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THE APPLICATION OF BIOMASS FOR CHP IN EUROPE

REGULATION AND ECONOMICS: The case of Amynteon

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Keywords: biomass, combined heat and power (CHP), District Heating (DH), energy efficiency, electricity, thermal energy, Thermal Energy Storage (TES), regulation, policy

Abstract

The European Union (EU) is committed to reduce carbon emissions by 80-95% in 2050, when compared to 1990. To reach this ambitious objective, a shift in energy consumption to low carbon, locally produced energy, and Renewable Energy Sources (RES) is needed. The use of biomass to produce electricity, heat and fuels could significantly help towards this direction. More specifically, the generation of electricity supplemented by the production of thermal energy (Combined Heat and Power - CHP) is an efficient way το achieve EU's targets. The produced thermal energy of the CHP plant could be used to supply District Heating Networks (DHN) of cities with cold climate.

In the context of this master's thesis, the application of biomass for CHP in Europe was studied. At the beginning was analyzed the policy framework for biomass and CHP in EU. Furthermore, an extensive analysis of the EU's legal regime of biomass and cogeneration from it was executed. This analysis was further extended for the case of Greece. Moreover, the available technologies for biomass CHP were studied and the main advantages and disadvantages of biomass, as well as applications of CHP plants worldwide, were presented.

Furthermore, a feasibility study concerning the installation of a CHP plant supplying with thermal energy the DHN of the city of Amynteon (Greece) was executed. Following a detailed energy study for the calculation of the installed electrical and thermal capacity of the specific plant, an extensive techno-economic analysis was performed, which proved that under certain conditions the relative investment could be profitable. Finally, an optimization study concerning the installation of a Thermal Energy Storage (TES) system in parallel with the CHP plant was also executed.

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Abbreviations

Associated Emission Limits (AELs)

Best Available Techniques (BAT)

Carbon Dioxide (CO_2)

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Combined Heat and Power (CHP)

Consumer Price Index (CPI)

Distributed Control System (DCS)

District Heating (DH)

District Heating Network (DHN)

District Heating Production System (DHPS)

Electricity from Cogeneration (ECHP)

Electrostatic precipitator (ESP)

European Environment Agency (EEA)

European Environmental Information and Observation Network (EIONET)

European Union (EU)

Feed-in premium (FIP)

Feed-in tariff (FIT)

Fluidized Bed Combustion (FBC)

Heat Exchangers (HE)

Heat Storage System (HSS)

High efficiency Cogeneration (HEC)

Green House Gases (GHG)

Independent Power Transmission Operator (IPTO)

Industrial Emissions Directive (IED)

Integrated Pollution Prevention and Control (IPPC)

Internal Rate of Return (IRR)

Instrumentation and Control (I&C)

Large Combustion Plant Directive (LCPD)

Liquefied Petroleum Gas (LPG)

Low-NOX burners (LNB)

Medium Combustion Plants (MCP)

Member States (MS's)

National Energy and Climate Plan (NECP)

Net Present Value (NPV)

Natural Gas (NG)

Nitrogen (N)

Operation and Maintenance (O&M)

Organic Rankine Cycle (ORC)

Public Power Corporation (PPC)

Refused Derived Fuels (RDFs)

Regulatory Authority for Energy (RAE)

Renewable Energy Sources (RES)

Sulfur (S)

Thermal Energy Storage (TES)

Trace Elements (TEs)

Waste Incineration Directive (WID)

Weighted Average Cost of Capital (WACC)

Wet flue-gas desulphurization (wet FGD)

Units of Measurement

MWe: Megawatt Electrical

MWth: Megawatt Thermal

1 MW = 1000 Watts

1 GW = 1000 MWatts

Chapter 1: Introduction

1.1 Introduction

To face climate changes, the European Union (EU) is committed to reduce carbon emissions by 80–95% in 2050, when compared to 1990. To reach this ambitious objective, a shift in energy consumption towards low carbon, locally produced energy, and Renewable Energy Sources (RES) is needed.[1] Renewable Energy Sources (RES) are the natural sources or processes that are constantly replenished. According to Article 2(1) of the Directive (EU) 2018/2001[2] of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources "energy from renewable sources" or "renewable energy" means "energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas".

1.2 Literature Review

The EU policy promotes the use of all RES and has as target to make the EU a global leader in this field. Among other RES, biomass could significantly contribute to the increase of RES share. More specifically, energy from biomass and the renewable share of waste contributes almost two-thirds of the 28 Member States (MS's) primary combined renewable energy production today and is expected to further increase through 2030.[3]

Biomass has been used as a fuel since humans first learned to control fire. Traditional biomass refers to wood, charcoal, agricultural residues and animal manure being used for cooking and heating in households. It is considered as a renewable and carbon neutral energy resource, as long as replanting takes place, because it releases the same amount of CO_2 during combustion as captured during growth.[4] Modern biomass for energy use can be divided into five broad categories: wood from forestry or wood processing; agricultural crops grown specifically for energy applications; residues from agricultural harvesting or processing; food waste; industrial waste and by-products from manufacturing processes.[5]

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[1] European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – Energy roadmap 2050, COM(2011)885 final (15/12/2011)

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L2001

[3] Sustainable and optimal use of biomass for energy in the EU beyond 2020, Final Report, PricewaterhouseCoopers EU, Services EESV's consortium, May 2017, https://ec.europa.eu/energy/sites/ener/files/documents/biosustain_report_final.pdf

[4] Mertzis D., Mitsakis P., Tsiakmakis S., Manara P., Zabaniotou A., Samaras Z., Performance analysis of a small-scale combined heat and power system using agricultural biomass residues: The SMARt-CHP demonstration project, Energy 64 (2014) p. 367, https://doi.org/10.1016/j.energy.2013.11.055

[5] Bourguignon D., Biomass for electricity and heating - Opportunities and challenges, Briefing September 2015, | European Parliamentary Research Service, https://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568329/EPRS_BRI(2015)568329_EN.pdf

Biomass can be used to produce electricity, heat and fuels. In view of an effective and efficient utilization of the available resources, power generation should always be supplemented, whenever possible, by the production and recovery of the heat available at the exhaust, thus promoting Combined Heat and Power (CHP) generation systems rather than conventional power generation[6]. While the power plants generating electricity from biomass can achieve an efficiency up to 35%, the CHP power plants, meaning the simultaneously generation of multiple forms of energy (mechanical, thermal. etc.) can achieve an efficiency up to 90%.[7]

Nowadays, the most used (dominating) CHP system for biomass is combustion and steam turbine, while steam engine is a commercial alternative in the small-scale segment. Also, gas engines run on gas from landfills or anaerobic digestion are commercially available.[8] Another technological option is the use of biomass in Organic Rankine Cycle (ORC) plants, which featuring lower efficiencies.[9] Two alternative technologies involve the gasification and pyrolysis of biomass.[10]

There are several studies analyzing the technologies of application of biomass CHP developed in recent years suitable for small medium or large plants with respect to their optimal use. Indicatively the European Renewable Energy Council[11], Stresov and Evans [12] and Breeze[13] present biomass CHP technologies. Salomon et al[14] present a technology review for small-scale biomass CHP plants and bioenergy policies in Finland and Sweden. In their study Rajesh et al[15] carry out techno-economic evaluations of cost-effective small-scale applications of CHP for the Norwegian market which are based on biomass. They concluded that the most promising technologies are the steam turbine based CHPs in the foreseeable future and possibly gasification and boiler and steam turbine or gas engine, provided that there will be improvements ORC in the near term future and district heat backpressure turbine and gasification-GT in the medium term future. Abbas et al[16] presented the different cogeneration systems for isolated

[6] Bernotat K, Sandberg T. Biomass fired small-scale CHP in Sweden and the Baltic States: a case study on the potential of clustered dwellings. Biomass Bioenergy 2004;27:521e30, https://doi.org/10.1016/j.biombioe.2003.10.010

[7] Braimakis K., Magiri-Skouloudi D., Grimekis D., Karellas S., Energy-exergy analysis of ultra-supercritical biomass-fuelled steam power plants for industrial CHP, district heating and cooling, Renewable Energy Volume 154, July 2020, Pages 252-269, https://doi.org/10.1016/j.renene.2020.02.091

[8] Kempegowda R., Skreibergb O., Tran K., Techno-economic Evaluations of Various Biomass CHP Technologies and Policy Measures Under Norwegian Conditions, Energy Procedia Volume 20, 2012, Pages 1-10, https://doi.org/10.1016/j.egypro.2012.03.002

[9] Braimakis K., Thimo A., Karellas S., Technoeconomic Analysis and Comparison of a Solar-Based Biomass ORC-VCC System and a PV Heat Pump for Domestic Trigeneration, K. Braimakis, A. Thimo, S. Karellas, Technoeconomic analysis and comparison of a solar-based biomass ORC-VCC system and a PV heat pump for domestic trigene-ration, J. Energy Eng. 143 (2) (2017), 04016048, https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29EY.1943-7897.0000397

[10] Siwal S., Zhang O., Sun C., Thakur S., Gupta V., Thakur V., Energy production from steam gasification processes and parameters that contemplate in biomass gasifier – A review, Bioresource Technology Volume 297, February 2020, 122481, https://doi.org/10.1016/j.biortech.2019.122481

[11] European Renewable Energy Council . (2015). Renewable Energy in Europe Markets. Markets Trends and Technologies, Routledge

[12] Strezov, V., & Evans, T. J. (Eds.) (2015). Biomass processing technologies. Boca Raton: CRC Press, Taylor & Francis Group.

[13] Breeze, P. 2017, Combined Heat and Power, Elsevier –Academic Press, London.

[14] Salomón, M., Savola, T., Martin, A., Fogelholm, C.-J., Fransson, T.. (2011). Small-scale biomass CHP plants in Sweden and Finland. Renewable & Sustainable Energy Reviews - RENEW SUSTAIN ENERGY REV. 15. 10.1016/j.rser.2011.07.106.

[15] Rajesh S. Kempegowda, Øyvind Skreiberg, Khanh-Quang Tran (2012). Techno-economic evaluations of various biomass CHP technologies and policy measures under Norwegian conditions. Energy Procedia 20:1-10. doi: 10.1016/j.egypro.2012.03.002

[16] Abbas, T., Issa, M.and Ilinca, A. (2020) Biomass Cogeneration Technologies: A Review. Journal of Sustainable Bioenergy Systems , 10, 1-15. https://doi.org/10.4236/jsbs.2020.101001

communities. According to their conclusions steam cycle is suitable for energy production above 2000 KW. The steam turbines as a component of the system due to their high efficiency and because they are technologically sophisticated are appropriate for cogeneration plants. The ORC process has evolved significantly[17] and is suitable for medium power production from 200 to 2000 kW. Finally external combustion engines (such as stirling engine and Ericson engine) are used for micro CHP for residential use. Also in the report entitled "Catalogue of CHP Technologies" Darrow et al[18] review the technical and economic characterization of biomass resources, biomass preparation, energy conversion technologies, power production systems, and complete integrated CHP systems. In the Chapter Overview of CHP Technologies (pp 14-15) state that five technologies (reciprocating engine, gas turbine, boiler/steam turbine micro turbine and fuel cell) represented in 2014 the 97% of the CHP projects and 99 percent of the total installed CHP electric capacity in USA.

Furthermore, many researches examine the application of biomass CHP for supply with thermal energy the District Heating Networks (DHN) of many cities. Several studies present small scale innovative practices which were tested and transferred to upper levels of aggregation. Sartor and Dewallef[19] made an analysis based on simple models from thermodynamic combustion process, heat transfer and finance in order to provide evidence how can a retrofit of an existing system of a biomass CHP plant connected to a DHN be executed to optimize the heat storage volume and consequently the environmental, energetic and economic benefits. In their case study they selected as application framework the DHN of the University in Liège (Belgium). Noussan et al[20] applied a simulation model to a small DHN system in order to propose both design and operational system improvements. They studied the installation of a biomass-fired Organic Rankine Cycle (ORC) unit coupled to a Heat Storage System (HSS) in an existing DHN system located in Leini, a little town with 15.000 inhabitants near Turin. Prato et al[21] used as a test case a CHP-based district heating project in Northern Italy and focused they research on the development and integration of a code for dynamic simulation of heat distribution networks with a code for thermo-economics optimization of CHP systems, increasing the possibility of optimizing the matching between CHP plant and thermal users, through the exploitation of thermal storage capacity of the networks.

In energy production systems with renewables the literature review contains several indicators which influence the performance of biomass cogeneration plants.

[17] Quoilin, Sylvain & Van den Broek, Martijn & Declaye, Sé & Dewallef, Pierre & Lemort, Vincent. (2013). Techno-economic survey of Organic Rankine Cycle (ORC) systems. Renewable and Sustainable Energy Reviews , 22, 168-186. https://doi.org/10.1016/j.rser.2013.01.028

[18] Darrow, K. Tidball, R. Wang, . J. Hampson. A. (2017.) Catalog of CHP Technologies. U.S. Environmental Protection Agency Combined Heat and Power Partnership .

[19] Sartor, K.; Dewallef, P. Optimized Integration of Heat Storage Into District Heating Networks Fed By a Biomass CHP Plant. Energy Procedia 2017, 135, 317-326.

