per shift [92]. In this study, there are 2 operators 1 shift supervisor for each shift, but one maintenance worker for 3 shifts. Maintenance operator comes when needed and it is assumed one maintenance worker for three shifts. Besides, there is no bagging operator because biopellets are sent only to CHP plant.

The plant is operated with 3 shifts, for three shifts 9 permanent labours and 1 maintenance labour is needed as seen in the Table 3.45. In 2006 the cost of a labour in Turkey is 1.200 YTL, according to this value: cost of the labour is calculated for year 2010 with interest rate [156]. The requirement for personnel in marketing and administration depends on 2 active personnel in this field [93]. For general manager monthly salary and other management employee salary are 4000 TL and 2500 TL respectively [147, 157]. Administrative expenses for the CHP plant are supposed to be the same as the biopellet plants. On the other hand, continuous shift work with 1.4 persons per shift on average will be needed for the operation of the entire plant. In the CHP plant, it is assumed that there are 2 workers in each shift. Totally there is 6 employees including maintenance labour.

Table 3.44: Operational cost of the biopellet plant and CHP plants of Case A [92, 6, 101, 155-158]

Biopellet Plant	Unit	Value	TL_{2010}
Administration labour cost	TL_{2010}/a	78,000	78,000
Operation labour cost	TL_{2010}/a	183,500	183,500
Sawdust feedstock	TL_{2010}/a	2,250,000	2,250,000
Sawdust carrying cost	TL_{2010}/a	156,000	156,000
Electricity Cost	TL_{2010}/a	106,200	106,200
Diesel cost	TL_{2010}/a	386,100	386,100
Corn starch cost	TL_{2010}/a	72,000	72,000
Maintenance Cost			
Sawdust storage	$\$_{2007}$/a	7,000	5,300
Grinding	$\$_{2007}$/a	5,616	5,000
Conditioner	$\$_{2007}$/a	1,100	875
Boiler	$\$_{2007}$/a	1,125	900
Biopellet mill	$\$_{2007}$/a	12,500	8,600
Cooling	$\$_{2007}$/a	800	712
Screening	$\$_{2007}$/a	460	400
Conveyor, tanks, etc.	$\$_{2007}$/a	5,000	3,800
Biopellet storage	$\$_{2007}$/a	7,000	5,300
Transport machinery	$\$_{2007}$/a	5,000	11,000
CHP plant	**Unit**	**Value**	**TL_{2010}**
Administration labour cost	TL_{2010}	78,000	78,000
Operation labour cost	TL_{2010}	110,000	110,000
Ash disposal	€$_{2002}$	29,313	21,750
Electricity costs	TL_{2010}	212,000	212,000
Maintenance cost			
Furnace and boiler	€$_{2002}$	122,500	93,000
Flue gas cleaning	€$_{2002}$	12,750	9,700
Ash container & conveyor	€$_{2002}$	3,000	1,900
CHP module	€$_{2002}$	102,500	78,000
Fuel conveyor	€$_{2002}$	15,000	15,200
District Heating	**Unit**	**Value**	**TL_{2010}**
Maintenance cost			
Pipe system	TL_{2005}	3,000	4,075
Pipe assembly	TL_{2005}	1,800	2,450
Pumping station	€$_{2002}$	490	1,038
Residential installation	€$_{2002}$	10,150	20,100
Electricity cost (pumping)	TL_{2010}	2,400	2,400

Table 3.45: Information about labour of biopellet plant [91].

Employee	Workers/Shift
Shift supervisor	1
Machine maintenance worker	1 (for 3 shifts)
Machinery equipment operator	2

3.4.1.3. Economic assessment results of Case A

According to calculations annual cost for Case A is 5,109,333 TL/a. Moreover, as stated in section 3.2.2.15 23% of the CHP heat is sold to district heating system. District heating system is assumed to substitute of natural gas heating. Therefore natural gas heating price is used in the calculations. Average price for natural gas heating is 0.066 TL_{2010}/kWh for residential space heating. Total revenue from heat sell is 464,640 TL/a. Specific electricity generation cost is calculated with the equation 3.3.

$$\text{Electrity price} = \frac{\text{Annual Costs}_{\text{case}} - \text{Annual Revenue}_{\text{heat sold}}}{\text{Annual kWh}_{\text{electricity}}\ \text{Produced}} \qquad \textbf{(3.3)}$$

The annuity (annual capital costs) can be calculated by multiplying the capital recovery factor (CRF) with the investment costs (equation 3.4).

$$\text{CRF} = \frac{(1+i)^n i}{(1+i)^n - 1} \qquad \textbf{(3.4)}$$

All in all, specific electricity cost for Case A is calculated as 0.276 TL/kWh_e without governmental substitutes. Considering the subsidy of 300,000 TL, the electricity cost is reduced 0.001 TL/kWh_el.

Turkey support the renewable-based electricity investments by regulations, for instance government give purchase guarantee for renewable-based electricity until 2015 electricity. Electricity selling price for the bioelectricity is set to 13.3 US cent/ kWh with the renewable-based energy law of Energy Market Regulatory Authority. Also for the first 5 years 0.4 US cent/ kWh will be paid because of cogeneration system use [64]. As a result the government guarantees the payment of 0.206 TL/ kWh_e but it is lower than cost of electricity of Case A.

Furthermore, distribution of the total annual cost of the biopellet plant, CHP plant and district heating can be analysed separately. Annual cost components for the biopellet plant A is showed in the Figure 3.28. Raw material has 70% of annual cost of the plant. Personnel and biopelletizing costs are 8% and 7% respectively. Biopelletizing costs are mainly because of the diesel use in the biopellet mill engines. During the biopelletizing cost occurs as a result of the diesel use in the biopelletizing mill and corn starch use as an addictive. Biopelleting has two biopellet mills, powered by diesel engines: each of them has a conditioning unit [84].

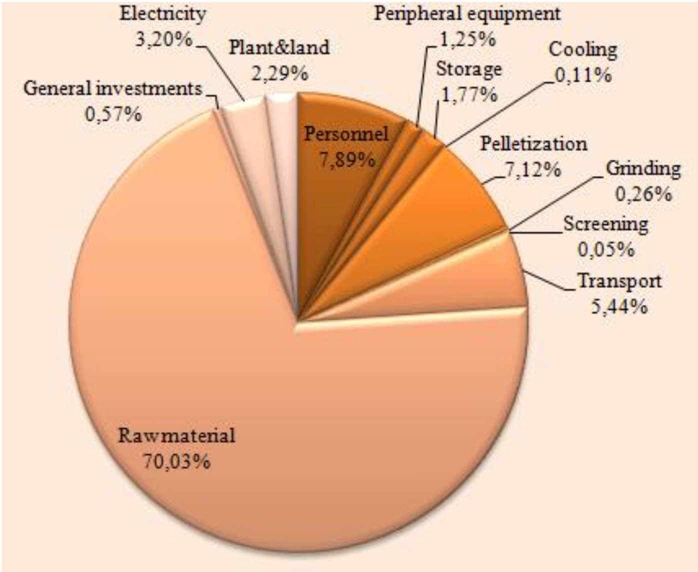

Figure 3.28: Share of annual cost in biopellet plant of Case A.

Transportation is also an important cost component because of long distance transport of residues. Carrying 50% water content residues cause high cost. As cleary seen in the Figure 3.28. Equipment construction has an insignificant effect on annual cost comparing operational and consumption costs. Operational and consumption costs include electricity, labour, energy, raw material etc. Biopellet production cost also can be calculated regarding to the analysis as 276 TL/$t_{biopellet}$.

The CHP plant is observed as standalone plant: however biopellet buying price is not used in this study. Biopellet buying price can be added in Figure 3.29 but in this study, biopellet and CHP plant work as partner so that biopellets are assumed to be produced for the CHP chain. The cost share except biopellet cost is given in Figure 3.29, CHP plant equipment cost are higher than biopellet plant equipment cost because of the high technology of CHP system.

The last part of Case A is district heating which has the lowest annual cost. Residential installations have high cost comparing other systems because heat stations, radiators, fittings and labour costs are expensive for houses. Also general investments include planning cost of the system. Piping system cost comprises assembly of the pipes and pipes own costs. Pump cost is taken but the capacity of this system is three times of this study, therefore it is assumed three pieces of the same pump are used in Case A [101]. In Figure 3.30 district heating cost for Case A is presented.

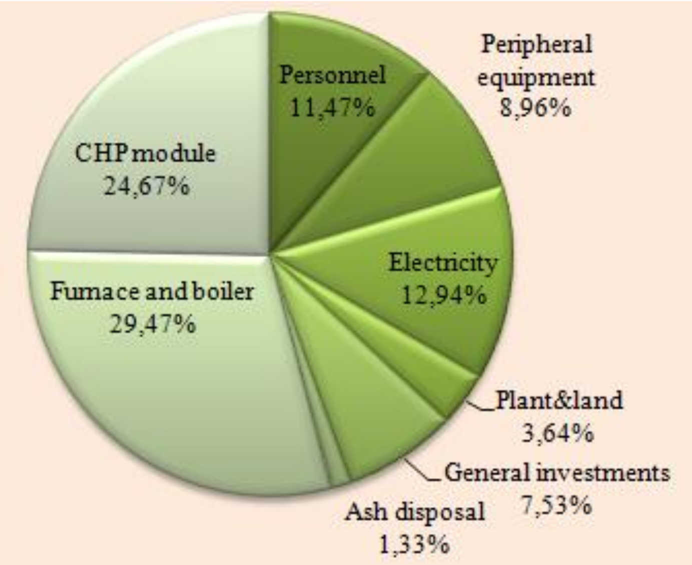

Figure 3.29: Share of annual cost in CHP plant of Case A.

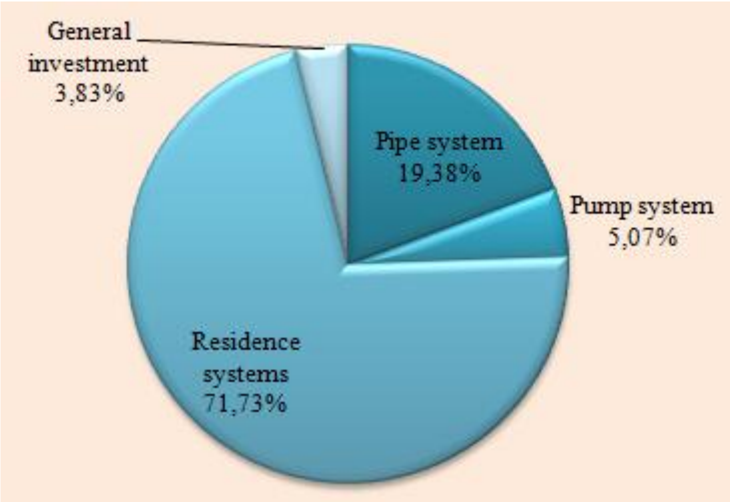

Figure 3.30: Share of annual cost in district heating of Case A.

To sum up, combination of biopellet plant, CHP plant and district heating case are represented in Figure 3.31. Shades of orange show the biopellet plant annual cost which is higher than CHP (shades of green) and district heating (shades of blue). Feedstock is almost half of the resulting cost. Besides the raw material cost, CHP equipments costs are higher than biopellet plant equipment cost because of the high technology requirement of CHP system. District heating only has a minor effect on annual cost with almost 2.5% of the total cost.

CHP equipment such as furnace and boiler and CHP module are important cost components. Management and labour expenses for two plants has 9% of the annual cost. Furthermore, electricity consumption during operations should take into consideration when the economy of the plants is observed. Detailed calculations of annual costs are presented in Appendix A.4 with its values.

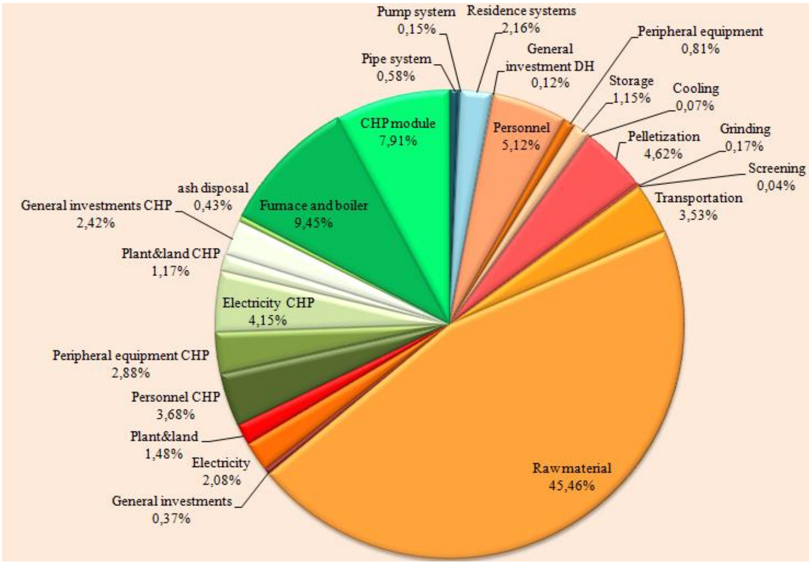

Figure 3.31: Annual cost share for the supply chain of Case A.

Payback period of the system is calculated as well. For the payback period calculation capital cost of the three component of the case: pellet plant, CHP plant and district heating are divided to annual cash inflow. Payback period is calculated as 75 years with equation 3.5 is used [81]. 75 years is a high payback periods. In order to make it reasonable investment pay back should be decreased by feed-in tariff and governmental supports. Annual cash in flow will increase when annual costs are decreased or annual gain is increased. Annual cash flow is calculated as the difference between sum of annual operation and consumption cost and sum of annual earned money from heat and electricity selling.

$$Payback\ period = \frac{Capital\ cost\ of\ the\ case}{Annual\ cash\ inflow} \qquad \textbf{(3.5)}$$

3.4.1.4. Estimation of capital cost of Case B

Capital investment values for Case B is indicated in the Table 3.46 whole the machine and land capital investment for the biopellet plant, CHP and district heating is given. Tax in Case B is lower than Case A even there is an extra drying system is exist in Case B. The reason of this in Case A transportation truck is included and their tax is higher than drying. In the biopellet fuelled Case B there is natural gas drying: biopellet transportation and biopellet storage at the CHP plant are differences between Case A and B. Moreover district heating is different than Case A as a consequence of difference in number of heated residences. General information, scaling factors and utilization periods are supposed be the same with Case A.

Table 3.46: Fixed capital investment data for biopellet and CHP plants of Case B [92, 101, 148-153].

Parameters	Unit	Values	TL_{2010}
Biopellet Plant			
Land Cost	TL_{2010}	536,000	536,000
Building	€$_{2009}$	250,000	316,000
Sawdust storage	$\$_{2007}$	280,000	213,000
Drying	$\$_{2007}$	192,000	115,000
Grinding	$\$_{2007}$	31,200	27,400
Biopelletizing			
Conditioner	$\$_{2007}$	43,900	35,000
Boiler	$\$_{2007}$	45,000	36,000
Biopellet mill	$\$_{2007}$	125,000	86,000
Cooling	$\$_{2007}$	31,800	28,500
Screening	$\$_{2007}$	18,300	16,000
Conveyor, tanks, etc	$\$_{2007}$	200,000	151,000
Biopellet Storage	$\$_{2007}$	280,000	213,000
Freight	$\$_{2007}$	79,000	60,000
Engineering	$\$_{2007}$	20,000	31,700
Project Management	$\$_{2007}$	10,000	15,800
Mechanical installation	$\$_{2007}$	40,000	63,300
Electrical installation	$\$_{2007}$	30,000	47,500
Tax	TL_{2010}	39,200	39,200
CHP Plant	Unit	Values	TL_{2010}
Land Cost	TL_{2010}	440,000	440,000
Building	$\$_{2008}$	280,000	231,000
Transport machinery	€$_{2008}$	200,000	167,700
Furnace and boiler	€$_{2002}$	4,900,00	3,726,000
Flue gas cleaning	€$_{2002}$	510,000	388,000
Ash container and conveyor	€$_{2002}$	120,000	75,300
Heat recovery	€$_{2002}$	Included	Included
Fuel conveyor	€$_{2002}$	800,000	608,300
CHP module	€$_{2002}$	4,100,00	3,117,700
Fuel storage unit	€$_{2002}$	600,000	463,000
Electric installation	€$_{2002}$	670,000	610,275
Hydraulic installation	€$_{2002}$	40,000	36,400
Steelworks	€$_{2002}$	Included	Included
Planning	€$_{2002}$	720,000	655,700
Weighbridge	€$_{2002}$	100,000	76,000
Tax of equipment	TL_{2010}	39,200	4,650
District Heating System	Unit	Values	TL_{2010}
Pipe system	TL_{2005}	194,000	133,000
Pipe assembly	TL_{2005}	110,000	82,000
Pumping station	€$_{2009}$	19,500	41,500
Residential installation	€$_{2009}$	644,000	1,300,000
Planning	TL_{2010}	88,000	88,000

3.4.1.5. Estimation of operating cost of Case B

Operational cost of Case B is listed in the Table 3.47. Operational costs comprise labour, maintenance, energy and fuel consumption for the operations.

Table 3.47: Operational cost of the biopellet plant and CHP plants of Case B[92, 6, 101, 150, 155-159].

Biopellet Plant	Unit	Value	TL_{2010}
Administration labour cost	TL_{2010}	78,000	78,000
Operation labour cost	TL_{2010}	183,500	183,500
Sawdust feedstock	TL_{2010}	2,250,000	2,250,000
Electricity cost	TL_{2010}	106,200	106,200
Diesel cost	TL_{2010}	215,500	215,500
Natural gas cost	TL_{2010}	524,200	524,200
Corn starch cost	TL_{2010}	72,000	72,000
Maintenance Cost			
Sawdust storage	$\$_{2007}$	7,000	5,300
Grinding	$\$_{2007}$	5,616	5,000
Drying	$\$_{2007}$	4,800	2,900
Conditioner	$\$_{2007}$	1,100	875
Boiler	$\$_{2007}$	1,125	900
Biopellet mill	$\$_{2007}$	12,500	8,600
Cooling	$\$_{2007}$	800	712
Screening	$\$_{2007}$	460	400
Conveyor, tanks, etc.	$\$_{2007}$	5,000	3,800
Biopellet storage	$\$_{2007}$	7,000	5,300
CHP plant	**Unit**	**Value**	**TL_{2010}**
Administration labour cost	TL_{2010}	78,000	78,000
Operation labour cost	TL_{2010}	110,000	110,000
Biopellet transportation cost	TL_{2010}	41,400	41,400
Ash disposal	€$_{2002}$	29,313	21,750
Electricity costs	TL_{2010}	212,000	212,000
Maintenance cost			
Furnace and boiler	€$_{2002}$	122,500	93,000
Flue gas cleaning	€$_{2002}$	12,750	9,700
Ash container & conveyor	€$_{2002}$	3,000	1,900
CHP module	€$_{2002}$	102,500	78,000
Transport machinery	$\$_{2007}$	5,000	4,200
Fuel conveyor	€$_{2002}$	2,000	15,200
Fuel storage	€$_{2002}$	15,000	1,1500
District Heating	**Unit**	**Value**	**TL_{2010}**
Maintenance cost			
Pipe system	TL_{2005}	4,800	6,600
Pipe assembly	TL_{2005}	3,000	4,000
Pumping station	€$_{2002}$	500	1,040
Residential installation	€$_{2002}$	16,000	32,400
Electricity Cost	TL_{2010}	3,500	3,500

Operational cost difference between Case A and B comes from natural gas use, transportation of wood biopellet and maintenance of varied equipment. Natural gas prices are used as the average of the values in EMRA website, its value is 4.92 TL_{2010}/kWh during the calculations. Diversity in CHP plant is storage unit and transportation of biopellet: transportation cost is accepted as expense of CHP plant

3.4.1.6. Economic assessment results of Case B

Firstly, specific electricity production cost is calculated by using the same equations like Case A. High fossil fuel use affects the cost of products negatively. According to calculations annual cost for the system is 5,671,129 TL/a, annual revenue from heat sold (1.38 MW heat is sold) 731,808 TL/a. Specific electricity production price is 0.294 TL/kWh. If MARKA funding is added annually to the annual cost of the system, specific electricity becomes 0.292 TL/kWh.

Moreover, share of the annual expenses of biopellet plant, CHP plant and district heating B will be indicated in this section. Some general results can be obtained from the economic values. In Figure 3.32, cost distribution of the biopelletizing unit is presented. Raw material has about 63% of annual cost of the plant. Besides it has less percentage comparing Case A, however it has the same cost. Increasing drying cost is the responsible of cost increment of the total system. Another cost area drying unit uses natural gas as fuel. Natural gas use constitutes almost 15% of the annual cost. During the biopelletizing cost occurs as a result of the diesel use in the biopelletizing mill and corn starch use as an addictive. As clearly seen in the Figure 3.32. Equipment construction has an insignificant effect on annual cost comparing operational and consumption cost. Operational and consumption cost include natural gas, electricity, labour, energy, raw material and so on. Additionally, biopellet production cost is 306 TL/ $t_{biopellet}$ for Case B.

When the CHP module is observed it is similar with the CHP plant in Case A, however there are some differences such as transportation. In second case biopellets are transported to the CHP plant by trucks because of the distance.

In the Figure 3.33 annual cost of CHP plant B defined clearly. Transportation and number of required storage is different than CHP of Case A but the rest of the cost is the same. Annual cost of equipments seems high because there is no feedstock biopellet cost. If the biopellet costs are added to the system results will be different.

As stated before produced biopellets are prepared for the CHP by the same cooperation.

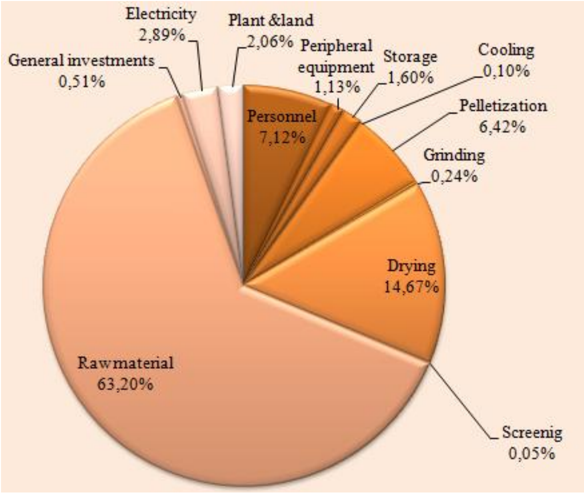

Figure 3.32: Share of annual cost in biopellet plant of Case B.

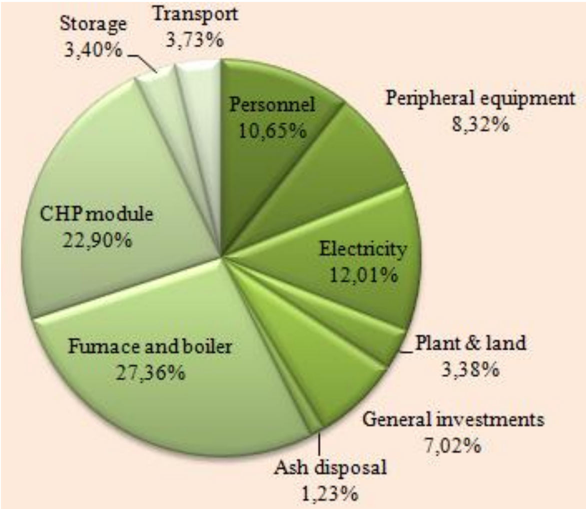

Figure 3.33: Share of annual cost in CHP plant of Case B.

District heating system of Case B has more cost than district heating of Case A, as an influence of heated houses. Residential systems are one of the expensive parts of the district heating and when the residence number increase cost and cost share of the system increases. District heating annual costs share is in the Figure 3.34.

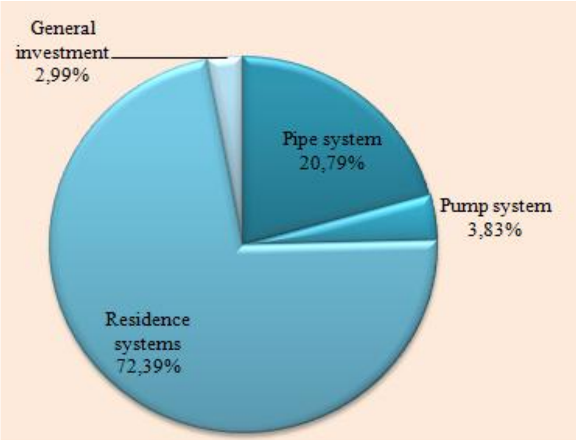

Figure 3.34: Share of annual cost in district heating of Case B**.**

When the biopellet fuelled CHP Case B supply chain is examined, it gives a general idea about the whole system for electricity generation instead of standalone biopellet plant, CHP plant and district heating. Figure 3.35 is the image of the annual cost proportion as percentages for Case B. Shades of the orange represent biopellet plant, shades of green CHP plant and shades of blue district heating. Raw material has the biggest share as expected, drying, CHP boiler and personal expenses are other cost areas. Rising drying cost make CHP and biopellet plant cost at similar level.

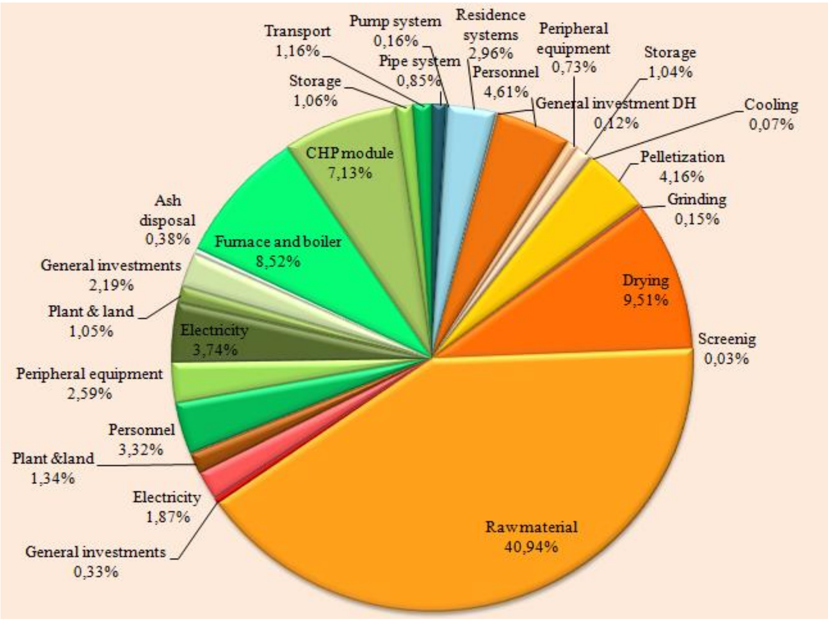

Figure 3.35: Annual cost share for the supply chain of Case B.

In Case B payback period of the system is calculated as 2,729 years with equation 3.5 used. This payback period is too high to be reasonable investment. It is more than case A because of natural gas consumption cost makes annual cost more than Case A even more heat selling gain occurred in Case B. Annual revenue is really small because of the annual comsumption costs are high. For increasing the revenue electricity feed-in tariff should be increase and government should give more support.

3.4.2. Economic assessment for cases using wood chips

In order to observe chip fuelled system, chipping in Turkey can be assessed. Therefore chipping is a new topic for Turkey: there are existing studies about it. Some calculation in Turkish forest, the production cost of the chip production on the road side is 292.78 TL/t in Aladağ Forest Operating Management, with 40 km transportation 60 TL/t in Gölkaya Forest Operating Management and the workshop chipping 95 TL/ ton in Denizli Forest Operating Management [138]. When the energy equality of the chip is taken as 4.65 MWh/t, these costs are respectively 62.96 TL/MWh 12.90 TL/MWh and 20.43 TL/MWh [135]. This cost does not comprise capital equipment investment. Only collecting, chipping and labour cost from collection until chip production. Differences between prices are based on the forest residues, collecting area, equipment and labour working style. For the calculation of this study chip production cost is accepted as 60 TL/t in 2009.

Forest residues are sold by Forest Operating Management in Turkey. In 2008, according to the regulations the price of the forest processing residues is 14.11 TL/ton. In order to produce 1 ton of wood chips, required amount is 1.08 tons of forest residues. As a result of this a producer should pay 15.17 TL for 1 tons of wood chips. The price of collecting, transportation and labour cost are not included that price, this is the price for only forest residues itself [135]. The price of wood chips in forest is assumed as 60 TL/ton.

Values for the CHP plant is the same with the other systems, only the difference is fuel preparation section so that CHP plant values in biopellet based systems are used in this case as well. General information about utilization time of chipping equipments is given in Table 3.48.

Table 3.48: General economic values for the chipping of Case C [134].

General conditions for chipping	Unit	Value
Utilization period of chipper	a	10
Utilization period of terrain transport	a	10
Utilization period of timber truck	a	10
Utilization period of cargo truck	a	10

3.4.2.1. Estimation of capital cost of Case C

In the capital cost calculation the system will be divided into three parts, in the first part the capital cost of chipping will be defined, on the other hand CHP plant will be discussed as second capital cost point and district heating will be the third part.

The chipping is done on the roadside – middle sized more robust machinery with higher power. However, it is necessary to use adequate hauling technology for transporting material to the roadside (skidder, graple-skidder, forwarder with enlarged loading area, bundler plus forwarder etc.) [134]. Capital cost of Case C is indicated in Table 3.49.

Table 3.49: Fixed capital investment data for Case C [90, 94, 134, 148, 151].

Chip Plant	Unit	Values	TL_{2010}
Chipper	€$_{2008}$	224,000	500,000
Terrain transport	€$_{2003}$	175,000	352,000
Forwarder	€$_{2003}$	175,000	352,000
Bulk cargo trucks	€$_{2008}$	200,000	167,700
CHP Plant	Unit	Values	TL_{2010}
Land Cost	TL_{2010}	440,000	440,000
Building	$\$_{2008}$	280,000	231,000
Furnace and boiler	€$_{2002}$	4,900,000	3,726,000
Flue gas cleaning	€$_{2002}$	510,000	388,000
Ash container and conveyor	€$_{2002}$	120,000	75,300
Heat recovery	€$_{2002}$	Included	Included
Fuel conveyor	€$_{2002}$	800,000	608,300
CHP module	€$_{2002}$	4,100,000	3,117,700
Fuel storage unit	€$_{2002}$	600,000	463,000
Electric installation	€$_{2002}$	670,000	610,275
Hydraulic installation	€$_{2002}$	40,000	36,400
Steelworks	€$_{2002}$	Included	Included
Planning	€$_{2002}$	720,000	655,700
Weighbridge	€$_{2002}$	100,000	76,000
Tax of CHP	TL_{2010}	76,000	76,000

3.4.2.2. Estimation of operating cost of Case C

Operating cost of the wood chip production from the forest is calculated according to the Turkish Forest General Management data [134]. During the chipping process, labour and energy costs are included in chips price as stated in chapter 3.4.

Wood residues can be considered as the by-product of the fire or industrial wood production. The cost of wood chip system can be started from carrying the wood residues to the road side in order to chipping. The selected chipping method, chipping area, structure of the land, the situation of roads and production methods affect the cost [135]. The cost of the wood chip supplying from the forest is given in the Table 3.50.