20 Noussan M., Abdin G. C., Poggio A., Roberto R. Biomass-fired CHP and heat storage system simulations in existing district heating systems. Applied Thermal Engineering 2014:71(2):729–735. doi:10.1016/j.applthermaleng.2013.11.021

[21] Prato A. P., Strobino F., Broccardo M., Giusino L. P. Integrated management of cogeneration plants and district heating networks. *Applied Energy* 2012:97:590–600. doi:10.1016/j.apenergy.2012.02.038

These include the costs of heat and power production[22], integrated management of cogeneration plants and district heating and efficiency [23], Internal Rate of Return (IRR) and Net Present Value (NPV) [24], energy evaluation[25,26,27]. *Exergy is defined as the maximal useful work obtained from a system while the system interacts with environment*[28]. Nowadays energy and exergy analyses are done also for biomass combined heat and power (CHP) plants.[29]

Several studies have analyzed the regulatory framework for biomass CHP in Europe. Sokolowski[30] examines European policies and legislation on CHP and more specifically how European Directives (First Electricity Directive (Directive 96/92/EC), Second Electricity Directive (Directive 2009/72/EC) influenced energy cogeneration and subsequently energy markets. He also presents the regime on public utilities' procurements with respect to production of electricity and heat (Directive 90/531/EEC and Directive 93/38/EEC) and the 1997 Strategy on CHP which had set the goal of 18% cogeneration in total gross electricity generation in 2010. He examines the CHP Directive in the light of energy market reform. Furthermore, he presents its regulatory tools and evaluates the overall European regulatory approach to CHP. With regard to the combined heat and power brought by the Clean Energy Package he analyzes the Energy Efficiency Directive (2012/27/EU) in its current version (as amended in 2018 and 2019 by the Regulation on the Energy Union Regulation (EU) 2018/1999) the Fourth Electricity Directive (Directive (EU) 2019/944) and the Third Electricity Regulation (Regulation (EU) 2019/943). Moreover he evaluates the legislation on renewables (Renewable Energy Directive from 2018- RED II, i.e. Directive (EU 2018/20010)) and the last revision of the EU ETS with their regulatory impact on combined heat and power. Cameron and Heffron[31] provide comprehensive coverage of the EU energy law in practice, evaluating the effectiveness of the Third Energy Package, the rise and importance of national and EU renewable energy measures in electricity markets.

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22 Taljan G., Verbič G., Pantoš M., Sakulin M., Fickert L. Optimal sizing of biomass-fired Organic Rankine Cycle CHP system with heat storage. Renewable Energy 2012:41:29–38. doi:10.1016/j.renene.2011.09.034 They present a novel methodology for Optimal Sizing of Biomass-Fired Organic Rankine Cycle (ORC) Combined Heat and Power (CHP) System with Heat Storage.

23 Prato A. P., Strobino F., Broccardo M., Giusino L. P. Integrated management of cogeneration plants and district heating networks. *Applied Energy* 2012:97:590–600. doi:10.1016/j.apenergy.2012.02.038

24 Noussan M., Abdin G. C., Poggio A., Roberto R. Biomass-fired CHP and heat storage system simulations in existing district heating systems. Applied Thermal Engineering 2014:71(2):729–735. doi:10.1016/j.applthermaleng.2013.11.021

25 Emergy analysis is an energy-based environmental accounting method that expresses all the process inputs (such as energy, natural resources, services) and outputs (products) in solar energy equivalents(25 Sha and Hurme,2012 :68)

26 Sha S., Hurme M. Emergy evaluation of combined heat and power plant processes. *Applied Thermal Engineering* 2012:43:67–74. doi:10.1016/j.applthermaleng.2011.11.063

27 Leduc S., Wetterlund E., Dotzauer E., Kindermann G. CHP or biofuel production in Europe? *Energy Procedia* 2012:20:40–49. doi:10.1016/j.egypro.2012.03.006

28 .Cao,K. & . Feng, X. The emergy analysis of multiproduct systems, Process Saf. Environ. Prot. 85 (2007) 494e500.

29 Park, S. R., Pandey, A. K., Tyagi, V. V., & Tyagi, S. K. (2014). Energy and exergy analysis of typical renewable energy systems. Renewable and Sustainable EnergyReviews30(2014)105–123

30 Sokołowski, M.. (2020). European Law on Combined Heat and Power. 10 Routledge.

31 Cameron, P.D., & Heffron, R.J. (eds) 2016, Legal aspects of EU energy regulation: the consolidation of energy law across Europe, 2nd edn, Oxford University Press, Oxford.

Talus[32] presents a critical overview of the European Union energy law and policy including biomass from 1950 till 2013.

Another group of studies address the policy framework for biomass in Europe. Many of them present the measures provided for by European countries' legislature with a view to provide with incentives for electricity cogeneration with biomass and focus on countries with high performance in CHP based on biomass. Other refer to energy policies of specific European countries. Eight member states are tagged as big CHP players (Finland, France, Germany, Italy, the Netherlands, Poland, Spain and the United Kingdom). Ten countries are considered medium (Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Hungary, Portugal, Romania, Slovakia, and Sweden) and another ten are labeled as small (Croatia, Cyprus, Estonia, Greece, Ireland, Latvia, Lithuania, Luxembourg, Malta and Slovenia). Sokolowski (2020) presents the regulatory framework with policies, tools and measures on cogeneration. Banja et al[33] present the support framework for biomass for energy based on reports from EU countries reports under RED and existing literature. Other studies focus on national policies and frameworks. More specifically for Greece there aren't many studies. Recently Gkonis et al[34] proposed a policy model for supporting the Greek National Energy and Climate Plan (NECP) which provides incentives inter alia for CHP in compliance with the draft or the Greek NECP for 2030, which was submitted to the EC (Greek Ministry of Environment and Energy, 2019). In the light of Greece's financial limitations they support the idea of mobilization of private funding through the use of appropriate financial mechanisms in order to achieve cost effective design towards the achievement of E.E. targets[35]. In view of the experience of Germany in renewables and especially in biomass in Scheftelowitz et al[36] are presented the lessons learned from the development of power provision from biomass. Under EEG (German: Erneuerbare-Energien-Gesetz) which was amended several times are analyzed power provision data from biomass sources between 2007 and 2015. Apart from individual studies, various international organisations monitor environmental policies of their members. Indicatively the European Environment Agency (EEA)[37] in close collaboration with the European Environmental Information and Observation Network (EIONET) and its 32 Member States (under Article 4 and Article 22 of the Directive 2009/28/EC) are submitted on a data portal. Also the IEA's Policies and Measures Database provides reports on past, existing or planned government policies and measures to reduce greenhouse gas

[32] Talus, K. 2013, EU energy law and policy: a critical account, Oxford University Press, Oxford.

[33] Banja, Manjola & Sikkema, Richard & Jegard, Martin & Motola, Vincenzo & Dallemand, Jean-François. (2019). Biomass for energy in the EU -The support framework. Energy Policy. 131. 215-228. 10.1016/j.enpol.2019.04.038.

[34] Gkonis, Nikolaos & Arsenopoulos, Apostolos & Stamatiou, Athina & Doukas, H.. (2020). Multi-perspective design of energy efficiency policies under the framework of national energy and climate action plans. Energy Policy. 140. 111401. 10.1016/j.enpol.2020.111401.

[35] Greek Ministry of Environment and Energy, 2019. National Energy and Climate Plan.

[36] Scheftelowitz, M., Becker, R., Thrän, D.. (2018). Improved power provision from biomass: A retrospective on the impacts of German energy policy. Biomass and Bioenergy. 111. 1-12. 10.1016/j.biombioe.2018.01.010.

[37] https://www.eea.europa.eu/el

emissions, improve energy efficiency and support the development and deployment of renewables and biomass[38].

Taking all the above into consideration, it derives that although studies on the thermodynamic and economical assessment of biomass CHP plants and the respective regulatory framework for many European countries are wide spread in literature, the respective analysis for Greece is very limited. Moreover, the penetration of biomass for CHP in Greece is also very limited and the installed capacity of the relative plants is significantly low. Furthermore, in the cities of Kozani, Ptolemais, Amynteon and Megalopolis are operating District Heating Networks (DHN), which are supplied with thermal energy from lignite fired power plants that will be phased out in the next years.

Therefore, there is a need to examine the regulating framework and the applicable technology for the installation of biomass CHP plants that will supply with thermal energy the local DHN mainly of cities located in north Greece, where the climate is colder. More specifically in this study will be examined the installation of a biomass CHP plant in the city of Amynteon, which will supply with thermal energy the DHN of the city and an extensive techno-economic assessment will be executed. Furthermore, an optimization study for maximizing the Internal Rate of Return (IRR) of the CHP plant's investment by installing a Thermal Energy Storage (TES) system in parallel with the CHP plant will be performed.

1.3 Outline

The thesis is structured in five different chapters. More specifically, in Chapter 2 is presented the regulation and the policy framework for biomass and CHP by utilizing biomass in Europe and Greece. At first, is presented the policy framework for biomass and CHP in European Union. Afterwards, is analyzed the legal regime of European Union for biomass and cogeneration from it. Finally, is studied the Greek Legal Regime for biomass and Cogeneration of Heat and Power.

In Chapter 3 is described the definition of biomass according to respective EU's regulation and explained why biomass is considered as Carbon Dioxide (CO_2) neutral. Then are analyzed the main Biomass to Energy Conversion Technologies and more specifically the Thermochemical Technologies, which are convenient for CHP. Afterwards, are described the main advantages and disadvantages of biomass. Finally, are presented the CHP for biomass applications and examples of application of this technology worldwide.

In Chapter 4 is analyzed the application of a CHP plant burning biomass which will feed with district heating power the city of Amynteon in West Macedonia. At the beginning is described the existing District Heating Network (DHN) of city of Amynteon. Then, is analyzed the energy study of the CHP power plant. Afterwards, an extended techno-economic assessment for this project is presented. Furthermore an economic assessment including sensitivity analysis, future retrofits and the main threats

[38] https://www.iea.org/policies

for the project are analyzed. Finally, an optimization study concerning the installation of a TES system is executed.

In Chapter 5 is made a general assessment of the research done and are presented the final conclusions. Moreover, suggestions for further research and improvement on the topic are presented.

Chapter 2: Biomass Policies and Regulatory Framework in Europe and Greece

2.1 Introduction

Many developed and developing countries have established regulatory frameworks for biomass and have provided different kinds of subsidies and incentives to support biomass production and the generation of electricity by biomass. This various policy mix globally has indisputably contributed to the development of infrastructure and technologies, successfully increasing the biomass use for electricity generation on a worldwide scale. More specifically, by 2017 biomass installed capacity in the EU almost three-folded in comparison with the 2005 figure, reaching 32 GW. This comprises a share of 7.7% in the total renewable electricity installed capacity.[39] In this chapter will be analyzed the policy and regulatory framework of biomass and CHP in Europe and Greece.

2.2 Policy

Increasing scientific and political concerns about climate change due to inter alia greenhouse gas emissions have sparked the interest for increased use of renewable energy[40]. In order to counteract the growing import dependence and to reduce the carbon dioxide of the energy production the energy agenda of the EU includes common policies and action plans on renewable energy resources, as well as monitoring processes of their implementation[41,42]. Electricity generation from RES through regulated markets is considered as a major strategic tool/policy to reduce carbon emissions, driven by regulation in the European Union (EU), which is a significant challenge for tackling climate change.

Biomass as a power source could play a significant role in the future energy mix and help EU to achieve the renewable energy targets. Electricity generation from biomass is an attractive low-carbon alternative option, uniquely qualified to meet European Unions' objectives for production of renewable electricity. For this reason, European countries are adapting support schemes for increasing the production of energy from RES.