Table 3.50: Cost comparison of woodchip production in different countries [135].

Country	Transport distance km	Chipping road side ($\$_{2002}$/MWh)
Japan	20-80	102.5
United Kingdom	20-80	12
Sweden	60	14.8
Finland	60	9.7

Operational costs based on maintenance, labour and fuel needs. The feedstock expenses are also showed in that section. The operational costs of the chipping and CHP plant are listed in the Table 3.51.

Table 3. 51: Operational Cost of the Biopellet Plant and CHP plant [6, 89, 92, 101, 150, 155-158].

Chip Plant	Unit	Value	TL_{2010}
Wood chip cost (collection, chip production, labour, internal transport etc.)	TL_{2008}/t	60	67
Annual woodchip cost	TL_{2008}/t	1,156,250	1,305,000
CHP plant	Unit	Value	TL_{2010}
Administration labour cost	TL_{2010}	78,000	78,000
Operation labour cost	TL_{2010}	110,000	110,000
Biopellet transportation cost	TL_{2010}	60,000	60,000
Ash disposal	€$_{2002}$	29,313	21,750
Electricity costs	TL_{2010}	212,000	212,000
Maintenance cost			
Furnace and boiler	€$_{2002}$	122,500	93,000
Flue gas cleaning	€$_{2002}$	12,750	9,700
Ash container & conveyor	€$_{2002}$	3,000	1,900
CHP module	€$_{2002}$	102,500	78,000
Transport machinery	$\$_{2007}$	5,000	11,000
Fuel conveyor	€$_{2002}$	20,000	15,200

Annual operating cost includes property tax/insurance, maintenance and spare parts, electricity, and other miscellaneous costs. A woody biomass boiler requires more labour and maintenance than wood biopellets boiler. In general, the average annual operating and maintenance cost of a wood residue boiler is larger than that of a wood biopellet boiler. Although chips based systems requires more labour and maintenance, in this study all the CHP plant cost are considered similar [151].

3.4.2.3. Economic assessment results of Case C

Turkey support the renewable-based electricity investments by regulations, for instance government give purchase guarantee for renewable-based electricity until 2015 electricity with reasonable prices as stated before. Although there is renewable-based energy support, it is not enough for biopellet based system. In this part, specific electricity cost calculated with equation 3.3, is better than biopellet based systems. Regarding to calculations annual cost for the system is 3,514,974 TL/a, annual revenue from heat sold 731,808 TL/a as the same Case B. Specific electricity production price is 0.166 TL/kWh$_e$ without funding. When the annual funding is added into system specific electricity cost becomes 0.164 TL/kWh$_e$.

Case C can be examined in three parts as chipping, the CHP plant and district heating. In the chipping part forest residues are collected and chipped. During chipping energy, labour and material costs are taken in chips cost. Annual chips costs are showed in Figure 3.36. Cost of the equipments also considered in the calculations separately. Chip cost, which includes all the operations from collecting to chip product, is the major expense component as normal. Transportation of the chips from forest to the CHP plant is also observed in the chipping part. Equipment cost and transportation cost are quite small with regard to chips cost.

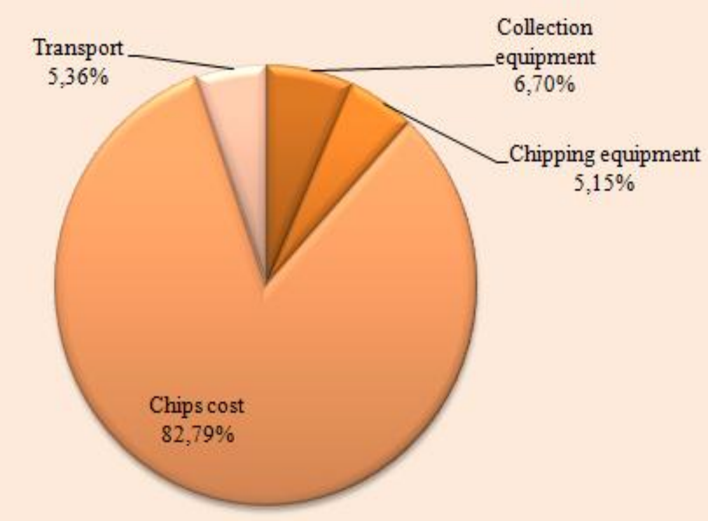

Figure 3.36: Share of annual cost in chips production of Case C.

The CHP plant in Case C is also similar with the CHP plants in Case A and B as understood from Figure 3.37. CHP module, furnace and boiler and electricity are the main cost components, however it should be taken into consideration chip buying price is not included in this graphic.

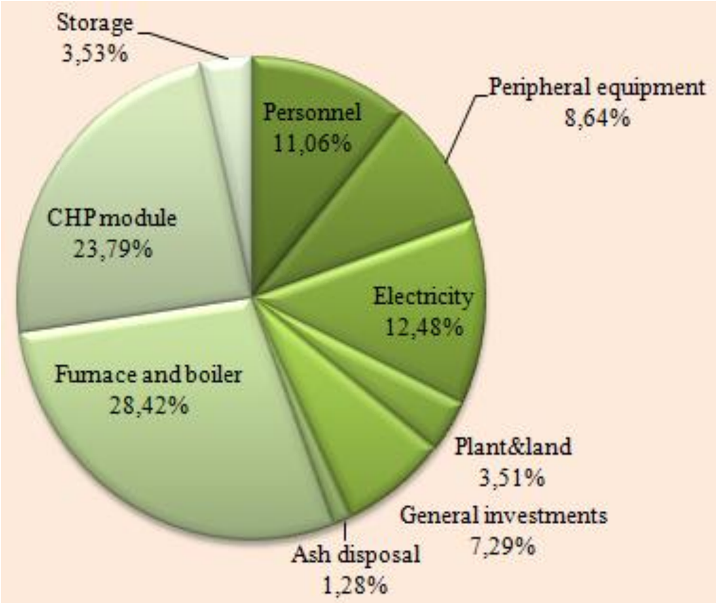

Figure 3.37: Share of annual cost in CHP plant of Case C.

Final responsible of the annual cost is district heating which is seen in Figure 3.38. It is totally the same with the district heating of the B. Because of the number of heated residues and used heat are the same.

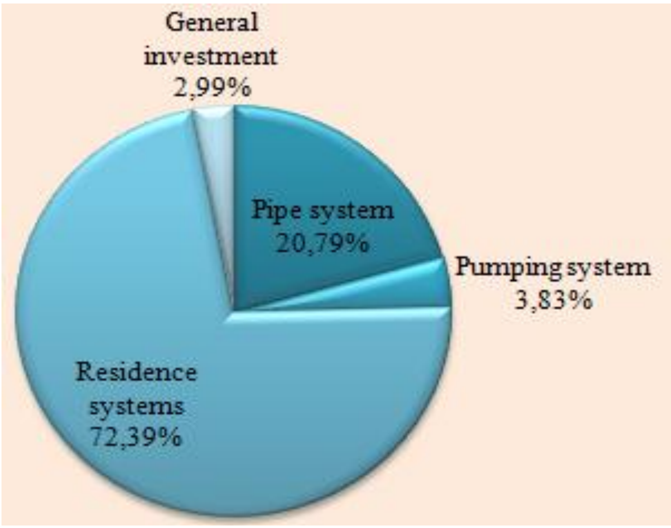

Figure 3.38: Share of annual cost in district heating of Case C.

When the whole chain of Case C is observed, it shows difference than the biopellet fuelled systems. The cost of the forest residues is relatively lower than wood processing industry residues, because there is no investment on forest residues.

It is obvious in Figure 3.39 CHP has almost half of the cost. The other cost belongs to mostly chips cost however it is cheap to produce chip from the forest and government support this kind of investments. 40% of the annual cost is resulted by chip cost for Case C. Other cost comes from CHP plant expensive equipments. Chipping process is not complicated as a result CHP plant cost are more than chipping part.

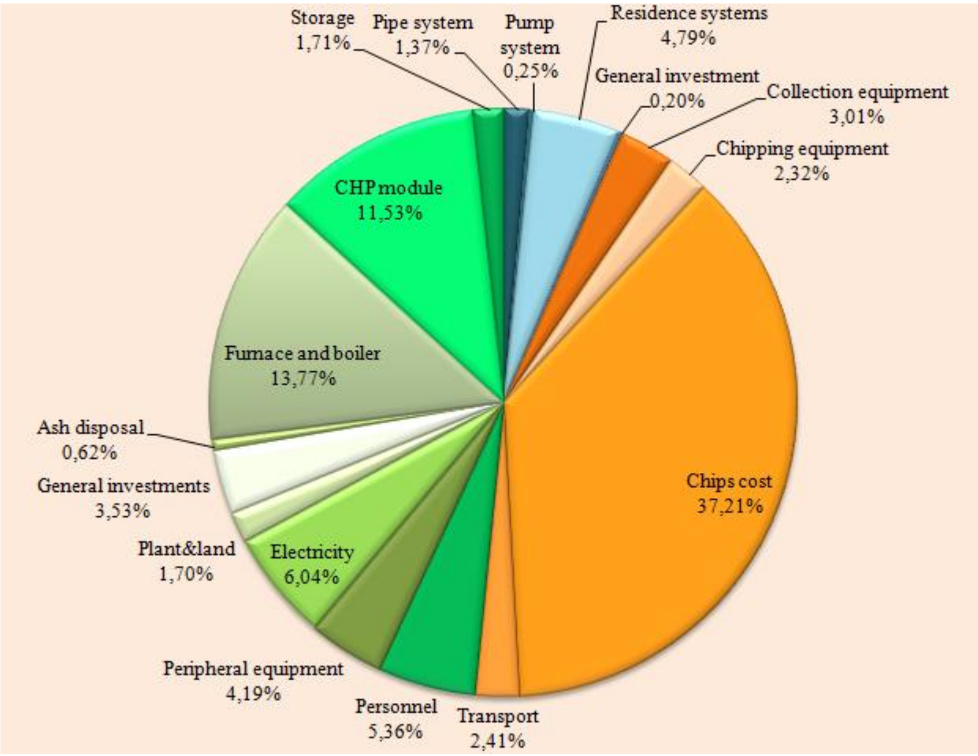

Figure 3.39: Annual cost share for the supply chain of Case C.

The payback period of Case C is 7 years which is the lowest between three cases. Annual cost of Case C is relatively lower than other two cases.

3.4.3. Discussion of economic analysis of the cases

The costs based on capital consist of the annual capital investment: land, plant, equipments and installations. All costs in connection with the manufacturing process, e.g. the costs of raw material, the heat for drying and the electricity demand are included in the group of consumption costs. The operating costs comprise costs originating from the operation of the plant, e.g. personnel costs and maintenance cost [93]. In Figure 3.40, annual capital, operational and consumption costs of three cases are illustrated.

A significant economic criteria specific electricity production price is compared for tree systems. Table 3.52 helps to compare the three systems. Electricity prices for 1 kWh are 0.276 TL/kWh$_e$, 0.294 TL/kWh$_e$ and 0.166 TL/kWh$_e$ for Case A, B and C without MARKA funding respectively. Besides, specific electricity prices become

0.275 TL/kWh$_e$, 0.292 TL/kWh$_e$, and 0.164 TL/kWh$_e$ with funding for Case A, B and C respectively. Specific electricity costs of systems are given in Table 3.52.

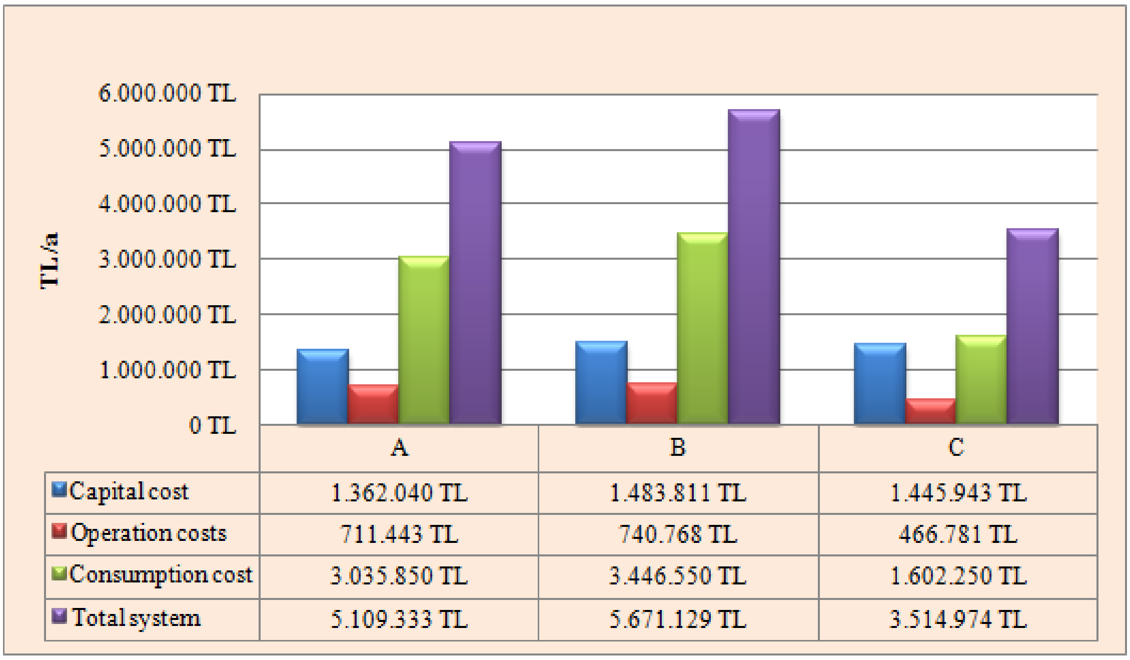

Figure 3.40: Annual capital, operational and consumption costs of three cases.

Table 3.52: Comparison of the specific electricity cost of three cases.

Economic criteria	Without funding	With funding
Case A specific electricity cost (TL$_{2010}$/kWh$_e$)	0.276	0.275
Case B specific electricity cost (TL$_{2010}$/kWh$_e$)	0.294	0.292
Case C specific electricity cost (TL$_{2010}$/kWh$_e$)	0.166	0.164

If the heat selling is increased electricity price will become lower. When heat is sold an industrial plant, it is possible to provide a stable heat demand. Residential heating requirement depends on seasons. Therefore, heat requirement of a household fluctuates during a year however it is not valid for industrial plants. If all the available amount of produced heat is assumed to be sold to the industry as a result of this profit increases. For Case A saleable heat is 18.16 GWh after drying, plant heating and system loss. On the other hand, saleable heat for systems B and C is 3.57 MW. The price for the heat sell is set as 0.065 TL/ kWh according to the average value of industrial natural gas heating in Turkey [159]. The specific electricity changes are given in the Table 3.53. Even if all the heat is sold, specific electricity cost of Case A and B with or without funding are higher than government bioelectricity applied price of 0.206 TL/kWh$_e$. This is an indicator to income governmental supports should be increased. For Case A and B the current applied prise is higher than feed-in tariff in order to make revenue reasonable level increment in government support is necessary. On the other hand, for the other systems current feed-in tariff is higher than specific electricity price of Case C. When profit margins are calculated, whether governmental supports are enough or not will be evaluated.

Table 3.53: Comparison of the specific electricity cost of observed systems when all heat is sold.

Economic criteria	Without funding	With funding
Case A specific electricity cost (TL_{2010}/kWh_e)	0.234	0.232
Case B specific electricity cost (TL_{2010}/kWh_e)	0.227	0.226
Case C specific electricity cost (TL_{2010}/kWh_e)	0.099	0.097

The wood fuel based electricity generation in CHP has been analysed using the LCA to evaluate emissions and economics with different scenarios. From the economic data biopellet production cost is high if natural gas is used for drying. The best choice based on economic criteria is wood chips system. Wood biopellets are more expensive than wood residues since they require extra processes and transportation. As a result, price increases in wood biopellets may affect the economic feasibility of the system more than that of the wood residue. More detailed data about the economic calculations are mentioned in the Appendix A.4.

Average electricity generation cost of Turkey is 0.125 TL/kWh_e and the calculated specific electricity cost of the systems, bioelectricity feed-in tariff and average electricity production costs can be compared as seen in the Figure 3.41. Capital F means MARKA funding [160, 105]. According to the results chips system is more economical but it should be observed by profit approach before deciding to make investment on chip Case C. It is clear that investors should sell all the possible heat and the feed in tariff should be increased by government to make biomass investments attractive. Payback period coparision of the three cases shows Case C has the best results clearly. Payback periods for Case A, Case B and Case C are 74, 2729 and 7 respectively. For Case A and Case B payback periods are so much for a plant but the important gain of these cases are environmental benefits which can not be measured by money.

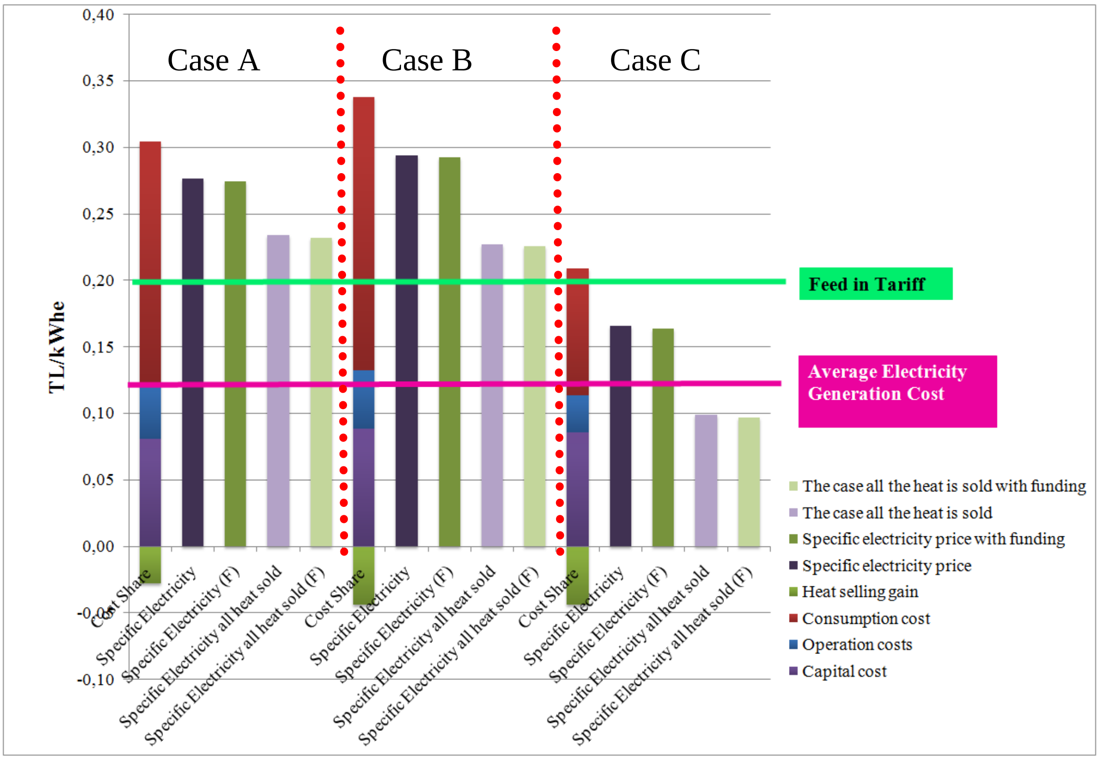

Figure 3.41: Specific electricity, feed in tariff and average electricity generation cost comparison [64, 160].

4. CONCLUSION and RECOMMENDATION

In this chapter, the current study will be summarized and derived results will be clarified. Moreover, some recommendations, outlook and further aspects are mentioned. Conclusion and recommendation part comprises 3 sections:

- Summary of Results
- Recommendation
- Outlook and Further Aspects

4.1. Summary of Results

The aim of the study is to analyse environmental and economic feasibility of woody biomass systems and to find the weak points to improve, savings and occasions.

First of all, this thesis presents determination of GWP of electricity generation from biopellet and chips feedstock in CHP system for power generation and heat distribution by district heating. By means of LCA analysis the environmental effects of the systems are assessed. GWP reductions (substitution of current electricity mix with bioelectricity) are presented. Thereby, global warming potential of each process is compared with each other and Turkish electricity mix.

Additionally, economic evaluation of the supply chains from feedstock to electricity to grid and heat to district heating is done for three cases. During economic evaluation economic assessment is applied as much as possible for every step of the study. Specific electricity cost is calculated for figure outing the economic feasibility of the study. Specific electricity costs of systems are compared with feed in tariff of government and average Turkish electricity generation cost.

To start with the brief information about the result of this thesisis that, wood chips fuelled Case C is more environmentally friendly than other systems. Also biopellet fuelled systems have considerable reduction in GWP. Turkish electricity mix emission level has 523.94 gCO_{2eq}/kWh_e. Systems A, B and C in this thesis have -15.00 gCO_{2eq}/kWh_e, 74.43 gCO_{2eq}/kWh_e and -78.63 gCO_{2eq}/kWh_e respectively.

Economic evaluation results are not as expected as environmental results. Biomass technologies should supported by local and international policies to make them attractive for investors. Indeed, the CO_2, CH_4 and NO_x emissions due to using imported fossil fuels will be decreased. Assurance of energy security will be provided for Turkey by substitution of bioenergy instead of import fuel [161].

Mass and energy calculations have important result in order to observe and understand the cases properly. To generate 1 kWh of electricity 1.29 kg and 1.32 kg of sawmill residues are required in Case A and Case B respectively. In Case C 1.76 kg of woody forest residues are used to produce 1 kWh of electricity. Energy contents of the feedstocks are 3.59 kWh, 3.63 kWh and 3.98 kWh for Case A, B and C respectively. Highest energy efficiency is belong two Case A with 78% total efficiency. Total efficieny of the other pellet Case B is 68% which is the lowest total efficiency. Wood chips case has 71% of total energy efficiency.

The results of economic analysis of the systems can be given in terms of specific electricity generation cost. Specific electricity costs without MARKA funding are 0.276 TL/kWh, 0.294 TL/kWh and 0.166 TL/kWh for systems A, B and C respectively. If the MARKA funding is used the prices get slightly lower, 0.275 TL/kWh, 0.292 TL/kWh and 0.164 TL/kWh. Moreover, another alternative to governmental support to increase the profitability of these plants is more efficient heat usage. When all the available heat (after plant use and heat loss) is sold, profitability of the systems will increase considerably. In Case A 2.27 MW heat can be sold and the specific electricity cost decreases to 0.234 TL/kWh without funding and 0.232 TL/kWh with funding. In Case B and C 3.57 MW heat is available for selling. Specific electricity costs changes for Case B as 0.227 TL/kWh without funding and 0.226 with funding TL/kWh. In Case C, the specific electricity costs become 0.099 TL/kWh (without funding) and 0.097 TL/kWh (with funding). Government suggests 0.206 TL/kWh price for bioelectricity for CHP system. Even though all available heat is sold specific electricity cost is over the governmental suggested price for biopellet system. Selling all the heat is not enough to make Case A and B profitable without additional supports. Payback period of the three cases are calculated as well. Payback periods are 75 years, 2,729 years and 7 years for Cases A, B and C respectively. For the Case A and Case B payback periods of whole systems and operations are too high to be investable. High payback periods should be decreased by improvements and governmental supports.

First of all systems have significant reduction in greenhouse emissions, especially chip systems has negative emission. According to environmental results application of wood based systems are reasonable. The second important result of this thesis is economic, wood based systems are costly systems compared to conventional systems. Only the chip based system seems economical but to decide the investment profitability analysis should be done. Government should promote biomass based systems and investors should find a way of selling whole available heat. Indeed, Turkey has an important biomass potential and if this potential is used with energy efficient systems and investors are supported by government, biomass will be an interesting alternative energy resource. It is obvious that the increasing demand for fuel flexibility and the increasing need for reduction of the emissions will result in an expanding use of biomass in the power and heat sector in future [162].

4.2. Recommendations

When the environmental and economic results of solid biomass and current fossil systems are compared, it is clear that fossil energy usage should be reduced or efficient use of energy system should be improved. When biopellet fuelled system results are evaluated, it is seen clearly that system using natural gas (Case B) has higher environmental impacts and higher expenses. In the biopellet plant drying is the most important cost component. Therefore, the best way is to integrate systems such as, district heating network, pulp mill, sawmill or CHP. The best system based on economy and environmental effects are chip based systems (Case C). Therefore, the operations before CHP are less complex than biopelletizing operations.

Moreover, for the economic view chipping seems more suitable than the other systems. The forest residue prices are low and there is no common usage of residues as the fact that feedstock demand is at reasonable levels. Turkish forest can be regulated for residue usage to generate energy. Also the industrial wood residues can be evaluated in biopelletizing but the final biopellet use can be changed for economic and industrial reasons. In Europe and USA biopellets are used for heating purpose in order to reduce environmental effects of fossil fuels. It can also be applied in Turkey instead of using in electricity generation. Consumption of biopellets for residential heating will reduce the GHG emissions.

In order to make system more environmentally friendly, renewable-based electricity, biodiesel and biogas can be used instead of current Turkish electricity diesel and natural gas based respectively.

Even if a reduction in GHG emissions and fossil energy consumption from bioenergy compared to their fossil reference system can be achieved, it should always be kept in mind that the cost of the bioenergy system is higher in current situation except wood chip systems (Case C).

Economic dimension should be improved by governmental supports and local investors. Almost all the technologies are imported from other countries that make biomass application costly. This problem can be solved by local investments and research and development studies. Government has some supports and funding for biomass related investment but it does not seem sufficient. The specific electricity cost of Case A and B is higher than government guaranteed price. Feed-in tariff is close to Case C specific electricity cost. In current conditions, systems A and B seems not attractive for the investor. In Cases of A and B government should encourage the investors with supports and funding. Also the funding and support are valid for Case C, but forest management can reduce the price in chipping as well.

Another way of reducing the price is expanding the size of the plants. Because of the most economical way to meet these demands are to increase the utilisation of biomass in larger CHP plants. It is possible to increase the transportation emission and cost by increasing plant size. An observation about the transportation of a large plant can be evaluated in another study.

With the district heating system, heat is provided to all residences only with CHP plant. If more buildings are to be heated, gas heating system can be added to the system for peak heat required. It is common to use a supporting system for peak heat demand in general but in this system peak energy is provided from CHP. For the peak heat demand in January heating requirement is used. If a cooling system is adapted to the system the waste heat can be used for cooling purpose as well. Another alternative to evaluate the waste heat is using in an industrial plant. There will be no heat demand fluctuation, and heat requirement will be stable.

The benefits could be multiple in terms of avoided environmental damage from substituted fossil fuel resources, rural development, improved energy security, and in general terms a move to a more sustainable electricity production. Clearly, biomass will only be an increasingly component of renewable resources. Provided that good practice is followed and that continued improvements in biomass production, logistics and conversion are obtained, the development of bioelectricity could be achieved with no significant environmental drawbacks and with an increasing economic viability.

In conclusion, energy production with local resources in an environmentally friendly way is significant for Turkey as a developing country. As mentioned before Turkish energy system depends on import fossil resources. Turkey should have clean, economic and local energy alternatives. In order to have energy diversity biomass is a new option for Turkey. Direct combustion of wood is very common in rural: however efficient use of wood in biomass conversion routes is not applied currently. Only pilot applications are used, but they should be more widespread. Turkey should develop projects on biomass and other kinds of renewable energy resources. Bioenergy can contribute significantly to a number of national and international policy priorities. In order to increase biomass investments, government should increase its support; otherwise it is not an attractive investment for interpreters. If it is belong to government it is another situation. Environmental benefits can become more important than economic benefits.

4.3. Outlook and Further Aspects

The next step of this study can be to analyse Turkish technologies instead of European technology in machine construction. Some raw material production and disposal for instance concrete, steel etc. as well as a machine construction, fuel such as diesel and natural gas production and consumption values should be found for conditions of Turkey.

Moreover, an integrated sawmill, biopellet plant and CHP system (three plants are integrated like Skelleftea CHP plant) can be observed according to economic aspects. Feedstock cost can be eliminated if the sawmill production capacity is big enough or it can provide an important proportion of feedstock.

Effect of moisture content in drying can be assessed. Thereby, dependency of emission values and economic value on natural gas can be observed.

In the economic evaluation of sawmill residues in alternative areas such as plywood production instead of biopelletizing can be another research. Other usage of the sawdust can be more economic and environmental. Favourable products of sawmill residues can take place of some products which can have cost and dangerous environmental effects.

It should be noticed that the results are limited to the global warming potential. Other environmental effects can be evaluated particularly.

REFERENCES

[1] **İşler, A. and Karaosmanoğlu, F.** (2010). Chapter 17: *Biofuels in Turkey,* Rethinking Structural Reform in Turkish Agriculture: Beyond the World Bank's Strategy -2010, ed. B. Karapınar, F. Adaman and G. Ozertan, Nova Science Publisher, In Press.

[2] **Meydan, Z.** (2009). Bioelectricity, Bachelor Thesis, Istanbul Technical University, Chemical Engineering Department.

[3] **Vinterback, J.** (2004). Pellets 2002: the first world conference on pellets, *Biomass and Bioenergy, **27,*** 513–520.

[4] **Orman Genel Müdürlüğü Biyoenerji Çalışma Grubu**, (2009). Orman Biyokütlesinden Enerji Üretimi. May 2009, Ankara.

[5] **World Energy Council, Turkish National Committee,** (2009). *Türkiye enerji raporu*, pp.29-30, December, 2009, Ankara

[6] **Energy Market Regulation Authority (EMRA) ,** official web site, http://www.epdk.gov.tr/. Date retrieved: 07.06.2011.

[7] **Tukker, A.** (2000). Life cycle assessment as a tool in environmental impact assessment, *Environmental Impact Assessment Review, **20***, 435–456.

[8] **Kneifel, J.** (2010). Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings, *Energy and Buildings, **42***,333–340.

[9] **European Biomass Industry Association EUBIA,** official web site , http://www.eubia.org/. Date retrieved: 03.02.2011.

[10] **Brochure Bioenergy,** European Biomass Industry Association, http://www.erec.org/fileadmin/erec_docs/Documents/Publications/Brochure_Bioenergy.pdf, 05.03.2009.

[11] **Saxena, R.C., Adhikari, D.K. and, Goyal, H.B.** (2009). Biomass-based energy fuel through biochemical routes: A review, *Renewable &Sustainable Energy Rewievs**, 13,*** 167-178**.**

[12] **Rosillo-Cale, F., Groot, P., Hemstock, S. L., Woods, J.** (2008). The Biomass Assessment Handbook Bioenergy for a Sustainable Environment. Earthscan Press, London.

[13] **Ozgur, M. A.** (2008), Review of Turkey's renewable energy potential, *Renewable Energy*, ***33,*** 2345-2356.

[14] **Sims R. E. H,** (2004). Bioenergy Options for a Cleaner Environment In Developed and Developing Countries. Elselvier.

[15] **Yuan, J. S, Tiller, K.H., Al-Ahmad, H. Stewart, N.R. and C. Neal Stewart Jr.** (2008). Plants to power: bioenergy to fuel the future, *Trends in Plant Science*, ***13***, 421-429.