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[39] Banjaa M., Sikkemab R., Jégarda M., Motolac V., Dallemand J., Banjaa M., Biomass for energy in the EU – The support framework, Energy Policy, Volume 131, August 2019, Pages 215-228, p. 217, https://doi.org/10.1016/j.enpol.2019.04.038

[40] Söderberg, C., & Eckerberg K., (2013). Rising policy conflicts in Europe over bioenergy and forestry. For Policy Econ. 33:112–119. doi: 10.1016/j.forpol.2012.09.015

[41] De Besi M, McCormick K. (2015).Towards a bioeconomy in Europe: national, regional and industrial strategies. Sustainability. 7(8):10461–10478. doi: 10.3390/su70810461

[42] Johansson J. (2018). Collaborative governance for sustainable forestry in the emerging bio-based economy in Europe. Curr Opin Environ Sustain. 32:9–16. doi: 10.1016/j.cosust.2018.01.009

2.2.1 Facts and figures on bioenergy in the EU

Bioenergy (the energy produced by biomass - DIRECTIVE (EU) 2018/2001) is the main source of renewable energy (59,2% in 2016) in the EU and plays a significant role in achieving the 2030 and beyond targets for sustainable development. Bioenergy not only contributes to renewable energy but also to the EU's energy security, as 96% of bioenergy feedstock is produced within the EU. Most of this comes from forestry. Based on 2016 data, Germany, France, Italy, Sweden and the UK are the five largest bioenergy consumers within the EU-28. However, the Scandinavian and Baltic countries and Austria consume the most bioenergy per capita. In figure 2.1[43] is illustrated the share of renewables in the EU's gross final energy consumption for 2016 and breakdown of the bioenergy contribution.[44]

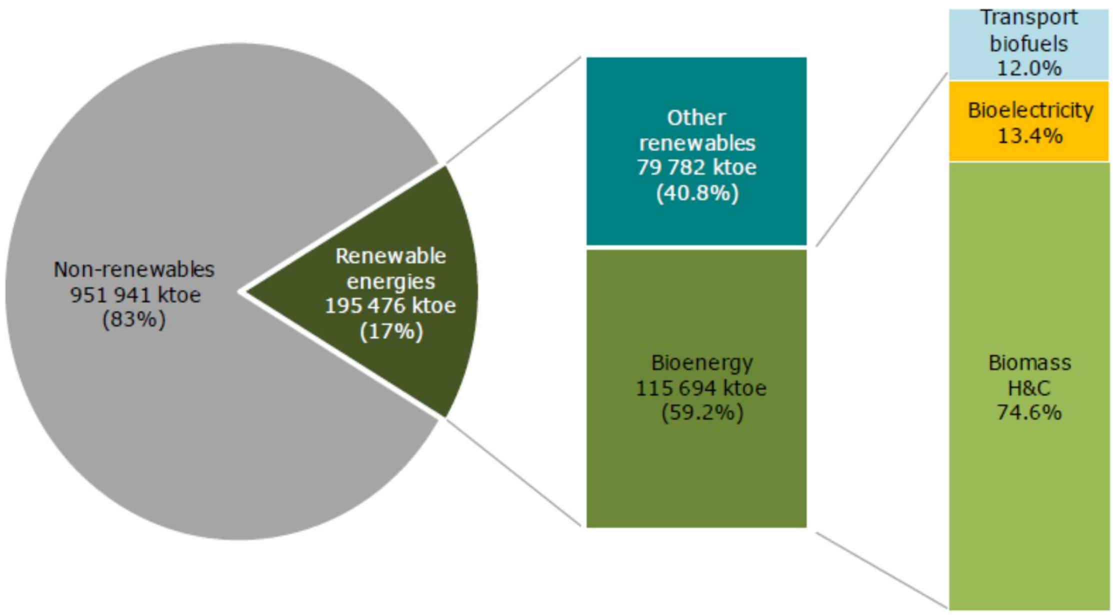

Figure 2.1 Share of renewables in the EU's gross final energy consumption for 2016 and breakdown of the bioenergy contribution

The Commission's long-term vision for a prosperous, modern, competitive and climate-neutral economy estimates that, by 2050, the gross inland consumption of bioenergy will amount to between 170 and 252 Mtoe (depending on the scenario). Figure 2.2[45] combines the 2005-2016 reported data for bioenergy and projections of bioenergy consumption, based on eight scenarios for mitigation options.

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[43] Data from the National Renewable Energy Action Plans (NREAPs) and Progress Reports from Member States (under Article 4 and Article 22 of the Directive 2009/28/EC), as well as from Eurostat energy statistics (2018a, 2018b)

[44] Brief on Biomass for Energy in the E.U., The European Commission's knowledge Centre for Bioeconomy 2019, https://publications.jrc.ec.europa.eu/repository/bitstream/JRC109354/biomass_4_energy_brief_online_1.pdf

[45] IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773, A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

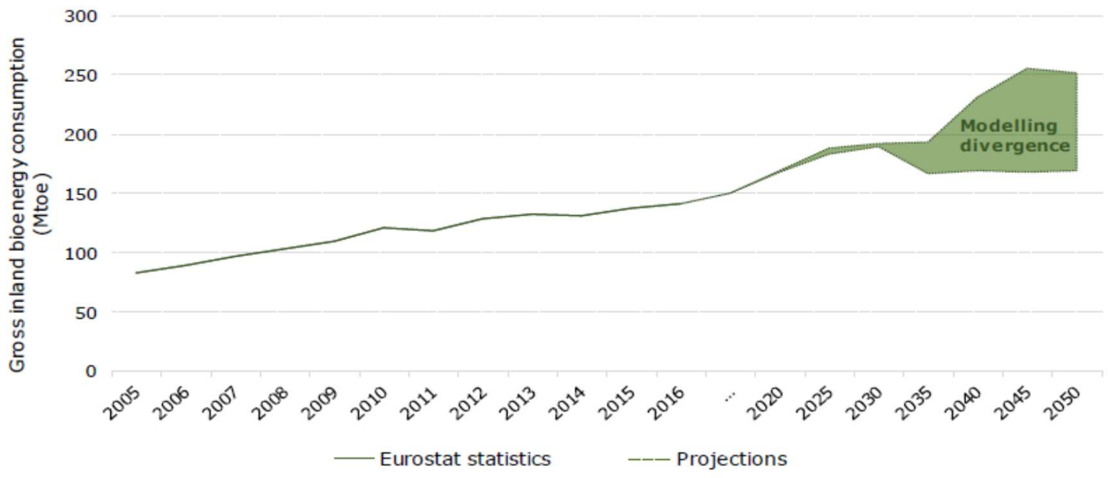

Figure 2.2 Gross inland bioenergy consumption during the period 2005-2016 and projections until 2050 based on mitigation scenarios

2.2.2 Types of support schemes to promote renewable energy in the EU

Support schemes on the promotion of renewables are intended to cover the gap between costs of energy (electricity or heat) and revenues.[46] Different approaches have been used to classify support schemes on the promotion of renewables. The support schemes can be: (i) regulatory (either focused on investments or generation); (ii) direct (either focused on investment or generation); (iii) indirect (environmental taxes); and (iv) voluntary (green tariffs, agreements, contribution to shareholder programs). The most common categorization of support schemes is the one that distinguishes between (i) price-based and (ii) quantity-based. The main support schemes for the promotion of renewable energy are feed-in tariff (FIT), feed-in premium (FIP), Quota (tradable green certificates) and Tender/Auctions.[47]

More than one-fourth of the support measures for renewables in the EU were dedicated to biomass in three sectors (electricity, heating/cooling and transport). Financial measures accounted for more than 60% of these measures; the rest was regulatory and soft measures. FIT and FIP are the main support schemes for biomass in the electricity sector. On the other hand, as concerns the biomass use in the heating/cooling sector, subsidy is the main type of support. Overall, the Netherlands leads with 60 incentives for biomass in electricity and heating/cooling sectors followed by the Czech Republic (45), Greece (41), Germany (32) and Lithuania(32). [48] The main

[46] Banjaa M., Sikkemab R., Jégarda M., Motolac V., Dallemanda J., Biomass for energy in the EU – The support framework, Energy Policy Volume 131, August 2019, Page 218, https://doi.org/10.1016/j.enpol.2019.04.038

[47] Banja, M., Jegard, M., Monforti-Ferrario, F., Dallemand, J., Taylor, N., Motola, V., Sikkema, R., 2017b. Renewable energy in the EU: an overview of support schemes and measures. In: Joint Research Centre, EC, Energy Efficiencies and Renewables. Directorate C. Publication Office of the European Union Retrieved from. https://publications.europa.eu/en/publication-detail/-/publication/83d9ab2f-647d-11e8-ab9c-01aa75ed71a1/language-en.

[48] Banjaa M., Sikkemab R., Jégarda M., Motolac V., Dallemanda J., Biomass for energy in the EU – The support framework, Energy Policy Volume 131, August 2019, Page 220, https://doi.org/10.1016/j.enpol.2019.04.038

support schemes that are used in Greece for use of biomass in electricity and heating/cooling sector are FIT and subsidy, respectively.

2.3 Introduction to EU regulatory framework

The section aims at giving an overview of the European Union legal regime on renewable energy sources (RES). More precisely, it focuses on biomass,[49] which is called "*the sleeping giant*". [50] Not only does biomass have numerous advantages over conventional energy sources, but it is also far more preferable than other renewable energy sources, due to its relatively low costs, less dependence on short-term weather changes and lower carbon footprint. Furthermore, it promotes regional economic structures and guarantees farmers alternative income sources. Despite its enormous potential, however, biomass has not been fully exploited yet. It is worth mentioning that the growth in bioenergy in the European Union over the period 2005–2017 was mainly attributed to biogas[51] rather than solid biomass. Currently, an ever-increasing number of EU Member States are establishing mechanisms to support the deployment of biomass through capacity markets. Since biomass tends to become central pillar of the European Union's energy policy, the latter has set up a number of rules - both hard and soft law - in order to provide the supporting legal framework for the promotion of biomass and become a global leader in the field of renewable energy sources.

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[49] For further details on biomass see: N. Scarlat, J.-F. Dallemand, F. Monforti-Ferrario and V. Nita 'The role of biomass and bioenergy in a future bioeconomy: policies and facts' (2015) 15 *Environmental Development* 3. M. Banjaa, R. Sikkemab, M. Jégarda, V. Motolac and J.-Fr. Dallemanda 'Biomass for energy in the EU – The support framework' (2019) 131 *Energy Policy* 215. S. Gerssen-Gondelach, D. Saygin, B. Wicke, M. Patel and A. Faaij 'Competing uses of biomass: assessment and comparison of the performance of bio-based heat, power, fuels and materials' (2014) 40 *Renewable Sustainable Energy Reviews* 964. R. Sikkema, J.-Fr. Dallemand, C. Matos, M. Van der Velde and J. San Miguel-Ayanz 'How can the ambitious goals for the EU's future bioeconomy be supported by sustainable and efficient wood sourcing practices?' (2017) 32 [7] *Scandinavian Journal of Forest Research* 551. N. Scarlat, J.-Fr. Dallemand, F. Monforti-Ferrario, M. Banja and V. Motola 'Renewable energy policy framework and bioenergy contribution in the European Union – An overview from National Renewable Energy Action Plans and Progress Reports' (2015) 51 *Renewable and Sustainable Energy Reviews* 969. The European Commission's Knowledge Centre for Bio-economy Brief on biomass for energy in the European Union Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC109354/biomass_4_energy_brief_online_1.pdff (accessed 22.4.2020). IEA Bioenergy, IRENA and FAO Bioenergy for Sustainable Development Available at: https://www.ieabioenergy.com/wp-content/uploads/2017/01/BIOENERGY-AND-SUSTAINABLE-DEVELOPMENT-final-20170215.pdf (accessed 22.4.2020). European Commission Biomass Available at: https://ec.europa.eu/energy/topics/property-fieldtopicparent/biomass_en, Bio-economy policy Available at: https://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=strategy, Updated Bioeconomy Strategy 2018 Available at: https://ec.europa.eu/knowledge4policy/publication/updated-bioeconomy-strategy-2018_en (accessed 22.4.2020). European Industrial Bioenergy Initiative (EIBI) Available at: https://setis.ec.europa.eu/implementation/eii/eii-dedicated-sections/bio-eii (accessed 22.4.2020). WikiBiomass Bioenergy-related policy Available at: https://www.eubia.org/cms/wiki-biomass/policy/ (accessed 22.4.2020).

[50] European Parliament resolution on the share of renewable energy in the EU and proposals for concrete actions (OJ C 227 E, 21.9.2006, p. 599–608).

[51] M. Banjaa, M. Jégardb, V. Motolac and R. Sikkemad 'Support for biogas in the EU electricity sector – A comparative analysis' (2019) 128 *Biomass and Bioenergy* 105313. https://doi.org/10.1016/j.biombioe.2019.105313

2.3.1 The European Union Legal Regime

The first[52] and second[53] European Union energy packages focused primarily on liberalization and energy market structure and did not include detailed provisions related to biomass.

The Directive 2001/77/EC made explicit reference to the biomass as a renewable energy source, and included, for the first time, the following definition: "*[b]iomass is the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste*". It was clarified however, that the aforementioned definition did not prejudge the use of a different definition in national legislation, for purposes other than those set out in the Directive in question.

2.3.2 Directive 2009/28/EC (RED-I)

The promotion of biomass culminated in 2009, when Directive 2009/28/EC[54] (RED-I) was published pursuant to article 194[55] of the Treaty on the Functioning of the European Union,[56] which lays the specific legal basis for the field of energy, based on shared competences between the European Union and the Member States. More specifically, the aforementioned Directive provides that "*each Member State shall adopt a national renewable energy action plan setting national targets for the share of energy from renewable sources consumed in transport, electricity, heating and cooling in 2020, taking into*

[52] Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity (OJ L 27, 30.1.1997, p. 20–29).

[53] Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC (EE L 176, 15.7.2003, p. 37-56). It is no longer in force, since Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity repealed Directive 2003/54/EC (EE L 211, 14.8.2009, p. 55-93).

[54] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (EE L 140/5.6.2009, p. 16-62).

[55] "*1. In the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, Union policy on energy shall aim, in a spirit of solidarity between Member States, to: (a) ensure the functioning of the energy market; (b) ensure security of energy supply in the Union; (c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and (d) promote the interconnection of energy networks.*" Such measures however, do not adversely affect Member States' sovereign right to exploit their own resources and power to decide their energy policy and their national energy mix, since "indigenous energy resources are a national, not European, resource". Report of the International Energy Agency (IEA) Available at: https://www.iea.org/reports/world-energy-outlook-2008 (accessed 22.4.2020). Furthermore, Article 194 par 2 (c) provides that, by way of derogation from the decision-making procedure provided for in paragraph 1 and without prejudice to Article 114, any matter relating to the disposition in question shall be unanimously adopted. On the contrary, the European Parliament and the Council shall decide what action is to be taken by the European Union in order to achieve the environmental policy by a qualified majority. L. Hancher and F.-M. Salerno 'Energy Policy After Lisbon' in A. Biondi, P. Eeckhout and St. Ripley (eds), *European Union Law after Lisbon* (Oxford University Press 2012).