[16] **Kaparaju, P**., et al. (2009). Bioethanol, biohydrogen and biogas production from wheat straw in a biorefinery concept. Bioresource Technology ***100***: 2562–2568.

[17] **Lasure, L., Zhang, Min,** "Bioconversion and Biorefineries of the Future", Pacidic National Laboratory, National Renewable Energy Laboratory. http://www.pnl.gov/biobased/docs/biorefineries.pdf. Date retrieved: 20.04.2010.

[18] **Burel, C.** Industrial or White Biotechnology Research for Europe, EuropaBio.www.bio-economy.net/reports/files/sra.pdf. Date retrieved: 1.06.2011.

[19] **European Biomass Association (AEBIOM),** (2008). A Pellet Road Map for Europe, www.aebiom.org. Date retrieved: 12.06.2010.

[20] **European Biomass Association (AEBIOM),** (2007). Pellets for small-scale domestic heating systems. www.aebiom.org. Date retrieved: 21.12.2010.

[21] **Maker, T. M.** (2004). Wood-Chip Heating Systems A Guide For Institutional and Commercial Biomass Installations, Biomass Energy Resource Center Montpelier, Vermont.

[22] **Parviainen, J.** (2010). Small/ micro Scale Gasification Systems Combined Heat and Power (CHP) from Wood Chips, WENET Sustainable Energy Solutions.

[23] **Marini, F. and Palmieri, S.** (2008). The Ecological Plant in Castel D'aiano the CHP system of Castel d'Aiano school campus: wood chips gasification and Stirling engine.

[24] **Bridgwater, A. V., Toft, A.J., and Brammer, J.G.,** (2002). A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion, *Renewable and Sustainable Energy Reviews*, ***6(3),*** 181-246

[25] **Biomass Combustion and co-firing: an reverview IEA**, IEA Bioenergy Task 32, IEA official web site http://www.ieabcc.nl/, Date retrieved: 02.02.2009.

[26] **Çetinkaya, M.** (2004). Used Cookıng Oil Originated Biodiesel as a Generator Fuel, MSc Thesis, Istanbul Technical University, Chemical Engineering Department.

[27] **Çeliktaş, S. Sevgili, T and Koçar, G.** (2008). A snapshot of renewable energy research in Turkey, *Renewable Energy,* **xxx**, 1-8.

[28] **Solino, M., Prada, A., Vazquez, M.X** (2008). Green electricity externalities: Forest biomass in an Atlantic European Region, *Biomass and Bioenergy*, xx.

[29] **REN21 (Renewable Energy Policy Network for the 21st Century**), (2011). Renewables 2011 Global Status Report.

[30] **Edited Liebard, A.** (2009). The State of Renewable Energies in Europe 9th EurObserv'ER Report édition 2009, http://www.eurobserv-er.org/downloads.asp. Date retrieved: 16.02.2010.

[31] **Heinimo, J., Junginger, M.** (2009). Production and trading of biomass for energy – An overview of the global status, *Biomass and Bioenergy*, ***33***, 1310-1320.

[32] **EurObserv'ER**, (2009). Solid Biomass Barometer, *Systèmes Solaıres Le Journal Des Énergies Renouvelable***s, 194.**

[33] **Europe's Energy** directives, EC Official web site, http://www.energy.eu/. Date retrieved: 02.02.2009.

[34] **Khan, A.A., Jong, W., Jansens, P. J., Spliethoff, H.,** (2009). Biomass combustion in fluidized bed boilers: problems and remedies, *Fuel Processing Technology*, ***90***, 21-50.

[35] Edited **Wach, E.** (2009). **Final report on producers, traders and consumers of mixed biomass pellets,** Development and promotion of a transparent European Pellets Market Creation of a European real-time Pellets Atlas, Gdansk,Poland.

[36] **Wolf, A., Vidlund, A., Andersson, E.** (2006). Energy-efficient pellet production in the forest industry—a study of obstacles and success factors, *Biomass and Bioenergy*, ***30 (2006)***, 38–45.

[37] Edited **Hiegl, W. and Janssen, R.** (2009). Pellet market overview report EUROPE, Development and promotion of a transparent European Pellets Market Creation of a European real-time Pellets Atlas, Munich, Germany.

[38] **OPET Sweden**, (2001). Refined biomass– a source for climate change and business opportunities.

[39] **Wahlund, B., Yan, J., Westermark, M.** (2004). Increasing biomass utilisation in energy systems: A comparative study of CO2 reduction and cost for different bioenergy processing options, *Biomass and Bioenergy*, ***26 (2004)***, 531 – 544.

[40] **Skelleftea Kraft**, (2009). Bioenergy A sustainable energy source**.** www.skekraft.se. Date retrieved: 11.03.2011.

[41] **Jonsson, C. Y. C.** (2009). Wooden Fuel Pellets Raw material composition, mechanical strength, moisture content, particle size distribution and processing, MSc. Thesis, Wood Technology Department of Skelleftea Campus, Division of Wood Science and Technology, Lulea University of Technology

[42] **Blanchard, M., P., et al**. (2007). IEA Bioenergy Task 40 Global Wood Pellets Markets and Industry: Policy Drivers, Market Status and Raw Material Potential. http://www.canbio.ca/documents/publications/ieatask40pelletandraw materialstudynov2007final.pdf

[43] **Kristensen, T.** (2009). Fuel flexibility in the new coal, biomass and oil fired CHP plant Amager Unit 1 Copenhagen.

[44] **Dong Energy,** (2010). Welcome to Avedore Power Station. http://www.dongenergy.com/en/Pages/index.aspx. Date retrieved:11.11.2009.

[45] **Ryckmans, Y.** (2006). Fuel flexibility in coal power plants with co-firing. Electrabel. http://www.electrabel.be/. Date retrieved:23.05.2010.

[46] **Enecon Pty Ltd.,** (2007). Bioenergy in the Avon SEDO Project No. P588 Study Report for AVONGRO. http://www.avongro.com.au/documents/AvongroStudyReport-final.pdf. Date retrieved:22.04.2011.

[47] **Hassine, I. B. and Eicker, U.**, (2011). Simulation and optimization of the district heating network in Scharnhauser Park, 2nd European Conference on Polygeneration – 30th March-1st April, 2011–Tarragona, Spain.

[48] **Strzalka, R.**, **Ulbrich, R. And Eicker, U**. (2010). Optimisation of Combustion Process in Biomass-fuelled Cogeneration Plant, *CHEMICAL ENGINEERING TRANSACTIONS*, ***Volume 21***, 469-475.

[49] **Nederhoff, E. And Hputer, B.** (2008). CHP, co-generation, renewable energy and CO2. *Grower*, ***63(6)***, 2008, p. 30-31.

[50] **Gokcol, C., Dursun, B., Alboyacı, B and Sunan, E**., (2009). Importance of biomass energy as alternative to other sources in Turkey, *Energy Policy*, ***37 (2009)***, 424–431.

[51] **Akpınar, A., et al** (2008). Energy situation and renewables in Turkey and environmental effects of energy use, *Renewable and Sustainable Energy Reviews*, ***12 (2008)***, 2013–2039.

[52] **Erdoğdu, E.** (2008). An expose´ of bioenergy and its potential and utilization in Turkey, *Energy Policy*, ***36***, 2182– 2190.

[53] **Türkyılmaz, O.** (2011). Türkiyenin Enerji Görünümü, UCTEA Chamber of Mechanical Engineers, http://www.mmo.org.tr/resimler/dosya_ekler/c37b2409594d49d_ek.pdf?tipi=66&turu=X&sube=0. Date retrieved:30.06.2011.

[54] **Ozturk, M., Bezir N. Ç., and Ozek, N.** (2008). Hydropower–water and renewable energy in Turkey: Sources and policy, *Renewable and Sustainable Energy Reviews*, **xxx.**

[55] **Balat, M.** (2005). Use of biomass sources for energy in Turkey and a view to biomass potential, *Biomass and Bioenergy*, ***29***, 32–41.

[56] **Demirbaş, A**. (2008). Importance of biomass energy sources for Turkey, *Energy Policy*, ***36***, 834–842.

[57] **Kaygusuz., K.** (2003). Energy policy and climate change in Turkey, *Energ Conversion and Management*, ***44(10),*** 1671–1688.

[58] **Belen, İ,** (2010). National Initiative and Strategy Development for Strengthening Utilization of Wood Energy in Turkey, *Workshop on "Policy options for wood energy"*, 1 - 4 June 2010 Minsk, Belarus.

[59] **World Energy Council Turkish National Committee,** (2008). 2007-2008 Türkiye Enerji Raporu, Ankara, Turkey.

[60] **GE-Jenbacher GmbH & Co.** OHG. Adana Atık su Arıtma Tesisi Kojenerasyon Santralı / Adana,

http://www.topkapigroup.com.tr/eng/pdf/adana.pdf. Date retrieved: 27.12.2010.

[61] **Dokuz Eylül Üniversitesi,** Ankara Merkezi Atıksu Arıtma Tesisi ASKİ – Belka A.Ş. *web.deu.edu.tr/cevre/pala/**aski**.ppt*. Date retrieved: 11.2.2010.

[62] **Pehlivan, E.** Biyogaz ve Biyogaz Uygulamaları, http://www.emo.org.tr/ekler/0d936dc2a4718f8_ek.pdf. Date retrieved: 11.2.2010.

[63] **Cargill Gıda,** Türkiyede Enerji Verimliliğine "Evet" Dedi, (2008). Cargill Haberler, Ocak 2008, 22–23.

[64] **Law no. 5346**: Electricity Market Licensing Regulation, and the second is the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy.

[65] **Taşkıran, I.,** (2010). Energy Production from Forest Biomass, *24thIUFRO Conference for Specialists in Air Pollution and Climate Change Effects on Forest Ecosystems,* 25th March 2010, Antalya.

[66] **Toklu, E.,et al**, (2010). Energy production, consumption, policies and recent developments in Turkey, *Renewable and Sustainable Energy Reviews,* ***14***, 1172–1186.

[67] **BioCandeo,** (2010). Model project plan: TERM – Sustainable Biomass Import Project summary "Integrating Forest Fire Protection and Sustainable Wood Pellet Production in Turkey". http://web.ogm.gov.tr/birimler/merkez/egitim/Dokumanlar/disiliskiler subesi/p let%20%C3%BCretimi/Presentation%20kick-off%20event%20v29%20april%20full.pdf.

[68] **Garcia, G. G., et al**., (2009). Life cycle assessment of flax shives derived second generation ethanol fueled automobiles in Spain, *Renewable and Sustainable Energy Reviews,* **13**, 1922–1933.

[69] **Finnveden, G., et al.** (2009). Recent developments in Life Cycle Assessment, *Journal of Environmental Management*, ***91***, 1–21.

[70] **Roy, P., et al.** (2009). A review of life cycle assessment (LCA) on some food products, *Journal of Food Engineering*, ***90***, 1–10.

[71] **Buratti, C. and Francesco, F.** (2010). Life cycle assessment of biomass production: Development of a methodology to improve the environmental indicators and testing with fiber sorghum energy crop, *Biomass and Bioenergy*, ***34***, 1513-1522.

[72] **Koroneos, C., Dompros, A. and Roumbas, G. (**2008). Hydrogen production via biomass gasification—A life cycle assessment approach, *Chemical Engineering and Processing*, **47**, 1261–1268.

[73] **Gnansounou, E., et al**. (2009). Life cycle assessment of biofuels: Energy and greenhouse gas balances, *Bioresource Technology*, ***100***, 4919–4930.

[74] **Sebastian, F., Royo, J. and Gomez, M**. (2010). Cofiring versus biomass-fired power plants: GHG (Greenhouse Gases) emissions savings

comparison by means of LCA (Life Cycle Assessment) methodology, *Energy**, xxx (2010),*** 1-9.

[75] **MacLean, H., McKecknie, J., Zhang, Y.** (2009). Life cycle Assessment of Wood Pellet Use in Ontario's Nanticoke and Atikokan Generating Stations, OPG January 20, 2009.

[76] **Carpentieri, M., Corti, A. and Lombardi, L**. (2005). Life cycle assessment (LCA) of an integrated biomass gasification combined cycle (IBGCC) with CO2 removal, *Energy Conversion and Management*, ***46***, 1790–1808.

[77] **Roth, B.** (2010). Analysis of biofuel production regarding the country specific context of South Africa based on a life cycle assessment, MSc thesis, Mechanical and Process Engineering, Darmstadt University.

[78] **Cherubini, F., et al.** (2009). Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations, Resources, *Conservation and Recycling*, ***53***, 434–447.

[79] **Curran, M. A., Mann, M. and Norris, G.** (2005). The international workshop on electricity data for life cycle inventories, *Journal of Cleaner Production*, ***13***, 853-862.

[80] **Bureau of Energy Efficiency**, Material and Energy Balance. http://emt-india.com/BEE-Exam/GuideBooks/1Ch4.pdf. Date retrieved: 20.06.2011**.**

[81] **Turton, R., et al** (2009). Analysis, Synthesis and Design of Chemical Processes 3rd edition, Prentice Hall.

[82] **Tolvanen, J.** (2008). Life cycle costs LCC approach for big motor-driven systems savings, *Feature WORLD PUMPS*, November 2008, 24-27.

[83] **Bloch, H.P.** (1998). Chapter 5 Life Cycle cost Studies, *Improving Machinery Reliability*, 259-312.

[84] **Fantozzi, F., Buratti C**. (2010). Life cycle assessment of biomass chains: Wood pellet from short rotation coppice using data measured on a real plant, *Biomass and Bioenergy*, ***34****,* 1796-1804.

[85] **Mani, S.** (2005). A system analysis of biomass densification process, PhDs Thesis, The University of British Colombia, Chemical& Biological Engineering Department.

[86] **Magelli F., Boucher, K., Bi, H.T., Melin, S., Bonoli A**. (2009). An environmental impact assessment of exported wood pellets from Canada to Europe, *Biomass and Bioenergy*,***33***, 434-441.

[87] **Jungmeier, G.** (2008). Contribution of Increased Pellet Use for Climate Protection, Discussion Workshop, *European Pellets Roadmap up to 2020*, June 26, 2008, Bruxelle, Belgium.

[88] **Haberg, L., Sarnholm, E., Gode, J., Ekvall, T., Rydberg,** T. (2009). LCA calculations on Swedish wood pellet production chains, according to Renewable Energy Directive, Swedish Environmental Research

Institute. http://www3.ivl.se/rapporter/pdf/B1873.pdf. Date retrieved: 12.12.2010.

[89] **Raymer, A.K.P.** (2006). A comparison of avoided greenhouse gas emissions when using different kinds of wood energy, *Biomass and Bioenergy*, ***30***, 605–617.

[90] **Johansson, J., Liss, J. E, Gullberg, T. and Björheden, R.** (2006). Transport and handling of forest energy bundles—advantages and problems, *Biomass and Bioenergy*, ***30***, 334–341.

[91] **Özdemir, D.** (2011). Bioenergie.DAT (- WRH) project.

[92] **Campbell, K.** (2007). A Feasibility Study Guide for an Agricultural Biomass Pellet Company, AURI (Agricultural Utilization Research Institute).

[93] **Thek, G., Obernberger, I.** (2004). Wood pellet production costs under Austrian and in comparison to Swedish framework conditions, *Biomass and Bioenergy*, ***27*** ,671–693.

[94] **Obernberger, I., Thek, G**. (2004). Techno-economic evaluation of selected decentralised CHP applications based on biomass combustin in IEA partner countries final report. Graz, March 2004.

[95] **GaBi** Software product sustainability official website: , http://www.gabi-software.com/index.php?id=85&L=1&redirect=1. Date retrieved:01.01.2011.

[96] **Forsberg, G.** (2000). Biomass energy transport Analysis of bioenergy transport chains using life cycle inventory method, *Biomass and Bioenergy*, ***19***, 17-30.

[97] **Jungmeier, G., Resch, G. and Spitzer, J.** (1998). Environmental Burdens Over The Entire Life Cycle Of A Biomass Chp Plant, *Biomass and Bioenergy*, ***5***, 311-323.

[98] **Republic of Turkey Minister of Energy and Natural Resources** official web site: http://www.enerji.gov.tr. Date retrieved: 06.06.2011.

[99] **Trading Economy** web site, http://www.tradingeconomics.com/turkey/interest-rate. Date retrieved:15.03.2011.

[100] **Çokoksen, B**. (2010). Bölge Isıtma Sistemlerinin Ekonomiklik Alanının Belirlenmesi, MSc thesis, Mechanical Engineering, Yıldız Technic University.

[101] **Leuchtweis, C.** (2009). Erflogskaftoren für Bioenergieanlagen mit Nahwarmenetz am Beispiel evaluierter Biomasseheizwerke, *18th Symposium Bioenergie*, November 2009.

[102] **Rigamonti, L., Grosso, M. and Giugliano, M.** (2009). Life cycle assessment for optimising the level of separated collection in integrated MSW management systems, *Waste Management*, ***29 (2009)***, 934–944.

[103] **Demirbaş, M. F., Balat, M., Balat, H.** (2009). Potential contribution of biomass to the sustainable energy development, *Energy Conversion and Management*, ***50***, 1746–1760.

[104] **Gavcar, E., Aytekin, A., Şen, S**. (1999). Türkiye'de Orman Ürünleri Endüstrisinin Hammadde Kaynakları ve Karsılastıgı Problemler, *Tr. J. of Agriculture and Forestry*, ***23***, 243-248.

[105] **Doğu Marmara Kalkınma Ajansı** MARKA, http://www.marka.org.tr. Date retrieved: 01.02.2011.

[106] **Yalova Valiliği** web site. http://www.yalova.gov.tr. Date retrieved:11.03.2011.

[107] **Stahl, M.** (2008). Improving Wood Fuel Pellets for Household Use Perspectives on Quality, Efficiency and Environment, Faculty of Technology and Science Environmental and Energy Systems, Karlstad University.

[108] **Çalışkan, E.** (2011). personal interview.

[109] **Selkimaki M., et al**., (2010). Present and future trends in pellet markets, raw materials and supply logistics in Sweden and Finland, *Renewable Sustainable Energy Reviews*, xxx.

[110] **Hansen, M.T., Jein, A. R**. (2009). English Handbook for Wood Pellet Combustion, EUBIA – European Biomass Industry Association, Developed in the framework of the EU-funded PELLETATLAS project.

[111] **Google Maps**, Retrieved, 10. 02.2010, http://maps.google.com/.

[112] **Wahlund, B., Yan,J. And Westmark, M**. (2002). A total energy system of fuel upgrading by drying biomass feedstock for cogeneration: a case study of Skelleftea bioenergy combine, *Biomass and Bioenergy*, ***23,*** 271 – 281.

[113] **Mani, S., Sokhansanj, S. and Bi, X**. (2005). A Streamlined Life Cycle Analysis of Biomass Densification Process, http://www.nt.ntnu.no/users/skoge/prost/proceedings/aiche-2005/topical/pdffiles/T7/papers/575c.pdf.

[114] **Porter, P. A., Barry, J., Roger, S., and Mark, D.** (2008). *Growing Wisconsin Energy* A Native Grass Pellet Bio-Heat Roadmap for Wisconsin, Wisconsin Department of Agriculture Trade and Consumer Protection Agriculture Diversification and Development Program, www.agrecol.com. Date retrieved: 23.04.2010.

[115] **Fantozzi, F., Barbanera, M., Buratti,C.** Life Cycle Analysis of Wood Pellet From Src Through Direct Measurıng of Energy Consumption, Biomass Research Centre, University of Perugia, http://www.crbnet.it/File/Pubblicazioni/pdf/1249.pdf. Date retrieved:25.06.2010.

[116] **Devki Energy Consaltancy Pvt. Ltd**., 2006. Best Practice Manual Cogeneration, http://www.energymanagertraining.com/CodesandManualsCD-5Dec%2006/BEST%20PRACTICE%20MANUAL-COGENERATION.pdf. Date retrieved: 10.03.2011.

[117] **Perry, M. and Rossilo-Calle, F.** (2008). Recent trends and future opportunities in UK bioenergy: Maximising biomass penetration in a centralised energy system, *Biomass and Bioenergy, **32***, 688 – 701.

[118] **Ecoinvent Centre** web site: http://www.ecoinvent.org/home/.

[119] **Kanan, R., Tso, C.P., Osman, R., and Ho, H.K.** (2004). LCA–LCCA of oil fired steam turbine power plant in Singapore, *Energy Conversion and Management*, ***45***, 3093–3107.

[120] **TDG Energia SRL**, Used Steam Turbine Generator Set, Ref No: ST1018 G. www.tdg-energia.com. Date retrieved:03.04.2011.

[121] **Muench,R. K., Knauss,D. T., Purnell,J. G.** Study of Waste-Heat-Boiler Size and Performance of a Conceptual Marine COGAS System. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA173434. Date retrieved:03.04.2011.

[122] **Spohn, O. M**. (2009). Parametrised Life Cycle Assessment of Electricity Generation in Hard-Coal-Fuelled Power Plants with Carbon Capture and Storage, Institute of Energy Economy and Rational Use (IER). Stuttgart University.

[123] **Alfa Laval**, ALSYS 20 and 30 website at: www.alfalaval.com. Date retrieved:21.03.2011.

[124] **Türkyılmaz, Ö.** (2011). Armagaz Internal System Manager.Personal interwiev.

[125] **Yalçın, H.** (2005). Balıkesir Merkezinde Isıtma sektöründe Kullanılan Yakıtların Enerji ve ekserji Analizleri ve Çevresel Etkiler, MSc. Thesis, Environmental Engineering, Balıkesir University.

[126] **Say, S.** (2011). İstanbul Uygulamalı Gaz Ve Enerji Teknolojileri Araştırma Mühendislik Sanayi Ticaret A.Ş (UGETAM) personnal interview.

[127] **Oland C.B** (2004). Guide to Combined Heat and Power Systems for Boiler Owners and Operators, Oak Ridge National Laboratory, http://cibo.org/pubs/ornl-tm-2004-144.pdf. Date retrieved:10.01.2011.

[128] **Jensen, T. (**2010). Einsatz der bioenergie in Abhangigkeit von der Raum- und Siedlungsstruktur, Warme technologien zwischen technischer Machbarkeit, ökonomischer Tragfahigkeit, ökologischer wirksamkeit und sozialer Akzeptanz, pp, 144, 347, Straus Gmbh,Mörlenbach.

[129] **Indiamart** web site: http://www.indiamart.com/thermaflex-pipes-pvtltd/products.html. Date retrieved: 10.01.2011.

[130] **Dağsöz, A.K. and Yüksel**, H. M., (1999), Borulardaki Isı Kayıpları Ve Yalıtım Örnekleri, *IV. Ulusal Tesisat Mühendisliği Kongresi Ve Sergisi* Bildiriler Kitabı, İzmir http://arsiv.mmo.org.tr/pdf/0000042E.pdf. Date retrieved:10.01.2011.

[131] **PEWO Energietechnik GmbH** web site: www.pewo.de. Date retrieved:10.01.2011.

[132] **Fagernas, L., et al**. (2010). Drying of biomass for second generation synfuel production, *Biomass and Bioenergy, **34***, 1267-1277.

[133] **Pelkonen, P., Hakkila, P., Karjalainen, T., Schlamandinger**, (2001). Woody Biomass as an Energy Source- Challenges in Europe, http://www.efi.int/files/attachments/publications/proc39_net.pdf. Date retrieved: 12.01.2011.

[134] **Liska, S., et al.** (2010). General Assessment of Jenz Hem 420 D Chipper Operatıng in the Czech Republic Conditions, *Formec 2010 Forest Engineering: Meeting the Needs of the Society and the Environment*, July 11 – 14, 2010, Padova – Italy.

[135] **Eker, M., Çoban, H.O. and Alkan, H.** (2010). Hasat Artıkları Tedarik Zincirine Yönelik Sistem Tasarımı, *III. Ulusal Karadeniz Ormancılık Kongresi 20-22 Mayıs 2010*, ***Cilt: II***, 524-534.

[136] **König A.** (2009)**.** Ganzheitliche Analyse und Bewertung konkurrierender energetischer Nutzungspfade für Biomasse im Energiesystem Deutschland bis zum Jahr 2030. Dissertation an der Fakultät für Energie-, Verfahrens- und Biotechnik der Universität Stuttgart.

[137] **Eltrop E., et al.** (2007). Leitfaden Bioenergie, Planung, Betrieb und Wirtschaftlichkeit von bioenergieanlagen, Fachagentur NachwaschsendeRohstoffe e.V., Nova- Institut Gmbh, Hürth, p80.

[138] **Orman Genel Müdürlüğü Biyoenerji Komisyonu**, (2009). Türkiyede Odunsu Biyokütleden Temiz Enerji Üretimi, Şubat 2009, Ankara. http://www.ogm.gov.tr/dokumanlar/biyoenerjiraporu0209.pdf. Date retrieved: 06.12.2010.

[139] **Enez, K.** (2008). Ormancılıkta Üretim İşçiliğinde Antropometrik verilerin ve çalışma duruşlarının Kaza Risk Faktörleri Olarak Değerlendirilmesi, Phd. Thesis, Forest Engineering, Karadeniz Technical University.

[140] **Raymer, A. K. P. (**2006). A comparison of avoided greenhouse gas emissions when using different kinds of wood energy, *Biomass and Bioenergy****, 30***, 605–617.

[141] **Goglio, P. and Owende, P. M. O.** (2009). A screening LCA of short rotation coppice willow (Salix sp.) feedstock production system for small-scale electricity generation, *Biosystems engineering*, ***103***, 389 – 394.

[142] **Heller, M.C:, Keoleian, G. A. and Volk, T.A**. (2003). Life cycle assessment of a willow bioenergy cropping system, *Biomass and Bioenergy,* ***25***. 147 – 165.

[143] **Kumar, A., Camereon, J.B., and Flynn, P.C.** (2003). Biomass power cost and optimum plant size in western Canada, *Biomass and Bioenergy*, ***24,*** 445 – 464.

[144] **Kimming, M., et al.** (2011), Life cycle assessment of energy self-sufficiency systems based on agricultural residues for organic arable farms, *Bioresource Technology*, ***102***, 1425–1432.

[145] **Obernberger, I., and Thek, G.** (2008). Cost Assessment of Selected Decentralised CHP Applications Based on Biomass Combustion and Biomass Gasification, *16th European Biomass Exhibition*, June 2008, Valencia, Italy.

[146] **Anthony K.** (1997). Chapter 2: Plant acquisition policy and maintenance life-cycle costs, *Strategic Maintenance Planning***,** pp 9-21.

[147] **Sultana, A., Kumar, A., and Harfield, D**. (2010). Development of agri-pellet production cost and optimum size, *Bioresource Technology,**101,*** (2010) 5609–5621.

[148] **Hürriyet emlak** official website: http://www.hurriyetemlak.com/ Date retrieved: 11.02.2011.

[149] **Höldrich, A., Epp, C., Witzelsperger, J.** (2009). Feasibility Study for Mixed Biomass Pellets Production In the German Sample Region: Straubing, Bavaria. Pellet Atlas, Intelligent Energy Europe.

[150] **Voulgaraki, S., Balafoutis, A., and Papadakis, G**. Feasibility Study for a Mixed Biomass Pellets Manufacturing Plant in Greece Selected Target Region: Larissa Prefecture. Pellet Atlas, Intelligent Energy Europe.

[151] **Chau, J., et al.** (2009). Economic sensitivity of wood biomass utilization for greenhouse heating application, *Applied Energy*, ***86***, 616–621.

[152] **Kalıncı, Y.** (2006). Dikilide Jeotermal Bölgesel Isıtma Sisteminin Araştırılması, MSc. Thesis, Mechanical Engineering, Dokuz Eylül University.

[153] **MMO Zonguldak Şube**, (2009). Çates Atık Isısı İle Bölgesel Isıtma İmkânları, MMO Zonguldak Sube Enerji Komisyonu Raporu http://www.mmo.org.tr/subeler/index.php?sube=18. Date retrieved:01.03.2011.

[154] **Pertol Ofisi** official website: http://www.poas.com.tr/. Date retrieved:01.03.2011.

[155] **Bilpa Nakliye Orman Ürünleri** web site, http://www.bilpainsaat.com.tr/Files/fiyat/MUDURNU%20F%C4%B0YAT%20L%C4%B0STES%C4%B0.pdf. Date retrieved:01.03.2011.

[156] **Kadiroğlu A.R.,** 2006. Sanayide Enerji Verimliliğinin Arttırılması En Verimli Endüstriyel Tesis Yarışması, Oyka Kağıt Ambalaj Sanayi. www.eie.gov.tr/turkce/en_tasarrufu/uetm/...**2006**/E_**oyka**.doc. Date retrieved:01.03.2011.

[157] **Human Resources Management** official website: http://www.hrm.com.tr/basinda_hrm_arsiv14.asp#yonetici. Date retrieved:01.03.2011.

[158] **Erdal M.,** (2010). Taşıma Hesapları, Gazi University. http://websitem.gazi.edu.tr/site/merdal/files. Date retrieved:03.03.2011.

[159] **İGDAŞ. A.Ş,** Retrieved on 20.02.2011. http://www.igdas.com.tr/Dynamic/YakitFiyatKarsilastirmasi.igd

[160] **Electrical Manufacturers Association** official website: http://www.eud.org.tr/TR/Genel/BelgeGoster.aspx?F6E10F8892433CFFAAF6AA849816B2EF658371B912254297. Date retrieved:08.03.2011.

[161] **BIOMASA, Association of Legal Entities**, (2006). FEASIBILITY STUDY Mixed Pellets Production in SLOVAKIA. Pellet Atlas, Intelligent Energy Europe.

[162] **Zabetta, E.C., et al**, (2009). Biomass and Waste Co-combustion – European Experience, *ELECTRIC POWER 2009*, May 12-14th, Rosemont, Illinois.

APPENDICES

Appendix A1

Biopellet Feedstock Procurement

Capacities of the selected wood processing plant in the cities are given in this part.

Table A.1.1: Sawmill plants and their capacities in Yalova.

Company Name	Website	E-mail	Product Capacity
Duman Tepe Orman Ürünleri	http://www.dumantepe.com.tr/	fabrika@dumantepe.com.tr	7300 m^3/a
Başaran Orman Ürünler	http://www.basaranorman.com/Hakkimizda.aspx	info@basaranorman.com	21900 m^3/a
Ekban Orman Ürünleri	http://www.sekban.com.tr/urunler/urunler.htm	e-mail: info@sekban.com.tr	20000 m^3/a
Harputoğlu Orman Ürünleri	http://www.harputoglu.com	harputoglu@harputoglu.com	21000 m^3/a
Arın orman ürünleri	http://www.arin.com.tr/tr2.html	info@arın.com.tr	10000 m^3/a
Pehlivan orman ürünleri	http://www.pehlivanormanurunleri.com.tr/	pehlivan@pehlivanormanurunleri.com.tr	20000 m^3/a

Table A.1.2: Sawmill plants ans their capacities in Sakarya.

Company Name	Website	E-mail	Product Capacity
Sakarya Kerestecilik San. Ve Tic. A.Ş.	http://www.sakaryakereste.com.tr/indexeng.html	info@sakaryakereste.com.tr	43000 m^3/a
Veysel Yıldırım Kerestecilik	http://www.veyselyildirim.com/hakkimizda.php		20000 m^3/a

Table A.1.3: Sawmill plants ans their capacities in Kocaeli.