[56] Consolidated version of the Treaty on the Functioning of the European Union (OJ C 326, 26.10.2012, p. 47–390).

account the effects of other policy measures relating to energy efficiency on final consumption of energy, and adequate measures shall be taken to achieve those national overall targets, including cooperation between local, regional and national authorities, planned statistical transfers or joint projects and national policies to exploit the full potential of biomass".

In respect to biomass, greater mobilization of existing timber reserves should be promoted and new forestry systems should be developed. For this reason, national sectoral 2020 targets[57] and estimated shares of energy from renewable sources in electricity, transport, heating and cooling shall include measures on the promotion of the use of energy from biomass, taking into account: "*(i) biomass availability - both domestic potential and imports - and (ii) measures to increase biomass availability, taking into account other biomass users (agriculture and forest-based sectors)*".

The European Commission has a pivotal role to play in promoting biomass. To start with, it should "*review the possible inclusion of other biomass applications and modalities relating thereto*" and should analyze "*the requirements for a sustainability scheme for energy uses of biomass, other than bioliquids and biofuels, taking into account the need for biomass resources to be managed in a sustainable manner*". "*That report shall be accompanied, where appropriate, by proposals for a sustainability scheme for other energy uses of biomass, to the European Parliament and the Council*". "*If the analysis done for that purpose demonstrates that it would be appropriate to introduce amendments, in relation to forest biomass, in the calculation methodology in Annex V or in the sustainability criteria relating to carbon stocks applied to biofuels and bioliquids, the Commission shall, where appropriate, make proposals to the European Parliament and the Council at the same time in this regard*". "*The Commission may also decide that voluntary national or international schemes setting standards for the production of biomass products contain accurate data for the purposes of Article 17 par 2 or demonstrate that consignments of biofuel comply with the sustainability criteria set out in Article 17 par 3 to 5*". For this reason, "*each Member State shall submit a report to the Commission on progress in the promotion and use of energy from renewable sources by 31 December 2011 and every two years thereafter. The sixth report, to be submitted by 31 December 2021, shall be the last report required*". The report shall detail, inter alia, developments in the availability and use of biomass resources for energy purposes and changes in commodity prices and land use within the Member State associated with its increased use of biomass and other forms of energy from renewable sources. "*The Commission should also monitor the commodity price changes associated with the use of biomass for energy and any associated positive and negative effects on food security, as well as all installations to which Article 19 par 6 applies*". Moreover, it shall analyze in its reports, "*the impact of increased demand for biomass on biomass using sectors*". In addition to that, "*it is appropriate to monitor the impact of biomass cultivation, such as through land-use changes, including displacement, the introduction of invasive alien species and other effects on biodiversity and effects on food production and local prosperity*". In this context, "*the Commission should consider all relevant sources of information, including the FAO hunger map*".

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[57] Available at: https://ec.europa.eu/clima/policies/strategies/2020_en (accessed 22.4.2020).

For their part, “*Member States shall promote conversion technologies that achieve a conversion efficiency of at least 85 % for residential and commercial applications and at least 70 % for industrial applications*”. They shall also “*ensure that certification schemes or equivalent qualification schemes become or are available by 31 December 2012 for installers of small-scale biomass boilers and stoves*”. Where relevant, “*they shall take steps with a view to developing a district heating infrastructure to accommodate the development of heating and cooling production from large biomass, solar and geothermal facilities*”. Directive 2009/28/EC on the promotion of the use of energy from renewable sources has been partially amended by Directive (EU) 2015/1513.[58]

2.3.3 Directive (EU) 2018/2001 (RED-II)

RED-I has already set a binding target of at least a 20% share of energy from renewable sources in the gross final energy consumption in the European Union by 2020. However, mandatory sustainability and greenhouse gas (GHG) emissions saving criteria have been set only for biofuels, whilst with regard to solid (mostly forest) and gaseous (mostly agricultural) biomass, only recommendations were issued by the European Commission,[59] which in fact, were not even uniformly implemented in the Member States. For this reason, in November 2016, the European Commission published its “*Clean Energy for all Europeans*”[60] initiative. As substantial part of this package,[61] the Commission adopted a legislative proposal[62] for a recast of the Renewable Energy Directive. Directive (EU) 2018/2001[63] (RED-II) entered into force on 24 December 2018, Member States have to transpose it into national law by 30 June 2021 and it shall be applied from 1 July 2021 onwards.[64]

The aforementioned Directive promotes the growth of the share of renewable energy sources in the total amount of energy consumed in the European Union by 2030 and includes a binding renewable energy target of 32%, an indicative annual increase of

[58] Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (OJ L 239, 15.9.2015, p. 1–29).

[59] Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling SEC(2010) 65 final SEC(2010) 66 final (/* COM/2010/0011 final */).

[60] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank - Clean Energy for all Europeans (COM/2016/0860 final).

[61] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank - A Framework Strategy for a resilient Energy Union with a forward - looking Climate Change Policy (Brussels, 25.2.2015 COM(2015) 80 final).

[62] Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast) [COM/2016/0767 final - 2016/0382 (COD)].

[63] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (OJ L 328, 21.12.2018, p. 82–209).

[64] In the context of the co-decision procedure, a general approach was approved by the Council of the European Union on 18 December 2017, whilst the European Parliament's plenary session backed a negotiating position on 17 January 2018. Trilogue negotiations were launched in February and an informal agreement between the institutions was reached on 14 June 2018.

1.3% and an upwards revision clause by 2023. The rules serve to create an enabling environment to accelerate public and private investment in innovation and modernization in the field of renewable energy sources, strengthen consumer rights to renewable energy self-consumption and promote energy communities and district heating. They also seek to enhance mechanisms for cross-border cooperation, simplify administrative processes, provide guiding principles on financial support schemes for renewable energy sources and mainstream the use of the sources in question in the transport and in the heating and cooling sector, whereas the "*energy efficiency first*" principle is to become a guiding one.

The most important however, is that Directive RED II includes, for the first time, updated and mandatory sustainability and GHG emissions saving criteria for both biofuels used in transport and bioliquids, and solid and gaseous biomass fuels used for heat and power. The sustainability criteria address environmental aspects, such as soil quality, land use and biodiversity, whereas the GHG emissions saving criteria ensure that bioenergy is used only if it achieves high emission savings compared to fossil fuels. It is also worth mentioning that both criteria apply irrespective of the origin of biomass, so also when imported from non-EU countries. Only electricity produced from biomass, which is compliant with the sustainability and GHG emissions saving criteria and is generated in biomass power plants meeting specific criteria, counts as national contribution to the European Union's overall target and may be eligible for financial support under a support scheme.

More specifically, biomass must reflect at least 70% GHG savings (for installations starting operation from 2021 till 2025) and at least 80% (from 2026 onwards) compared to fossil fuel-based electricity generation. On the other hand, in order to minimize the administrative burden, the sustainability and GHG emissions saving criteria apply only to solid biomass and gaseous biomass fuels used in biomass power plants with a rated thermal input ≥ 20 MW and 0.5MW respectively. Bioenergy from non-agricultural waste and residues needs to fulfill only GHG emissions saving criteria. Default GHG emission values and calculation rules are provided in Annex VI of Directive (EU) 2018/2001. The Commission can revise and update the default GHG emission values when technological developments render it necessary. Member States are allowed to set a lower threshold or to impose additional sustainability criteria, whereas economic operators have the option to either use default GHG intensity values provided in RED II or to calculate actual values for their pathway. Moreover, "*Member States shall ensure that certification schemes or equivalent qualification schemes are available for installers of small-scale biomass boilers and stoves*". The aforementioned "*schemes may take into account existing schemes and structures as appropriate and shall be based on the criteria laid down in Annex IV*". Certifications awarded shall be recognized "*by other Member States in accordance with those criteria*". Finally, the use of biomass from food and feed crops, for which there is a high indirect land-use change risk, will be phased out gradually by 2030 for the calculation of a Member State's gross overall consumption of renewable energy. "*Indirect land-use change occurs when the cultivation of crops for biofuels, bioliquids and biomass fuels displaces traditional production of crops for food and feed purposes*" and as such may "*lead to the extension of agricultural land into areas with high-carbon stock*" causing additional GHG emissions.

2.3.4 Other non-binding legal instruments

Equally important to the aforementioned Directives have been numerous non-binding legal instruments, which are listed non-exhaustively below:

1. In the context of the European Commission
   - Communication from the Commission - Energy for the future: renewable sources of energy - Green Paper for a Community Strategy.[65]
   - Communication from the Commission - Energy for the future: renewable sources of energy - White Paper for a Community Strategy and Action Plan.[66]
   - Communication from the Commission - Biomass Action Plan.[67]
   - Communication from the Commission to the Council and the European Parliament - An Energy Policy for Europe.[68]
   - Commission Decision establishing a template for National Renewable Energy Action Plans under Directive 2009/28/EC.[69]
   - Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling.[70]
   - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A Roadmap for moving to a competitive low carbon economy in 2050.[71]
   - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Energy Roadmap 2050.[72]
   - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Innovating for sustainable Growth: A Bioeconomy for Europe.[73]
   - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Renewable Energy: a major player in the European energy market.[74]

[65] Brussels, 20.11.1996 COM(96) 576 final.
[66] COM(97)599 final.
[67] {SEC(2005) 1573}/* COM/2005/0628 final */.
[68] {SEC(2007) 12}/* COM/2007/0001 final */.
[69] OJ L 182, 15.7.2009, p. 33–62.
[70] {SEC(2010) 65 final SEC(2010) 66 final}/* COM/2010/0011 final */.
[71] /* COM/2011/0112 final */.
[72] /* COM/2011/0885 final */.
[73] Brussels, 13.2.2012 SWD(2012) 60 final.
[74] /* COM/2012/0271 final */.

- Communication from the Commission - A new EU Forest Strategy: for forests and the forest-based sector.[75]
- Communication from the Commission - Delivering the internal electricity market and making the most of public intervention.[76]
- Staff working document European Commission - Guidance for the design of renewables support schemes accompanying the document "Communication from the Commission - Delivering the internal market in electricity and making the most of public intervention".[77]
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A policy framework for climate and energy in the period from 2020 to 2030.[78]
- Communication from the Commission — Guidelines on State aid for environmental protection and energy 2014-2020.[79]
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank - A Framework Strategy for a resilient Energy Union with a forward - looking Climate Change Policy.[80]
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank - Clean Energy for all Europeans.[81]
- Clean Energy for all Europeans – Unlocking Europe's growth potential.[82]
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank - Third Report on the State of the Energy Union.[83]
- In-depth analysis in support on the COM(2018) 773: A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.[84]
- One step closer towards fulfilling the Energy Union: Commission welcomes Parliament Committee votes on Clean Energy Package.[85]

[75] /* COM/2013/0659 final */.
[76] Brussels, 5.11.2013 C(2013) 7243 final.
[77] Brussels, 5.11.2013 SWD(2013) 439 final.
[78] /* COM/2014/015 final */.
[79] OJ C 200, 28.6.2014, p. 1–55.
[80] Brussels, 25.2.2015 COM(2015) 80 final.
[81] COM/2016/0860 final.
[82] Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_16_4009 (accessed 22.4.2020).
[83] Brussels, 23.11.2017 COM(2017) 688 final.
[84] Available at: https://ec.europa.eu/knowledge4policy/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en (accessed 22.4.2020).
[85] Available at: https://ec.europa.eu/info/news/one-step-closer-towards-fulfilling-energy-union-commission-welcomes-parliament-committee-votes-clean-energy-package-2018-jul-10_en (accessed 22.4.2020).

2. In the context of the European Parliament
- European Parliament resolution on the share of renewable energy in the EU and proposals for concrete actions.[86]
- European Parliament resolution on heating and cooling from renewable sources of energy.[87]
- European Parliament resolution on a strategy for biomass and biofuels.[88]
- European Parliament resolution on the Road Map for Renewable Energy in Europe.[89]
- Parliament resolution on towards a new Energy Strategy for Europe 2011-2020.[90]
- European Parliament resolution on energy infrastructure priorities for 2020 and beyond.[91]
- European Parliament resolution on innovating for sustainable growth: a bio-economy for Europe.[92]
- European Parliament resolution on a 2030 framework for climate and energy policies.[93]
- European Parliament resolution on the renewable energy progress report.[94]
- European Parliamentary Research Service – Briefing: EU sustainability criteria for bioenergy.[95]

[86] OJ C 227 E, 21.9.2006, p. 599–608.
[87] OJ C 290 E, 29.11.2006, p. 115.
[88] OJ C 317 E, 23.12.2006, p. 890.
[89] OJ C 219 E, 28.8.2008, p. 82.
[90] OJ C 99 E, 3.4.2012, p. 64.
[91] OJ C 33 E, 5.2.2013, p. 46.
[92] OJ C 75, 26.2.2016, p. 41–46.
[93] OJ C 93, 24.3.2017, p. 79–102.
[94] OJ C 91, 9.3.2018, p. 16.
[95] Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2017/608660/EPRS_BRI(2017)608660_EN.pdf (accessed 22.4.2020).