Company Name	Website	E-mail	Product Capacity
Saglam Kereste	http://www.saglamkereste.com/	info@saglamkereste.com	8400 m^3/a
Ekşioğlu	http://www.eksiogluorman.com.tr/tr/dinamik.asp?id=46	serdarkuruçay@eksigluorman.com.tr	15000 m^3/a
Üç Kardeşler İnşaat Kerestecilik	http://www.3kambalaj.com/iletisim.asp	nfo@3kambalaj.com	20000 m^3/a
Cepal Orman Ürünleri	http://www.cepal.com.tr/irtibat.html	info@cepal.com.tr	20000 m^3/a

However, in this study it is assumed that the feedstock comes from selected facility in the region. The detailed information about facility data are displayed in Table A. 1.1

Table A.1.4: Total wood, sawmill residues and biopellet production capacity values of selected cities.

City	Annual Product	Total wood feedstock	Residues volume	Residues weight	Biopellet produced
Yalova	100200	137260.3	37060.3	9895093.2	5541252.2
Kocaeli	63400	86849.32	23449.3	6260967.1	3506141.6
Sakarya	63000	86301.37	23301.4	6221465.8	3484020.8
Total			83811		12531415

Distance calculations are done in this section. Although distance calculation for the plant shows Skarya is the best city, Yalova is preferred to build the whole change because of its strategic location. Distances of the cities are given below.

Table A.1.5: Distances between three cities in km.

	Yalova	Kocaeli	Sakarya
Yalova	-	84	115
Kocaeli	84	-	62
Sakarya	115	62	-

Linear programming methods are used in order to find the suitable place for biopellet plant taking consideration the distances and feedstock capacities. Carrying cost is calculated by the following assumption. Carrying of 1 ton of biopellet is 1 unit, distance between cities and the ton of the biopellet can be produced by multiplying one city to find the total carrying cost in terms of unit.

Table A.1.6: Weighted carrying cost in case of Yalova.

	Yalova	Kocaeli	Sakarya	Carrying cost (unit)
Yalova	5	84	115	5541
Kocaeli	84	5	62	3506
Sakarya	115	62	5	3484
Total				722884

Table A.1.7: Weighted carrying cost in case of Kocaeli.

	Yalova	Kocaeli	Sakarya	Carrying cost (unit)
Yalova	5	84	115	5541
Kocaeli	84	5	62	3506
Sakarya	115	62	5	3484
Total				699005

Table A.1.8: Weighted carrying cost in case of Sakarya.

	Yalova	Kocaeli	Sakarya	Carrying cost(unit)
Yalova	5	84	115	5541
Kocaeli	84	5	62	3506
Sakarya	115	62	5	3484
Total				872044

According to carrying cost Kocaeli is the best city in three of them. However, Yalova is preferred to build the plants. Average weighted distance for Yalova is 57.6 km, it is assumed as 58 km during the calculations. The capacity percentages of the residues are multiplied by the distances and the average distance is calculated.

Appendix A2

CHP plant Calculations

Table A.2.1: Scaling functions of selected wood fuel and CHP plants component [122].

Plant component (abbreviation)	Parameterised scaling function $P_{component}$	Basic correlation to plant engineering
Steam generator (SteamG)	$f_{SteamG} = \frac{P_{th,Firing}}{P_{th,Firing,reference}}$	Constant heat flow density in heat transfer systems
Condenser (Cond)	$f_{Cond} = \frac{P_{th,cooling}}{P_{th,cooling,reference}}$	Constant heat flow density in heat transfer systems
Generator (Gen)	$f_{Gen} = \frac{P_{el,Gross}}{P_{el,Gross,reference}}$	Constant electricity density in conductors
Piping and fittings (Pipe)	$f_{Pipe} = \sqrt{\frac{P_{th,firing}}{P_{th,firing,reference}}}$	Constant mass flow density in pipes: mass of pipes is predominantly determined by the surface of the pip
Feedstock storage (FeedS)	$f_{FeedS} = \sqrt[\frac{2}{3}]{\frac{P_{th,firing}}{P_{th,firing,reference}}}$	Constant specific fuel feed ratio. Surface of building corresponds to the squared cube root.
Machine house (MachH)	$f_{\mathrm{MachH}} = \sqrt[\frac{2}{3}]{\frac{P_{el,firing}}{P_{el,firing,reference}}}$	Power Plant Capacity as reference for machine volume. Surface of building corresponds to the squared cube root.
Feed-water pumps (FWP)	$f_{FWP} = \frac{P_{el,Steam\ turbine}}{P_{el,Steamtrubine,reference}}$	Steam Turbine determines the steam cycle, the amount of feed-water and thus the dimensioning of the feed water pump
Cooling unit (cool)	$f_{Cond} = \frac{P_{th,cooling}}{P_{th,cooling,reference}}$	Constant heat flow density in heat transfer systems
Steam surbine (SteT)	$f_{SteT} = \sqrt{\frac{P_{el,Steam\ turbine}}{P_{el,Steam\ turbine,reference}}}$	Constant gas volume flow per cross-sectional area

Appendix A3

District Heating

Table A.3.1: Natural gas consumption of a 100 m^2 residence in Yalova, in 2010 [124].

Month	m^3 of Natural gas consumption for 100 m^2 residence
January	190,9
February	241,3
March	176,9
April	146,1
May	72,3
June	28,3
July	19,8
August	13,2
September	36,5
October	56,6
November	106,5
December	147,6

Calculation of the district heating pipes:

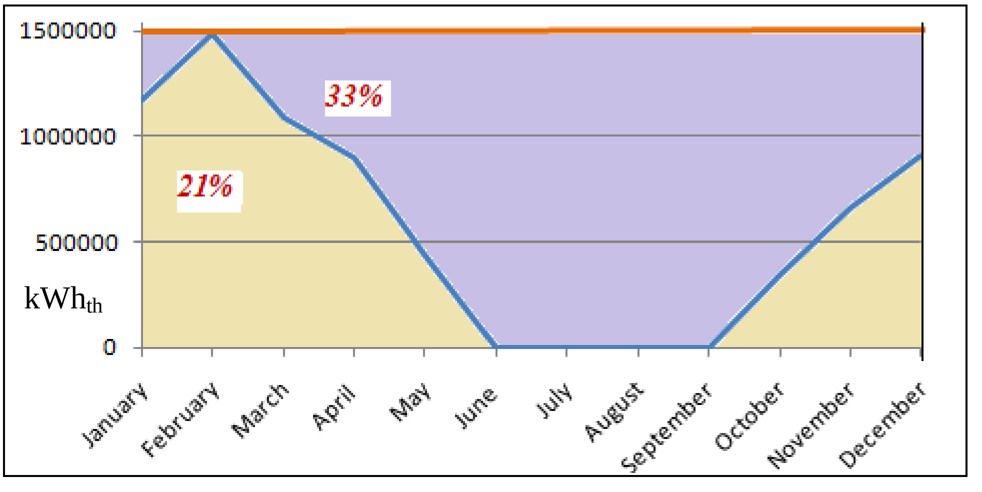

Figure A.3. 1: Heating curve of Case A.

33% of the heat is not used due to absence of heat demand especially summer months. 21% of the heat is used for district heating.

Biopellet fuelled Case A district heating system

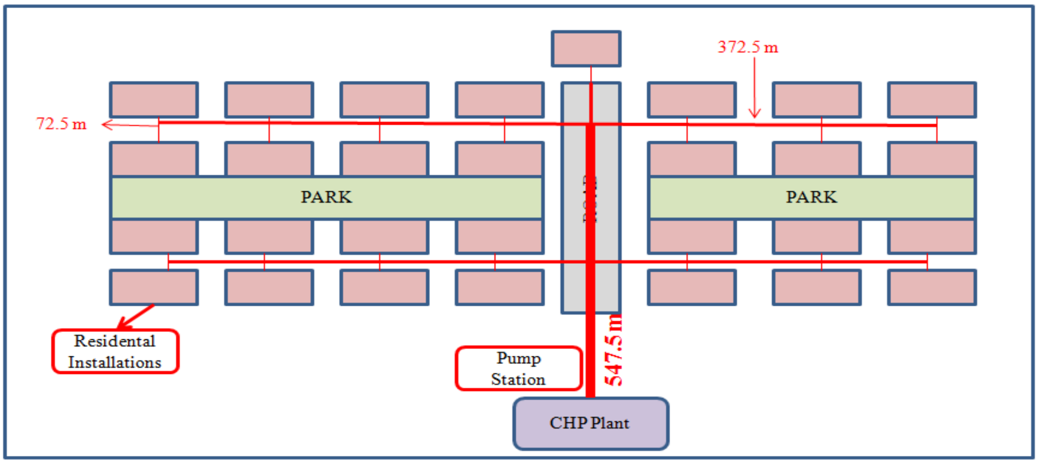

Figure A.3.2: Hypothetical district heating settlement for Case A.

ρ= 957 kg/m^3 [87]
ΔT= 30 K (hot water comes 60-70 ^{o}C and leaves system 30-35 ^{o}C)
c_p= 4.184 kJ/kgK
v_1= 3 m/s at primary distribution pipes
v_2= 2.5 m/s at secondary distribution pipes
v_3= 1.5 m/s at tertiary distribution pipes
D:diameter of pipe

$$D = \sqrt{\frac{4.Q}{\pi.c_p \Delta T.\rho.v}} \qquad (*)$$

Primary pipe diameter:
Q_h= 4136 kJ/s , heat flow is calculated

Secondary pipe diameter:

For the secondary pipe Q_h is distributed into four pipes as seen in the Figure for the pipe settlement.

Q_h= (4136/4) kJ/s= 1034 kJ/s

<u>Tertiary pipe diameter:</u>

For the tertiary pipe Q_h is distributed into 29 pipes as seen in the Figure for the pipe settlement.

Q_h= (4136/29) kJ/s= 143 kJ/s

Biopellet fuelled Case B&C district heating system

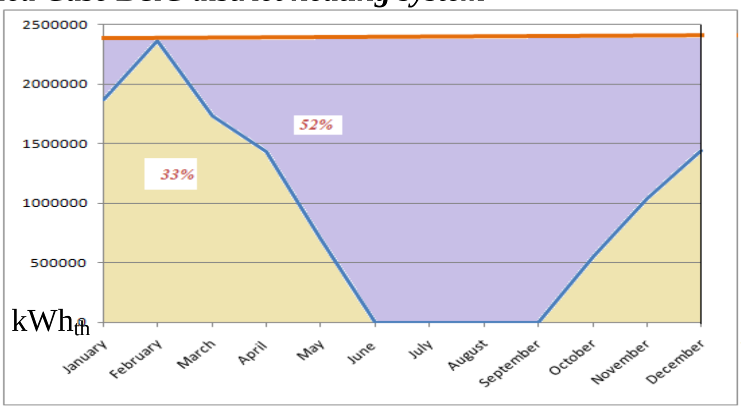

Figure A.3.3: Heating curve of Case B&C.

52% of the heat is not used due to absence of heat demand in summer months. 33% of the heat is used for district heating.

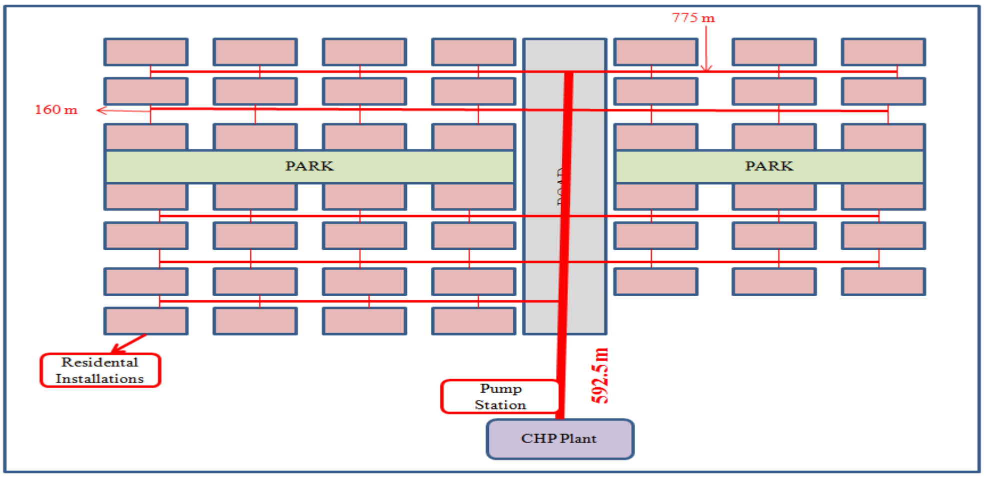

Figure A.3 4: Hypothetical heating system settlement for Case B&C.

ρ= 957 kg/m^3
ΔT= 30 K hot water comes 60-70 ^{o}C and leaves system 30-35 ^{o}C
c_p= 4.184 kJ/kgK
v_1= 3 m/s at primary distribution pipes
v_2= 2.5 m/s at secondary distribution pipes
v_3= 1.5 m/s at tertiary distribution pipes
D:diameter of pipe

$$D = \sqrt{\frac{4.Q}{\pi.c_p \Delta T.\rho.v}} \qquad (*)$$

Primary pipe diameter:
Q_h= 6560 kJ/s, heat flow is calculated

Secondary pipe diameter:

For the secondary pipe Q_h is distributed into four pipes as seen in the Figure for the pipe settlement.

Q_h= (6560/9) kJ/s= 729 kJ/s

Tertiary pipe diameter:

For the tertiary pipe Q_h is distributed into 460 pipes as seen in the Figure for the pipe settlement.

Q_h= (6560/46) kJ/s= 143 kJ/s

(* **Blesl, M,** 2002. Räumlich Hoch aufgelöste Modellierung leitungsgebundener Energieversorgungssysteme zur Deckung des Niedertemperaturwärmebedarfs, University of Stuttgart)

Appendix A4

Economic calculations

Transportation cost

$$F= Kx(0.0007xM+0.01)$$

M: transport distance (km)
K: ton carrying coefficient for Turkey (TL)
F: Carrying price (TL/t)
For sawdust
M= 58 km
K= 120 TL/day in 2007
F= 6.072 TL/t
For biopellet and chips
M= 20 km
K= 120 TL/day in 2007
F= 2.88 TL/t

Detailed cost of the systems

More detailed data about the economic calculations are mentioned below. When TL_{2010} values are calculated scaling factor is used regarding to plant size. $\$_{2010}$ values are the base price of the equipments in their original size as a result values are crecalculated with scaling factor for the plant capacity and equipment.

Table A.4.1: Biopellet plants costs**.