2.3.5 The European Union Legal Regime on Cogeneration of Heat and Power[96]

The European Union has taken ambitious energy and climate policy objectives to reduce greenhouse gas emissions by 20%, to increase the share of renewable energies to 20% and to save 20% of energy by the year 2020. European Union's Energy Policy aims to promote security of supply, sustainable development and competitiveness. Cogeneration of Heat and Power can play a crucial role in fulfilling the aforementioned policy objectives, since it can contribute to energy security, sustainable energy, a better environment and can combat climate change. In addition, cogeneration constitutes European technology know-how with growing export possibilities, promoting European competitiveness and offering opportunities for economic development, both locally and internationally. The European Commission has put forward numerous arguments in favour of cogeneration, including that cogeneration plants are less vulnerable to terrorism than central power plants, as they are smaller, and an eventual attack will have less impacts. It is the hope of the Commission and of many others that the legal regime can promote the use and development of cogeneration in the European Union, where the widespread use of district heating constitutes a stable foundation for cogeneration. For these reasons, a specific legal framework recognizing the benefits of cogeneration has been introduced, based on common definitions and methodologies

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[96] M. Sokołowski, *European Law on Combined Heat and Power* (Routledge 2020). C. Frangopoulos, *Cogeneration – Technologies, Optimisation and Implementation* (The Institution of Engineering and Technology 2017). M. Gambini and M. Vellini 'High Efficiency Cogeneration: Electricity from Cogeneration in CHP Plants' (2015) 81 *Energy Procedia* 430. V. Havelský 'Energetic efficiency of cogeneration systems for combined heat, cold and power production' (1999) 22 *International Journal Refrigeration* 479. M. Kanoglu and I. Dincer 'Performance assessment of cogeneration plants' (2009) 50 *Energy Conversation and Management* 76. D. Gvozdenac, B. Uroševic´ Gvozdenac, C. Menke, D. Uroševic´ and A. Bangviwat 'High-efficiency cogeneration: CHP and non-CHP energy' (2017) 135 *Energy* 269. D. Uroševic´, D. Gvozdenac and V. Grkovic´ 'Calculation of the power loss coefficient of steam turbine as a part of the cogeneration plant' (2013) 59 *Energy* 642. J. Wang, Y. Dai and L. Gao 'Energy analyses and parametric optimisations for different cogeneration power plants in cement industry' (2009) 86 *Applied Energy* 941. M. Gambini and M. Vellini 'On Selection and Optimal Design of Cogeneration Units in the Industrial Sector' (2019) 7 *Journal of Sustainable Development of Energy, Water and Environment Systems* 168. M. Gambini and M. Vellini 'High Efficiency Cogeneration: Performance Assessment of Industrial Cogeneration Power Plants' (2014) 45 *Energy Procedia* 1255. F.-W. Payne 'Cogeneration/CHP in Industry' (2002) 18 [3] *Cogeneration and Competitive Power Journal* 5. R. Hite 'Cogeneration/Combined Heat and Power: An Overview (2002) 17 [3] *Cogeneration and Competitive Power Journal* 64. B.-F. Kolanowski 'Pitfalls of Cogeneration' (2002) 17 [3] *Cogeneration and Competitive Power Journal* 52. M. Gambini, M. Vellini, T. Stilo, M. Manno and S. Bellocchi 'High-Efficiency Cogeneration Systems: The Case of the Paper Industry in Italy' (2019) 12 *Energies* 335. Y.-N. Adıgüzel, Ö. Çomakli and İ. Ekmekci 'Economical evaluation of a cogeneration system for a building complex' (2015) 7 [3] *SAGE Journals* 1. Y. Kikuchi, Y. Kanematsu, R. Sato and T. Nakagaki 'Distributed Cogeneration of Power and Heat within an Energy Management Strategy for Mitigating Fossil Fuel Consumption' (2015) 20 [2] *Journal of Industrial Ecology* 289. Science Direct Cogeneration Available at: https://www.sciencedirect.com/topics/engineering/cogeneration (accessed 24.4.2020). A. Kalam, A. King, E. Moret and U. Weerasinghe 'Combined heat and power systems: economic and policy barriers to growth' (2012) 6 [1] *Chemistry Central Journal* Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3332257/ (accessed 24.4.2020). The American Society of Mechanical Engineers - A Greener, Less Expensive Cogeneration Plant Available at: https://www.asme.org/topics-resources/content/a-greener-less-expensive-cogeneration-plant (accessed 24.4.2020). ENERGY.GOV Top 10 Things You Didn't Know About Combined Heat and Power Available at: https://www.energy.gov/articles/top-10-things-you-didn-t-know-about-combined-heat-and-power (accessed 24.4.2020).

and establishing the principles as to how the Member States could support the technology in question.[97]

One background for the European Union Legal Regime on cogeneration was the Commission's cogeneration strategy from 1997[98] setting an overall indicative target of doubling the share of electricity production from cogeneration in total Community electricity production from 9% in 1994 to 18% by 2010. That strategy has paved the way for the following legal framework.

2.3.6 Directive 2004/8/EC on the promotion of cogeneration

The Directive 2004/8/EC[99] aimed "*to increase energy efficiency and improve security of supply by creating a framework for promotion and development of high efficiency cogeneration of heat and power, based on useful heat demand and primary energy savings in the internal energy market, taking into account the specific national circumstances especially concerning climatic and economic conditions*". It included, for the first time, definitions of the following terms: cogeneration, useful heat, economically justifiable demand, electricity from cogeneration, back-up electricity, top-up electricity, overall efficiency, efficiency, high efficiency cogeneration, efficiency reference value for separate production, power to heat ratio, cogeneration unit, micro-cogeneration unit, small scale cogeneration and cogeneration production. Article 4 and 5 introduced the efficiency criteria of cogeneration and the guarantee of origin of electricity from high-efficiency cogeneration correspondingly. Article 6 and 7 regulated the Member States' obligation to establish an analysis of the national potential for the application of high-efficiency cogeneration, including high-efficiency micro-cogeneration, and to support cogeneration - existing and future units, respectively. Article 8 set rules considering the electricity grid system and tariff issues, whereas Article 9 determined the administrative procedures to be followed. Article 10 and 11 provided that both the Member States and the European Commission shall "*publish a report with the results of the analysis and evaluations carried out*" in the field of cogeneration. Moreover, according to Article 12, Member States may use other calculation methods than the ones provided for in Annexes, without prejudice to Article 5 par 1 and Article 10 par 3 or for the purpose of issuing a guarantee of origin or for statistical purposes, whereas according to Article 13, the threshold values used for calculation of electricity from cogeneration, of efficiency of cogeneration production and primary energy savings and the guidelines for determining the power to heat ratio shall be adapted to technical progress. Annex I referred to the cogeneration technologies covered by the Directive in question, Annex II introduced the concept of "*Electricity from Cogeneration*" (ECHP), Annex III described the methodology for determining the efficiency of the cogeneration process, whereas Annex IV set "*the criteria for analysis of*

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97 INFORSE EUROPE EU Energy Policy Available at: http://www.inforse.org/europe/eu_cogen-di.htm (accessed 24.4.2020).

98 COM(97) 514 final "A Community strategy to promote combined heat and power (CHP) and to dismantle barriers to its development".

99 Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC (OJ L 52, 21.2.2004, p. 50–60).

national potentials for high-efficiency cogeneration". It is worth mentioning that "*the efficiency reference values shall be calculated according to the following principles: (i) For cogeneration units as defined in Article 3, the comparison with separate electricity production shall be based on the principle that the same fuel categories are compared; (ii) Each cogeneration unit shall be compared with the best available and economically justifiable technology for separate production of heat and electricity on the market in the year of construction of the cogeneration unit; (iii) The efficiency reference values for cogeneration units older than 10 years of age shall be fixed on the reference values of units of 10 years of age; (vi) The efficiency reference values for separate electricity production and heat production shall reflect the climatic differences between Member States*". Thus, the Directive supported substantial capacity expansion of cogeneration, but it did so in a way that maximized efficiency and emission reductions.[100]

2.3.7 Directive 2012/27/EU on energy efficiency

The Directive 2012/27/EU[101] repealed the Directive 2004/8/EC, confirming all of its points in the Annexes I and II. More specifically, it provides that "*Member States shall adopt policies which encourage the due taking into account at local and regional levels of the potential of using efficient heating and cooling systems, in particular those using high-efficiency cogeneration*". It also provides that, where the assessment referred to in paragraph 1[102] and the analysis referred to in paragraph 3[103] "*identify a potential for the application of high-efficiency cogeneration and/or efficient district heating and cooling, whose benefits exceed the costs, Member States shall take adequate measures for efficient district heating and cooling infrastructure to be developed and/or to accommodate the development of high-efficiency cogeneration and the use of heating and cooling from waste heat and renewable energy sources*". Furthermore, the Energy Efficiency Directive provides that each Member State shall carry out a comprehensive assessment of the efficiency potential for thermal systems, namely heating and cooling.[104] At the request of the Commission, "*the assessment shall be updated and notified to it every five years*". Member States shall also conduct a cost-benefit analysis relating to the potential of using cogeneration when "*(a) a new thermal*

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[100] M. Gambini and M. Vellini 'High Efficiency Cogeneration: Electricity from Cogeneration in CHP Plants' (2015) 81 *Energy Procedia* 430. M. Gambini, M. Vellini, T. Stilo, M. Manno and S. Bellocchi 'High-Efficiency Cogeneration Systems: The Case of the Paper Industry in Italy' (2019) 12 *Energies* 335.

[101] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC (OJ L 315, 14.11.2012, p. 1–56). Directive 2012/27/EU was amended by Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 (OJ L 156, 19.6.2018, p. 75–91).

[102] "*1. By 31 December 2015, Member States shall carry out and notify to the Commission a comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling, containing the information set out in Annex VIII. If they have already carried out an equivalent assessment, they shall notify it to the Commission.*"

[103] "*3. For the purpose of the assessment referred to in paragraph 1, Member States shall carry out a cost-benefit analysis covering their territory based on climate conditions, economic feasibility and technical suitability in accordance with Part 1 of Annex IX. The cost-benefit analysis shall be capable of facilitating the identification of the most resource-and cost-efficient solutions to meeting heating and cooling needs. That cost-benefit analysis may be part of an environmental assessment under Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment.*"

[104] The most recent assessment was made in December 2015 and the next one is due by 31 December 2020.

electricity generation installation with a total thermal input exceeding 20 MW is planned, in order to assess the cost and benefits of providing for the operation of the installation as a high-efficiency cogeneration installation; (b) an existing thermal electricity generation installation with a total thermal input exceeding 20 MW is substantially refurbished, in order to assess the cost and benefits of converting it to high-efficiency cogeneration; (c) an industrial installation with a total thermal input exceeding 20 MW generating waste heat at a useful temperature level is planned or substantially refurbished, in order to assess the cost and benefits of utilizing the waste heat to satisfy economically justified demand, including through cogeneration, and of the connection of that installation to a district heating and cooling network; (d) a new district heating and cooling network is planned or in an existing district heating or cooling network a new energy production installation with a total thermal input exceeding 20 MW is planned or an existing such installation is to be substantially refurbished, in order to assess the cost and benefits of utilizing the waste heat from nearby industrial installations". However, under certain circumstances, facilities falling within the scope of the aforementioned provision may be exempt from a cogeneration cost-benefit analysis. "*Without prejudice to Article 16 par 2 of the Directive 2009/28/EC*[105] *and taking into account Article 15 of the Directive 2009/72/EC*[106] *and the need to ensure continuity in heat supply, Member States shall ensure*

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[105] *"2. Subject to requirements relating to the maintenance of the reliability and safety of the grid, based on transparent and non-discriminatory criteria defined by the competent national authorities: (a) Member States shall ensure that transmission system operators and distribution system operators in their territory guarantee the transmission and distribution of electricity produced from renewable energy sources; (b) Member States shall also provide for either priority access or guaranteed access to the grid-system of electricity produced from renewable energy sources; (c) Member States shall ensure that when dispatching electricity generating installations, transmission system operators shall give priority to generating installations using renewable energy sources in so far as the secure operation of the national electricity system permits and based on transparent and non-discriminatory criteria. Member States shall ensure that appropriate grid and market-related operational measures are taken in order to minimize the curtailment of electricity produced from renewable energy sources. If significant measures are taken to curtail the renewable energy sources in order to guarantee the security of the national electricity system and security of energy supply, Members States shall ensure that the responsible system operators report to the competent regulatory authority on those measures and indicate which corrective measures they intend to take in order to prevent inappropriate curtailments."*

[106] *"1. Without prejudice to the supply of electricity on the basis of contractual obligations, including those which derive from the tendering specifications, the transmission system operator shall, where it has such a function, be responsible for dispatching the generating installations in its area and for determining the use of interconnectors with other systems.*

2. The dispatching of generating installations and the use of interconnectors shall be determined on the basis of criteria which shall be approved by national regulatory authorities where competent and which must be objective, published and applied in a non-discriminatory manner, ensuring the proper functioning of the internal market in electricity. The criteria shall take into account the economic precedence of electricity from available generating installations or interconnector transfers and the technical constraints on the system.

3. A Member State shall require system operators to act in accordance with Article 16 of Directive 2009/28/EC when dispatching generating installations using renewable energy sources. They also may require the system operator to give priority when dispatching generating installations producing combined heat and power.

4. A Member State may, for reasons of security of supply, direct that priority be given to the dispatch of generating installations using indigenous primary energy fuel sources, to an extent not exceeding, in any calendar year, 15 % of the overall primary energy necessary to produce the electricity consumed in the Member State concerned.

5. The regulatory authorities where Member States have so provided or Member States shall require transmission system operators to comply with minimum standards for the maintenance and development of the transmission system, including interconnection capacity.

6. Transmission system operators shall procure the energy they use to cover energy losses and reserve capacity in their system according to transparent, non-discriminatory and market-based procedures, whenever they have such a function.

that, subject to requirements relating to the maintenance of the reliability and safety of the grid, based on transparent and non-discriminatory criteria set by the competent national authorities, transmission system operators and distribution system operators when they are in charge of dispatching the generating installations in their territory: (a) guarantee the transmission and distribution of electricity from high-efficiency cogeneration; (b) provide priority or guaranteed access to the grid of electricity from high-efficiency cogeneration; (c) when dispatching electricity generating installations, provide priority dispatch of electricity from high-efficiency cogeneration in so far as the secure operation of the national electricity system permits". During the aforementioned procedures, "*Member States may set rankings as between, and within different types of, renewable energy and high-efficiency cogeneration, and shall in any case ensure that priority access or dispatch for energy from variable renewable energy sources is not hampered*". Moreover, they "*may particularly facilitate the connection to the grid system of electricity produced from high-efficiency cogeneration from small-scale and micro-cogeneration units. Member States shall, where appropriate, take steps to encourage network operators to adopt a simple notification "install and inform" process for the installation of micro-cogeneration units to simplify and shorten authorization procedures for individual citizens and installers*". "*Subject to the requirements relating to the maintenance of the reliability and safety of the grid, Member States shall also take the appropriate steps to ensure that, where this is technically and economically feasible with the mode of operation of the high-efficiency cogeneration installation, high-efficiency cogeneration operators can offer balancing services and other operational services at the level of transmission system operators or distribution system operators*". For their part, "*transmission system operators and distribution system operators shall ensure that such services are part of a services bidding process, which is transparent, non-discriminatory and open to scrutiny*". "*Member States may allow producers of electricity from high-efficiency cogeneration wishing to be connected to the grid to issue a call for tender for the connection work*". In addition, the Energy Efficiency Directive provides for guarantees of origin for proving the origin of electricity produced from high-efficiency cogeneration plants. However, no use is specified for such guarantees, so their use may also be enabled when disclosing the use of energy from high-efficiency cogeneration. Finally, "*Member States shall ensure that any available support for cogeneration is subject to the electricity produced originating from high-efficiency cogeneration and the waste heat being effectively used to achieve primary energy savings. In respect to public support to cogeneration, it shall be subject to State Aid rules, where applicable*". Annex I enshrines the general principles for the calculation of electricity from cogeneration, whereas Annex II describes in details the methodology for determining the efficiency of the cogeneration process upon which Member States are based in order to submit statistics on primary energy savings achieved by application of cogeneration.[107]

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7. Rules adopted by transmission system operators for balancing the electricity system shall be objective, transparent and non-discriminatory, including rules for charging system users of their networks for energy imbalance. The terms and conditions, including the rules and tariffs, for the provision of such services by transmission system operators shall be established pursuant to a methodology compatible with Article 37(6) in a non-discriminatory and cost-reflective way and shall be published."

[107] P. Zangheri, M. Economidou and N. Labanca 'Progress in the Implementation of the EU Energy Efficiency Directive through the Lens of the National Annual Reports' (2019) 12 [6] *Energies* 1107. European Parliamentary Research Service Implementation of the Energy Efficiency Directive

2.3.8 Directive (EU) 2018/2001 (RED-II)

The Directive (EU) 2018/2001[108] defines "*the "waste heat and cold" as the unavoidable heat or cold generated as by-product in industrial or power generation installations or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible*". It also provides that "*Member States shall introduce appropriate measures in their building regulations and codes in order to increase the share of all kinds of energy from renewable sources in the building sector*", taking into account, inter alia, and national measures relating to cogeneration. Furthermore, "*guarantees of origin created pursuant to Article 14 par 10*[109] *of the Directive 2012/27/EU may be used to substantiate any requirement to demonstrate the quantity of electricity produced from high-efficiency cogeneration. For the purposes of paragraph 2 of the Article,*[110] *where electricity is generated*

(2012/27/EU): Energy Efficiency Obligation Schemes European Implementation Assessment Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/579327/EPRS_STU(2016)579327_EN.pdf (accessed 24.04.2020). European Commission Cogeneration of Heat and Power Available at: https://ec.europa.eu/energy/topics/energy-efficiency/cogeneration-heat-and-power_en (accessed 24.04.2020).

[108] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (OJ L 328, 21.12.2018, p. 82–209).

[109] "*10. On the basis of the harmonized efficiency reference values referred to in point (f) of Annex II, Member States shall ensure that the origin of electricity produced from high-efficiency cogeneration can be guaranteed according to objective, transparent and non-discriminatory criteria laid down by each Member State. They shall ensure that this guarantee of origin complies with the requirements and contains at least the information specified in Annex X. Member States shall mutually recognize their guarantees of origin, exclusively as proof of the information referred to in this paragraph. Any refusal to recognize a guarantee of origin as such proof, in particular for reasons relating to the prevention of fraud, must be based on objective, transparent and non-discriminatory criteria. Member States shall notify the Commission of such refusal and its justification. In the event of refusal to recognize a guarantee of origin, the Commission may adopt a decision to compel the refusing party to recognize it, in particular with regard to objective, transparent and non-discriminatory criteria on which such recognition is based.*
The Commission shall be empowered to review, by means of delegated acts in accordance with Article 23 of this Directive, the harmonized efficiency reference values laid down in Commission Implementing Decision 2011/877/EU (26) on the basis of Directive 2004/8/EC by 31 December 2014."

[110] "*2. To that end, Member States shall ensure that a guarantee of origin is issued in response to a request from a producer of energy from renewable sources, unless Member States decide, for the purposes of accounting for the market value of the guarantee of origin, not to issue such a guarantee of origin to a producer that receives financial support from a support scheme. Member States may arrange for guarantees of origin to be issued for energy from non-renewable sources. Issuance of guarantees of origin may be made subject to a minimum capacity limit. A guarantee of origin shall be of the standard size of 1 MWh. No more than one guarantee of origin shall be issued in respect of each unit of energy produced.*
Member States shall ensure that the same unit of energy from renewable sources is taken into account only once.
Member States shall ensure that when a producer receives financial support from a support scheme, the market value of the guarantee of origin for the same production is taken into account appropriately in the relevant support scheme.
It shall be presumed that the market value of the guarantee of origin has been taken into account appropriately in any of the following cases: (a) where the financial support is granted by way of a tendering procedure or a tradable green certificate system; (b) where the market value of the guarantees of origin is administratively taken into account in the level of financial support; or (c) where the guarantees of origin are not issued directly to the producer but to a supplier or consumer who buys the energy from renewable sources either in a competitive setting or in a long-term renewables power purchase agreement.
In order to take into account the market value of the guarantee of origin, Member States may, inter alia, decide to issue a guarantee of origin to the producer and immediately cancel it.
The guarantee of origin shall have no function in terms of a Member State's compliance with Article 3. Transfers of guarantees of origin, separately or together with the physical transfer of energy, shall have no effect on the decision

from high-efficiency cogeneration using renewable sources, only one guarantee of origin specifying both characteristics may be issued". Moreover, according to Article 14, where a "*Member State exercises the option referred to in point (b) of paragraph 4,*[111] *it may exempt operators of the district heating and cooling systems exploiting high-efficiency cogeneration from the application of that point*". Likewise, an operator of a district heating or cooling system may refuse to connect and to purchase heat or cold from a third-party supplier, where "*the system lacks the necessary capacity due to other supplies of heat or cold produced by high-efficiency cogeneration*".

2.3.9 Delegating Regulations and non-binding legal instruments

Equally important to the aforementioned Directives have been numerous Delegating Regulations and non-binding legal instruments, which are listed non-exhaustively below:

- Commission - A Community strategy to promote combined heat and power (CHP) and to dismantle barriers to its development.[112]
- Proposal for a Directive of the European Parliament and of the Council on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC.[113]
- Communication from the Commission - Action Plan for Energy Efficiency: Realizing the Potential.[114]
- Commission Decision of 21 December 2006 establishing harmonized efficiency reference values for separate production of electricity and heat in application of Directive 2004/8/EC of the European Parliament and of the Council.[115]
- Communication from the Commission to the European Parliament and the Council - Europe can save more energy by combined heat and power generation.[116]
- Commission Decision of 19 November 2008 establishing detailed guidelines for the implementation and application of Annex II to Directive 2004/8/EC of the European Parliament and of the Council.[117]

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of Member States to use statistical transfers, joint projects or joint support schemes for compliance with Article 3 or on the calculation of the gross final consumption of energy from renewable sources in accordance with Article 7."

[111] *"4. Member States shall lay down the necessary measures to ensure that district heating and cooling systems contribute to the increase referred to in Article 23(1) of this Directive by implementing at least one of the two following options: […] b) Ensure that operators of district heating or cooling systems are obliged to connect suppliers of energy from renewable sources and from waste heat and cold or are obliged to offer to connect and purchase heat or cold from renewable sources and from waste heat and cold from third-party suppliers based on non-discriminatory criteria set by the competent authority of the Member State concerned, where they need to do one or more of the following: (i) meet demand from new customers; (ii) replace existing heat or cold generation capacity; (iii) expand existing heat or cold generation capacity."*

[112] COM(97) 514 final.

[113] OJ C 291 E, 26.11.2002, p. 182.

[114] {SEC(2006)1173} {SEC(2006)1174} {SEC(2006)1175} /* COM/2006/0545 final */.

[115] OJ L 32, 6.2.2007, p. 183–188.

[116] /* COM/2008/0771 final */.

[117] OJ L 338, 17.12.2008, p. 55–61.

- European Parliament resolution of 31 January 2008 on an Action Plan for Energy Efficiency: Realizing the Potential.[118]
- Regulation (EC) No 219/2009 of the European Parliament and of the Council of 11 March 2009 adapting a number of instruments subject to the procedure referred to in Article 251 of the Treaty to Council Decision 1999/468/EC with regard to the regulatory procedure with scrutiny — Adaptation to the regulatory procedure with scrutiny — Part Two.[119]
- Proposal for a Directive of the European Parliament and of the Council on energy efficiency and repealing Directives 2004/8/EC and 2006/32/EC.[120]
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Energy Efficiency Plan 2011.[121]
- Commission Implementing Decision of 19 December 2011 establishing harmonized efficiency reference values for separate production of electricity and heat in application of Directive 2004/8/EC of the European Parliament and of the Council and repealing Commission Decision 2007/74/EC.[122]
- Commission Staff Working Paper Note on References to Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market in Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market.[123]
- European Commission Staff Working Document - Progress Report on Energy Efficiency in the European Union accompanying the Document Report from the Commission to the European Parliament and the Council Progress Report on the application of Directive 2006/32/EC on Energy End-Use Efficiency and Energy Services and on the Application of Directive 2004/8/EC on the Promotion of Cogeneration Based on a Useful Heat Demand in the Internal Energy Market.[124]
- Commission Delegated Regulation (EU) 2015/2402 of 12 October 2015 reviewing harmonized efficiency reference values for separate production of electricity and heat in application of Directive 2012/27/EU of the European Parliament and of the Council and repealing Commission Implementing Decision 2011/877/EU.[125]
- Commission Delegated Regulation (EU) 2019/826 of 4 March 2019 amending Annexes VIII and IX to Directive 2012/27/EU of the European Parliament and of the

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[118] OJ C 68 E, 21.3.2009, p. 18-25.
[119] OJ L 87, 31.3.2009, p. 109–154.
[120] /* COM/2011/0370 final - COD 2011/0172 */.
[121] Brussels, 8.3.2011 COM(2011) 109 final.
[122] OJ L 343, 23.12.2011, p. 91–96.
[123] Brussels, 9.2.2012 SWD(2012) 13 final.
[124] /* SWD/2013/0541 final */.
[125] OJ L 333, 19.12.2015, p. 54–61.

Council on the contents of comprehensive assessments of the potential for efficient heating and cooling.[126]

- Intelligent Energy Europe and Cogeneration Observatory and Dissemination Europe Cogeneration Case Studies Handbook.[127]
- COGEN Europe Position Paper - Methodology & market developments for micro-cogeneration in the review of Lot1 Energy Labeling and Eco-design legislation.[128]

2.3.10 EU Regulation for Industrial Emissions

The European Union has several directives directly regulating the power industry. The EU Integrated Pollution Prevention and Control (IPPC) Directive specifies that best available techniques (BATs) for minimizing the environmental impact of a process should be applied. Environmental emissions from power plants have been regulated by either the Large Combustion Plant Directive (LCPD) or the Waste Incineration Directive (WID) via the IPPC process, depending on the fuel, but this role has now been taken over by the Industrial Emissions Directive (IED).[129]

Directive 2010/75/EU of the European Parliament and the Council on industrial emissions (IED) is the main EU instrument regulating pollutant emissions from industrial installations. The IED was adopted on 24 November 2010 and among other applies to combustion plants designed for production of energy, the rated thermal input of which is equal to or greater than 50 MW irrespective of the type of fuel used (Article28).[130] The IED entered into force on 6 January 2011 and had to be transposed by Member States by 7 January 2013.