	Value	Unit	$\$_{2010}$	TL_{2010}
Land Cost	536,000	TL_{2010}	-	536,000
Building manufacturing cost				
Biopellet plant	250,000	$€_{2009}$	353010	316,020
Purchased Equipment Cost				
Sawdust storage	280,000	$\$_{2007}$	294,467	212,441
Drying	192,000	$\$_{2007}$	201,920	115,120
Grinding	31,200	$\$_{2007}$	32,812.05	27,424
Conditioner	43,900	$\$_{2007}$	46,168	34,981
Boiler	45,000	$\$_{2007}$	47,325	35,858
Biopellet mill	125,000	$\$_{2007}$	131,458	85,979
Cooling	31,800	$\$_{2007}$	33,443	28,505
Screening	18,300	$\$_{2007}$	19,245	16,084
Conveyor. tanks. etc	200,000	$\$_{2007}$	210,333	151,744
Biopellet storage	280,000	$\$_{2007}$	294,467	212,441

Freight	79,000	$\$_{2007}$	83,081	59,938
Transport machinery raw material (2 truck assumption)	200,000	€ $_{2008}$	210,333	167,728
Plant office equipment and tools	60,000	$\$_{2007}$	63,100	45,523
Engineering				
Enginneering	20,000	$\$_{2007}$	21,033	31,666
Project management	10,000	$\$_{2007}$	10,517	15,834
Installation				
Mechanical	40,000	$\$_{2007}$	42,066	63,333
Electrical	30,000	$\$_{2007}$	31,550	47,500
Maintenance cost				
Sawdust storage	7,000	$\$_{2007}$	7,361	5,311
Drying	4,800	$\$_{2007}$	5,048	2,878
Grinding	5,616	$\$_{2007}$	5,906	4,936
Conditioner	1,097	$\$_{2007}$	1,154	874
Boiler	1,125	$\$_{2007}$	1,183	896
Biopellet mill	12,500	$\$_{2007}$	13,145	8,597
Cooling	795	$\$_{2007}$	836	712
Screening	457.5	$\$_{2007}$	481	402
Conveyor. tanks. etc	5,000	$\$_{2007}$	5,258	3,793
Biopellet storage	7,000	$\$_{2007}$	7,361	5,311
Transport machinery raw material (2 truck assumption)	5,000	$\$_{2007}$	5,258	4,193
Plant office equipment and tools	1,500	$\$_{2007}$	1,577	1,138
Labor Cost				
Labour administration and marketing	7,8000	TL_{2010}	-	78,000
Operation Labor Cost	183,517.822	TL_{2010}	-	183,518
Raw material cost				
Sawdust	2,250,000	TL_{2010}	-	2,250,000

Corn starch	72,000	TL_{2010}	-	72,000
Fuel cost				
Diesel	215,460	TL_{2010}	-	215,460
Natural gas	524,160	TL_{2010}	-	524,160
Electricity cost				
Electricity cost	106,200.36	TL_{2010}	-	106,200.36
Transportations				
Sawdust Transportation	130,114.285	TL_{2007}	-	156,067
Biopellet Transportation	34,560	TL_{2007}	-	41,453
Taxes	5,970.5	TL_{2010}	-	5,970

Table A.4.2: CHP plant costs without biopellet buying**.

	Value	**Unit**	**$\$_{2010}$**	**TL_{2010}**
Land Cost	440,000	TL_{2010}	-	440,000
Building manufacturing cost				
CHP plant building	280,000	$\$_{2008}$	294467	231,299
Purchased Equipment Cost				
Furnace and boiler	4,900,000	€$_{2002}$	5,596,669	3,726,103
Flue gas cleaning	510,000	€$_{2002}$	582,583	387,867
Ash container and conveyor	120,000	€$_{2002}$	113,078	75,284
Heat recovery	included	€$_{2002}$	-	-
Fuel conveyor	80,0000	€$_{2002}$	913,741	608,342
CHP module	4,100,000	€$_{2002}$	4,682,928	3,117,760
Fuel storage unit	600,000	€$_{2002}$	695,306	462,915
weighbridge	100,000	€$_{2002}$	114,217	76,042
Engineering				
Planning	720,000	€$_{2002}$	822,306	655,770
Installation				
Electric installation	670,000	€$_{2002}$	765,257	610,275
Hydrolic installation	40,000	€$_{2002}$	45,688	36,435
Steel works	included	€$_{2002}$	-	-
Labor Cost				
Labour administration and marketing	86,400	TL_{2006}	-	110,110
Operation Labor Cost	78,000	TL_{2010}	-	78,000
Electricity cost				
Electricity cost	212,738	TL_{2010}	-	212,738
Maintenance cost				

Furnace and boiler	122,500	€ $_{2002}$	139,916	93,152
Flue gas cleaning	12,750	€ $_{2002}$	14,564	9,696
Ash container and conveyor	3,000	€ $_{2002}$	2,826	1,882
Heat recovery	included	€ $_{2002}$	-	-
Fuel conveyor	20,000	€ $_{2002}$	22,843	15,208
CHP module	102,500	€ $_{2002}$	117,073	77,944
Fuel storage unit	15,000	€ $_{2002}$	17,382	11,572
Taxes				
Tax	55,650	€ $_{2002}$	63,492	42,271
Ash Disposal				
Ash Disposal	23,913	€ $_{2002}$	27,279	21,754

Table A.4.3: District Heating cost for Case A**.

	Value	**Unit**	**$\$_{2010}$**	**TL $_{2010}$**
Capital cost				
Pipe system	120,263	TL$_{2005}$	-	162,845
Pipe assembly	72,572	TL$_{2005}$	-	98,269
Pumping sation	19,500	€ $_{2009}$	27534	41,454
Residence	406,000	€ $_{2009}$	573,288	863,125
Planning	58,125	TL$_{2010}$	-	58,125
Maintenance cost				
Pipe system	3,006	TL$_{2005}$	-	4,071
Pipe assembly	1,814	TL$_{2005}$	-	2,456
Pumping sation	487.5	€ $_{2009}$	688.35	1,036
Residence	10,150	€ $_{2009}$	14,332	21,578
Operating cost				
Pump electrcity	2,476	TL$_{2010}$	-	2,476

Table A.4.4: District Heating cost for Case B&C**.

	Value	**Unit**	**$\$_{2010}$**	**TL $_{2010}$**
Capital cost				
Pipe system	194,909	TL$_{2005}$	-	263,922
Pipe assembly	117,617	TL$_{2005}$	-	159,263
Pumping sation	19,500	€ $_{2009}$	27534	41,454
Residence	644,000	€ $_{2009}$	846,611	1,294,633
Planning	86,963	TL$_{2010}$	-	86,963
Maintenance cost				
Pipe system	4,872	TL$_{2005}$		6,598

Pipe assembly	2,940	TL_{2005}		3,981
Pumping sation	487.5	€ $_{2009}$	688.35	1,036
Residence	16,100	€ $_{2009}$	21,165	31,865
Operating cost				
Pump electrcity	3,461	TL_{2010}	-	3,461

Table A.4.5: Chips cost until CHP plant.

	Value	Unit	$\$_{2010}$	TL $_{2010}$
Chipper	224,000	€ $_{2008}$	331,966	499,798
Terrain transport	175,000	€ $_{2003}$	234,218	352,631
Terrain transport	175,000	€ $_{2003}$	234,218	352,631
Transport machinery raw material (2 truck assumption)	200,000	€ $_{2008}$	210,333	167,728
Maintenance cost				
Chipper	5,600	€ $_{2008}$	8,299	12,494
Terrain transport	4,375	€ $_{2003}$	5,855	8,815
Terrain transport	4,375	€ $_{2003}$	5,855	8,815
Transport machinery raw material (2 truck assumption)	5,000	€ $_{2008}$	5,258	4,193
Raw material cost				
wood residues cost	1,156,250	TL $_{2009}$		1,305,297
Transport	55,500	TL $_{2009}$		58,968

The price of the heat and electricity is indicated in the Table A.4.5 according to the current Turkish values.

Table A.4.6: Electricity selling prices in Turkey [147].

Electricity	**kuruş / kWh**	**$\$_{2011}$ Cent / kWh**	**€$_{2011}$ Cent/ kWh**
Industrial	20.6957	13.6326	10.0153
Residential	23.8731	15.7256	11.5530
Natural gas	**kuruş / m^3**	**\$ Cent / m^3**	**€ Cent/ m^3**
Industry	48,9635	32.2531	23.6951
Residential	51.7634	34.0975	25.05

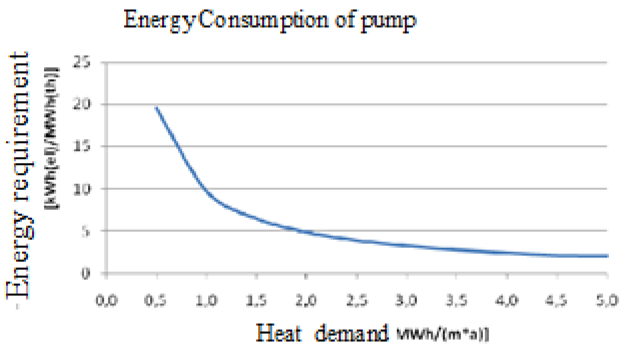

Figure A.4.1: Energy consumption of pump [88].

(** During economic calculations the sources which are mentioned in the references, are used: 6, 91, 92, 94, 97-101, 134, 81, 143-151)

Appendix A5

GaBi printscreen

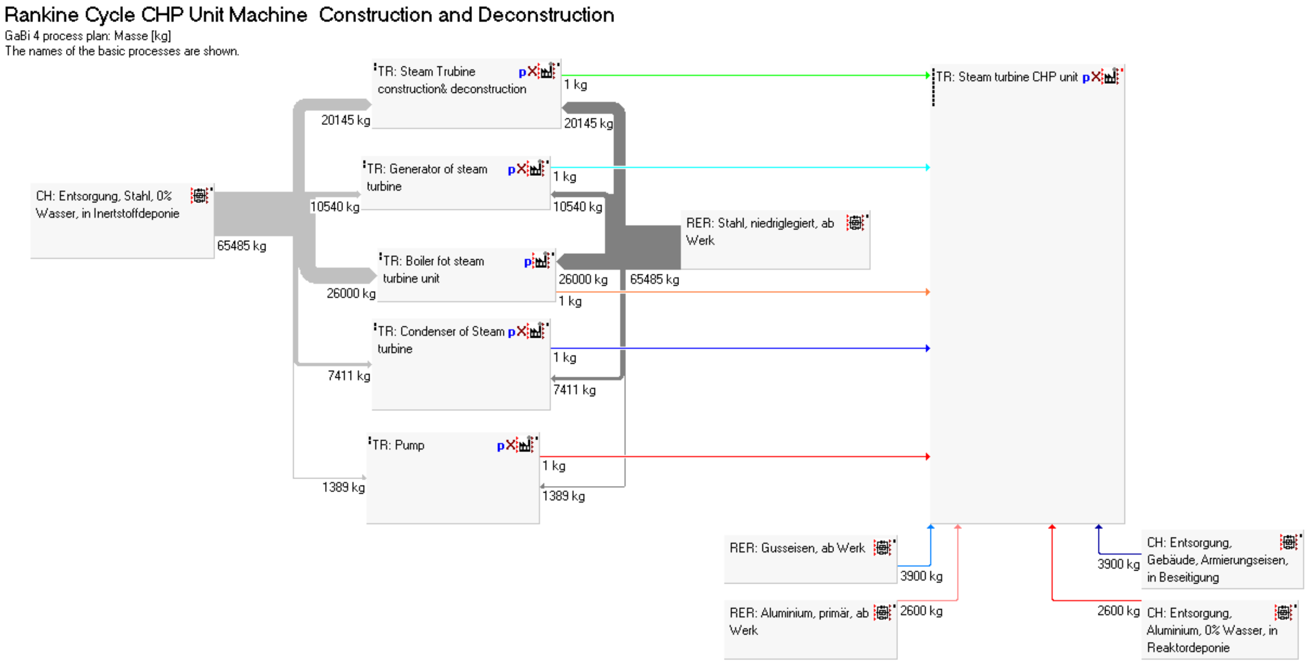

Figure A.5.1: Plan of the CHP unit in GaBi.

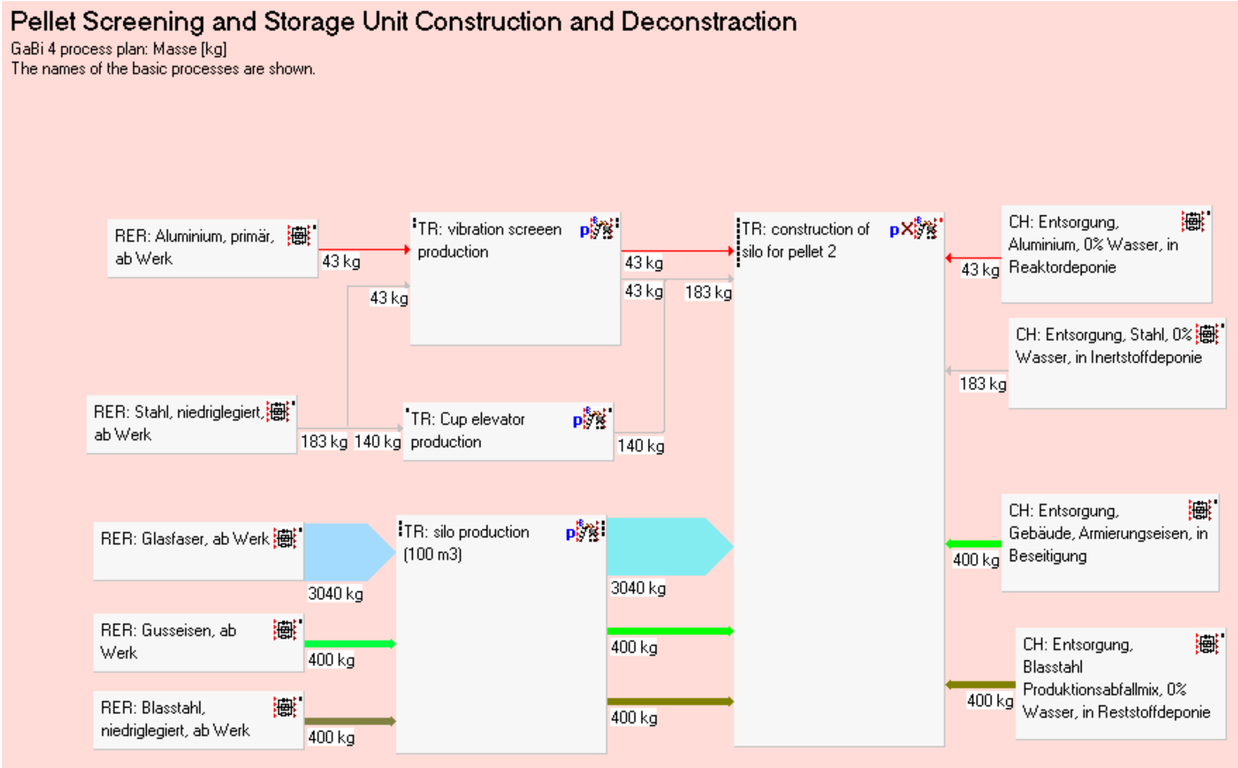

Figure A.5.2: Plan of the screening and storage unit in GaBi.

CURRICULUM VITAE

Candidate's Full Name: Zühal MEYDAN

Place and Date of Birth: Artvin, 10.10.1987

E-Mail: meydan@itu.edu.tr

Universities and Colleges attended:
Istanbul Technical University
Chemical Engineering, 2009
Industrial Engineering, 2010
University of Stuttgart, 2011 (ERASMUS)

Scholarship:
- The Scientific and Technological Research Council of Turkey (TÜBİTAK) National Scholarship Programme for MSc Students (2009-2011)
- ERASMUS Exchange programme (10 months) (2010-2011)

List of Publications:
- **Meydan Z**., İşler A., Karaosmanoğlu K., 2009. "Bioelectricity Generation from Biomass", *International Waste to Energy Symposium*, Istanbul, Turkey, 12-13 November 2009.
- **Meydan Z**., İşler A., Karaosmanoğlu K., 2010. "Biorefineries and Waste Management", *International Conference on Clean Energy (ICCE-2010),* Gazimagusa, Nord Cyprus, 15-17 September, 2010.
- **Meydan, Z., İşler, A., Karaosmanoğlu, F**., "Biorefineries and Waste Management", Special Issue of International Journal of Green Energy, Submitted.
- **Meydan Z**., **İşler A., Karaosmanoğlu K**., 2011. " LCA Applications in Turkey", *SETAC Europe 21st Annual Meeting,* Milano, Italy, 15-19 May 2011.