The IED aims to achieve a high level of protection of human health and the environment taken as a whole by reducing harmful industrial emissions across the EU, in particular through better application of Best Available Techniques (BAT). Around 50,000 installations undertaking the industrial activities listed in Annex I of the IED are required to operate in accordance with a permit (granted by the authorities in the Member States). This permit should contain conditions set in accordance with the principles and provisions of the IED.[131]

The IED uses Best Available Technology Reference Documents (BREF) to set the emission limit targets. A new version of the BREF document for large combustion plant LCP BREF was published on 17th August 2017 and plant operators will have until 18th August 2021 to comply with the revised BAT Associated Emission Limits (AELs). In

126 OJ L 137, 23.5.2019, p. 3–9.
127 Available at: http://hacchp.gr/wp-content/uploads/2017/03/CODE-Handbook.pdf (accessed 24.4.2020).
128 Available at: https://www.cogeneurope.eu/images/2018_08_24_COGEN_Europe_Position_Paper_Space_Heaters_Lot1_Energy_Labelling_Review_Final.pdf (accessed 24.4.2020).
129 Malmgren A. and Riley G., Biomass Power Generation, Reference Module in Earth Systems and Environmental Sciences 2018, Elsevier, https://doi.org/10.1016/B978-0-12-409548-9.11014-0
130 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32010L0075
131 https://ec.europa.eu/environment/industry/stationary/ied/legislation.htm

Chapter 10.2.2 of this Reference Document are summarized the conclusions for the combustion of solid biomass and/or peat and are defined the respective AELs.

On the other hand, the emission limit targets for medium power plants are regulated by Medium Combustion Plants (MCP) directive. "Medium combustion plants" in the EU legal environmental nomenclature mean combustion plants rated thermal input thereof is equal to or greater than 1 MW and less than 50 MW, irrespective of the type of fuel used.[132] The Medium Combustion Plant (MCP) Directive came into force on 18 December 2015. The European Commission estimates the approximate

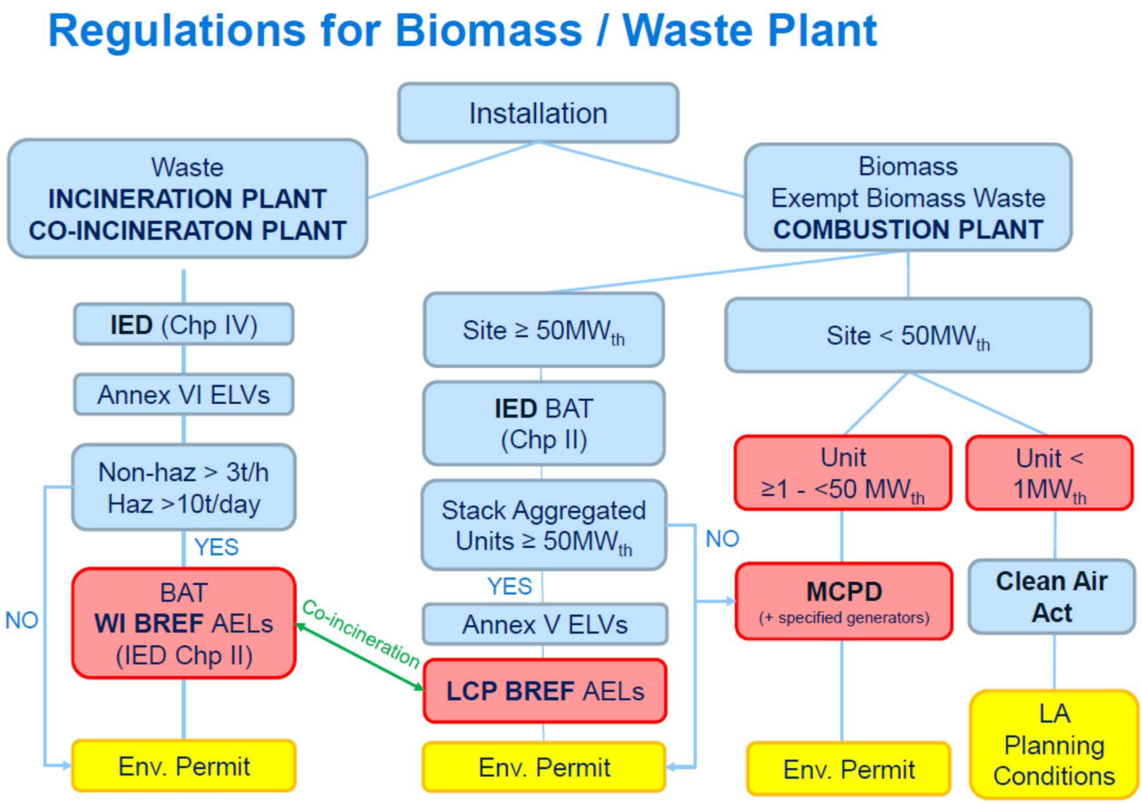

Figure 2.3 Regulations for biomass / Waste plant

number of medium combustion plants in the European Union at the level of 142,986. This Directive lays down rules to control emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and dust into the air from medium combustion plants, and thereby reduce emissions to air and the potential risks to human health and the environment from such emissions. This Directive also lays down rules to monitor emissions of carbon monoxide (CO). In figure 2.3 are summarized the applicable directives for setting emission limits for biomass combustion plants in EU.[133]

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[132] Vojáčeka O.,⁎, Sobotkab L., Macháčc J., Žilka M., Impact assessment of Proposal for a Directive on the limitation of emissions from medium combustion plants – National impact assessment compared to the European impact estimate, Renewable and Sustainable Energy Reviews, Elsevier, Volume 82, Part 2, February 2018, Pages 1854-1862, https://doi.org/10.1016/j.rser.2017.06.119

[133] Griffiths S. Dr., Developments in Biomass and Waste Emissions Regulation, Environmental Compliance – November 22, 2019, Uniper SE, https://www.uniper.energy/services/sites/default/files/2019-02/Developments_In_Biomass_And_Waste_Emissions_Regulations.pdf

2.4 Greek Legal Regime for biomass and Cogeneration of Heat and Power

2.4.1 Introduction

Distinctive feature of the legislation on electricity from Renewable Energy Sources (RES), in particular biomass, and through Cogeneration of Heat and Power (CHP), in the first instance, was the complexity exacerbated by the high number of laws applying at the same time and the numerous amendments. The fragmentation of competences[134] considering the issuance of production, installation and operating licenses, the time delay largely attributed to the required environmental authorizations,[135] coupled with the multi-year failure to adopt a Special Framework for Spatial Planning and Sustainable Development for RES, have made the regime even more complicated, cumbersome and ultimately ineffective. Indeed, according to a European Commission Report in May 2004, Greece proved to have a negative approach toward adopting and promoting RES, despite the significant solar and wind energy and biomass potential. In a second phase with a view to harmonizing Greek legislation with EU Law, the former was largely a simple means of transposing the relevant EU Directives into the domestic legal order.[136]

2.4.2 Domestic Legal Regime[137]

Although Law no 2244/1994 (Government Gazette A 168/7.10.1994) maintained the exclusive right of the Public Power Corporation (PPC) undertaking to generate, transport and distribute electricity from any source of energy, it also gave third parties the opportunity to generate electricity. More precisely, it permitted self-consumption of electrical energy in autonomous power plants with exploitation of biomass or through CHP, even in thermal power plants operating with conventional fossil fuels, provided that the latter is a back-up power unit and its capacity does not exceed the capacity of the main unit, which burns biomass. It also permitted self-consumption to independent producers operating power plants and CHP that are connected to the interconnected electricity network, provided that the technical specifications on connection to the

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134 Illustrative is the Joint Ministerial Decision 1726/2003 (Government Gazette B 552/8.05.2003), which attempted to reduce the competent authorities involved from 41 to 26.

135 E. A. Maria, 'Renewable Energy Sources Projects and Environmental Protection' (2001) 3 *Environment and Law* 338. Ibid, *Environmental Impact of Renewable Energy Sources Projects and Preventive Mechanisms of Law* (Polytechnion Crete 2005).

136 P. Kaprou, 'Energy Policy for Greece: Convergence or Divergence from the European Perspective' <http://www.e3mlab.ntua.gr/papers/Naftem00.pdf> accessed 12 December 2019.

137 V. Alexandropoulou, A. Gourzi and Ant. Koukouritaki, *Renewable Energy Sources* (Sakkoulas Athens - Thessaloniki 2014). Th. Fortsakis, *Energy Law* (Sakkoulas Athens - Komotini 2009). Ch. Hadjikonstantinou, *Renewable Energy Sources* (Sakkoulas Athens - Thessaloniki 2019). M. Karagiorgas, D. Zacharias and A. Kirkou, *Environmental Guide on Renewable Energy Sources* (WWF Athens 2010). M. Meng - Papantonis, *Energy Law* (Nomiki Bibliothiki Athens 2003). Th. Panagos, *The Legal Regime of the Energy Market* (Sakkoulas Athens - Thessaloniki 2012). N. Tsokanas, 'Renewable Energy Sources through the political texts and legal acts of EU and the related legal regime of Greece' (2004) 2 *Environment and Law* 184. K. Vatalis, *Collection of Legislation on Renewable Energy Sources* (Sakkoulas Athens - Thessaloniki 2010). Ibid, *Introduction to the Law of Electricity from RES* (Sakkoulas Athens - Thessaloniki 2007).

electricity network are met and they operate with biomass. Moreover, to the independent producers, whose power plants are connected to the interconnected electricity network and they supply the generated energy to the network, it permitted that they can generate electricity on condition that the power capacity does not exceed 50 MW and their installations operate with biomass or through CHP by burning natural gas with limits on power generated equal to or less than the thermal load of the companies that are supplied. Furthermore, the law defined CHP "*as the electricity generation (a) with conventional fuel combined with production of heating and/or cooling, (b) by energy recovery from non-toxic and environmentally friendly by-products of industrial combustion processes and (c) by recovery of waste heat*". It set limits on the capacity of the CHP plants and gave third parties the opportunity to either enter into programme agreements with the Public Power Corporation or set up subsidiaries with them in order to operate CHP units that produce electricity and heat and/or cooling by burning conventional fuel or industrial by-products. "*Independent producers can generate electricity through CHP by burning natural gas only if the Public Power Corporation does not agree, in writing, to conclude a programme agreement with them within four months following the submitted request from the interested parties*". The law also prohibited the installation of new solid-fuel-fired power plants, apart from biomass, as well as new liquid-fuel-fired power plants, except for CHP, in Attica. It established the basic principles of pricing of electricity, whereas the technical and financial conditions for the connection and supply to Public Power Corporation were to be regulated by the contract between the self-consumer or independent producer and the Public Power Corporation. Competent authority for the issuance of installation/expansion and operating licenses was the Minister of Industry, Energy and Technology.

Subsequently, Law no 2773/1999 (Government Gazette A 286/22.12.1999), which partially repealed Law no 2244/1994, harmonized the national legislation with Directive 96/92/EC on common rules for the internal market in electricity.[138] It contained the following definitions: generation of electricity from RES is the electricity produced, inter alia, from biomass or through CHP, whereas "*CHP is the electricity produced (a) by recovery of waste heat, (b) by energy recovery from non-toxic and environmentally friendly by-products of combustion processes of industries legally installed in Greek territory and (c) combined with production of heating provided that the resulting heat is directly directed to thermal loads and/or indirectly to cooling loads*". In the case that "*the CHP is not exclusively based on RES, the relation between the electric capacity and the thermal output of the CHP plant and the technologies applied should ensure that the total annual efficiency levels considering the useful heat of the CHP plant amount to at the least 65%. Particularly, in the case of the Combined Cycle technology, the efficiency levels should amount to 75%, whereas, in the case of self-consumers in the tertiary sector, the threshold is reduced to 60%*". The law also made compulsory the production and supply licenses issued by the Minister of Development, further to an opinion of the Regulatory Authority for Energy (RAE). Especially in the case of non-interconnected islands, prerequisite for granting a

[138] E. Papathanasopoulou, 'Implementation of Directive 96/92 on common rules for the internal market in electricity - Law no 2773/1999' (2000) *EEurD* 63.

production license is that the producer succeeds in a competition, unless the power plant exploits RES. In the context of promoting RES, a favorable tariff regime was established. In the same vein, regarding dispatching, the Transmission System Operator should grant priority to (a) power plants with capacity up to 50 MWe that generate electricity from RES and (b) power plants with capacity up to 35 MWe that generate electricity through CHP, as specified in the Grid Control Code for Electricity.

The purpose of Law no 2941/2001 (Government Gazette A 201/12.09.2001) was to simplify the permit granting procedures for electricity generation projects by RES, including projects for their connection to the System or Network, for the construction of substations and generally, for the accompanying projects, which were classified as projects of public interest, irrespective of the implementing body. Thus, expropriation was made easier. Derogations from the strict forestry and environmental legislation[139] were provided concerning the construction and installation of power plants using RES (eg Special Framework for Spatial Planning and Sustainable Development for RES). Power plants using RES were also subject to the most favorable provisions considering industrial projects and the provisions related to the projects of the Public Power Corporation, regardless of the implementing body.

Law no 3299/2004 (Government Gazette A 261/23.12.2004) initiated the promotion of biomass and CHP, by stating that state aid schemes apply to investment plans for the production of biomass from plants for the purpose to be used as raw material for generation of electricity, investment plans for the generation of electricity from biomass, investment plans for the CHP, regardless of the capacity of CHP plants, as well as to investment plans for the deployment of RES and CHP.

Law no 3426/2005 (Government Gazette A 309/22.12.2005) introduced minor amendments to Law no 2773/1999. To name but a few, it extended the obligation of the Transmission Operator to grant priority to the generation of electricity from RES or through CHP, even to CHP plants, whose capacity is up to 50 MWe and the electricity and thermal energy produced are directly supplied to customers.

Law no 3468/2006 (Government Gazette A 129 / 27.06.2006), on the one hand, transposed Directive 2001/77/EC on the promotion of electricity produced from RES in the internal electricity market, and on the other hand, promoted the generation of electricity from RES and through High efficiency Cogeneration (HEC) in order to put an end to the fragmentation of the relevant rules and to achieve national targets under Directive 2009/28/EC. It defined biomass as "*the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste*", whereas "*CHP is the simultaneous generation of thermal, electrical and/or mechanical energy, in a single process*". Moreover, "*High Efficiency Cogeneration (HEC) is (a) the cogeneration of heat and*

[139] E. A. Maria, 'Renewable Energy Sources Projects and Environmental Protection' (2001) 3 *Environment and Law* 338. Ibid, *Environmental Impact of Renewable Energy Sources Projects and Preventive Mechanisms of Law* (Polytechnion Crete 2005).

power providing primary energy savings of at least 10% in comparison to the thermal energy and electricity produced through separate processes and (b) the generation of electricity from small scale and micro cogeneration units providing primary energy savings, regardless of the energy saving target". Furthermore, "*small scale cogeneration is the cogeneration of heat and power unit with less than one (1) MWe capacity*", whereas "*micro cogeneration is the cogeneration of heat and power unit with less than fifty (50) kWe capacity*". The law also regulated issues related to the production, installation and operating licenses, the integration into the System and the non-interconnected islands, the connection to the grid and the pricing of electricity. What's more, it gave local self-government the opportunity to install non-profit-making power plants running on RES or through CHP in order to meet the energy needs of municipal utilities, child-care establishments, schools, health centers and hospitals.

Law no 3734/2009 (Government Gazette A 8/28.01.2009) harmonized Greek legislation with Directive 2004/8/EC on the promotion of CHP based on a useful heat demand in the internal energy market and supplemented the legal regime on the promotion of cogeneration of two or forms of useful energy. The law contains the following definitions: Combined Heat and Power (CHP), useful thermal energy, economically justifiable demand, electricity through CHP, back-up electric energy, supplementary electrical energy, overall efficiency, CHP unit, small scale cogeneration, micro cogeneration, High Efficiency Cogeneration (HEC), autonomous CHP plants, guarantees of origin of HEC, system of guarantees of origin of HEC, compact CHP units, operational data and efficiency reference values regarding CHP, which replace the corresponding definitions of Law no 3468/2006. "*CHP technologies include: combined cycle gas turbine with heat recovery, back pressure steam turbine, condensing steam turbine with extractions, turbine with heat recovery, reciprocating internal combustion engines, micro turbine, Stirling engine, fuel cell, steam engine, organic Rankine cycle and any other type of technology or combination of technological types falling within the definition of cogeneration*". The provisions of Law no 3468/2006 and Law no 2773/1999, as well as the relevant provisions of the Greek Grid and Exchange Code for Electricity, as amended, apply mutatis mutandis in order to ensure the transmission and distribution of electricity generated through HEC. In case of the power plants running on RES or through HEC, installation/expansion and operating licenses constitute a prerequisite. Competent for the issuance of the licenses in question is the General Secretary of the Region within the limits of which the plant is installed or the Minister of Development, depending on the category in which the project falls into. The law also expanded the obligation of the Transmission Operator to grant priority to self-concumers or independent producers generating electricity from RES or through CHP also in the case of non-interconnected islands.

Law no 3851/2010 (Government Gazette A 85/4.06.2010) amended the legal regime considering the competent authority and the criteria for granting a production license. More specifically, responsible for issuing the license in question is the Regulatory Authority for Energy (RAE), whose decision is subject to legal scrutiny by the Minister of Environment, Energy and Climate Change.[140] "*Power plants generating electricity from biomass or through HEC with an installed capacity of less than or equal to one (1) MW, power plants generating electricity through HEC or RES with an installed capacity up to five (5) MWe owned by public or private education or research institutions, as long as they operate exclusively for educational and research purposes, as well as power plants owned by the Center for Renewable Energy Sources and Savings (CRES), as long as they operate for conducting certification or measurements*", and "*autonomous RES and HEC power plants not connected to the System or the Network and not having the possibility of modifying their stand-alone function, with an installed capacity of less than or equal to five (5) MWe*", are exempted from the obligation to obtain a production license. The law also regulates the installation and operation of power plants running on RES or through HEC, as well as the integration into the System and the non-interconnected islands and the connection to the grid. It rationalizes the tariff of electricity generated from RES or through HEC and contains favorable regulations for the plants in question, including site-specific matters. It should be noted that the Preliminary Environmental Study and Evaluation is not required for the issuance of a production license, including licenses for connection to network projects, road and other access works. As a result, the production license by RAE relates solely to the technical and financial capacity of the project and is completely decoupled from the environmental authorization that follows. More precisely, Approval of Environmental Terms and Conditions of RES projects is a prerequisite only for the issuance of installation/expansion and operating licenses, except for certain cases, which are considered to have limited impact on the environment due to the low-capacity of the plant. In such a case, an exception certificate is issued.[141] According to the transitional provisions, by way of derogation from the general rules, even before being published the Decision of the Minister of the Environment, Energy and Climate Change, new applications for biomass power plants can be submitted and examined.

Law no 4001/2011 (Government Gazette A 179/22.08.2011) transposed Directive 2009/72/EC on the common rules for the internal market in electricity and repealing Directive 2003/54/EC, and brought about radical changes considering the structure and operation of the electricity market,[142] since it established an Independent Power Transmission Operator (IPTO or ADMIE SA), a Distribution Network Operator (DEDDIE SA) and an Operator of Electricity Market (LAGIE SA).[143] Legislative definitions, regulations and parameters of the pricing of electricity (feed-in-tariff) were amended in order to be in compliance with the new regime. It is also provided that, if the thermal energy is generated through CHP, the thermal energy production license

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[140] Energy Regulatory Authority, *Action Report July 2000 - December 2002* (Gavrilidis Publications 2004).
[141] E. A. Maria, 'Renewable Energy Sources Projects and Environmental Protection' (2001) 3 *Environment and Law* 338. Ibid, *Environmental Impact of Renewable Energy Sources Projects and Preventive Mechanisms of Law* (Polytechnion Crete 2005).
[142] G. Dellis, *Utility and Market,* vol. I (Ant. N. Sakkoulas Athens - Komotini 2008). N. Farantouris (ed), *Energy: Law, Economics & Politics* (Nomiki Bibliothiki Athens 2012). Ch. Tarnidou, *Modern energy markets* (Nomiki Bibliothiki Athens 2016).
[143] Aik. Eliadou, *The penetration of Public Law into the Regulation of Network* Markets (Nomiki Bibliothiki Athens 2010).

should be issued together with the electricity production license at the request of the interested parties.

Law no 4062/2012 (Government Gazette A 70/30.03.2012) incorporated Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, and promoted the further use of RES energy. It contained the definition of energy from renewable sources as the energy from renewable non-fossil sources, inter alia, from biomass, whereas the latter means the "*biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste*". It also provided that the National Renewable Energy Action Plan adopted by a ministerial decision and submitted to the European Commission should set out national targets for the share of energy from renewable sources consumed in electricity and take adequate measures, including cooperation between local, regional and national authorities, planned statistical transfers or joint projects, national policies to develop existing biomass resources and mobilize new biomass resources. "*As far as concerns biomass, it is necessary to promote technologies that achieve a conversion efficiency of at least 85% for residential and commercial applications and at least 70% for industrial applications*". Moreover, in the case that electricity is produced from biomass, "*Guarantees of Origin are issued only for the percentage of electricity corresponding to the biodegradable fraction*". The report on the progress made in promoting RES energy issued by the Investor's Advisory Service in cooperation with RAE and the Office monitoring the sustainability of biofuels and bio-liquids, which is approved by the Minister of the Environment, Energy and Climate Change and submitted to the European Commission, should be particularly referred to the progress in the availability of biomass resources for energy purposes, as well as to changes in commodity prices and land use associated with the increased use of biomass and other forms of energy from renewable sources.

Law no 4093/2012 (Government Gazette A 222/12.11.2012) (medium-term 2013-2016) imposed an exceptional solidarity fee on producers of electricity from RES or through HEC calculated on the sale price of electricity from 1.07.2012 to 30.06.2014. Minor regulations were introduced by Law no 4152/2013 (Government Gazette A 107/9.05.2013) (Urgent Implementation of Laws no 4046/2012, 4093/2012 and 4127/2013).

Law no 4203/2013 (Government Gazette A 235/1.11.2013) included detailed provisions for compensation issues and the installation licenses and change of installation position of a RES' power plant. A Transitional Charge for Security of Supply is also imposed on all power plants, including biomass power plants, as long as they are connected to the System and Network, while Power plants supply energy into the non-interconnected islands were exempted from the charge. The charge was differentiated by each category of energy sources.

Law no 4254/2014 (Government Gazette A 85/7.04.2014) (Measures implementing Memorandum of Understanding) amended the component factors of the tariff of electricity generated from RES or through HEC. It also contains provisions for granting state aid for generating electricity from RES or through HEC. However, it should be noted that the law abolished the favorable provision, according to which the biomass power plants, whose capacity does not exceed 0.5 MW, are exempted from the obligation to obtain Approval of Environmental Terms and Conditions.

Law no 4296/2014 (Government Gazette A 214/2.10.2014) provided that the applications submitted until 31.12.2015 for production license, connection offer and Approval of Environmental Terms and Conditions concerning biomass power plants that are to operate under the responsibility of Entities of Solid Waste Management or legal entities to which such competences have been delegated, are prioritized. Furthermore, the power absorption margin in areas designated as areas with a saturated grid should be allocated by the Transmission System Operator primary to applications for a definitive connection offer concerning biomass power plants that are to operate under the responsibility of Entities of Solid Waste Management or legal entities to which such competences have been delegated, as well as to biomass power plants that have submitted complete dossiers until 31.12.2014. In the case of biomass power plants, the competent authority should grant a definitive connection offer provided that exception certificate for environmental authorization has been submitted. The connection is activated only if the environmental authorization has been accomplished, in accordance with the applicable environmental legislation, and the administrative acts required have been submitted to the competent authority.[144]

The purpose of Law no 4414/2016 (Government Gazette A 149/9.08.2016) is to develop a new scheme for the promotion of RES and high-efficiency cogeneration, in accordance with the "*Guidelines for State Aids in the field of environment and energy (2014-2020)*" (Communication from the European Commission OJ C200/28.06.2014), and for "*their gradual integration and participation in the electricity market in the most cost-effective way for society*". It also seeks to exploit the potential of renewables, "*with a view to protecting the environment, diversifying the national energy mix, securing energy supply and boosting and developing the national economy*", as well as achieving national energy targets under Directive 2009/28/EC.[145] At the same time, an effort was made "*to support the operation of HEC plants, improve their energy efficiency and save primary energy*". The law specifies which power plants are subject to its scope ratione materiae and temporis and regulates the reference values regarding the compensation of power plants running on RES or through HEC. It also regulates the participation in the electricity market of RES and HEC plants that have concluded a Sliding Premium Operating Aid Contract and the balance responsibility of those having concluded an Operating Aid Contract with a

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[144] E. A. Maria, 'Renewable Energy Sources Projects and Environmental Protection' (2001) 3 *Environment and Law* 338. Ibid, *Environmental Impact of Renewable Energy Sources Projects and Preventive Mechanisms of Law* (Polytechnion Crete 2005).

[145] K. Douglas, 'Global Warming: Problems, Policies and Strategies, European and Greek' (2003) 2 *Environment and Law* 333. G. Karakostas, *Environment & Law. Law on the Management and Protection of Environmental Goods* (Nomiki Bibliothiki Athens 2011).

Fixed Tariff. Finally, it sets out the methodology for calculating the special price for RES and HEC technologies. However, the Energy Regulatory Authority, when adopting its opinion, should take into account the need for preventing any distortion of competition in raw materials market due to the promotion of biomass.[146]

Minor amendments were also made by Law no 4342/2015 (Government Gazette A 143/9.11.2015), Law no 4467/2017 (Government Gazette A 57/13.04.2017) and Law no 4495/2017 (Government Gazette A 167/3.11. 2017). In particular, the latter provides that, by way of derogation from the general rules, the power absorption margin in areas designated as areas with a saturated grid should be allocated by the Transmission System Operator primary to applications for a definitive connection offer concerning biomass power plants that are to operate under the responsibility of the Operator of the System for treating Solid Waste or legal entities to which such competences have been delegated, as well as to biomass power plants owned by natural or legal persons listed on the Register of Farmers and Rural Farms that are to operate in the Regional Unity, where their farms are located.

According to Law no 4496/2017 (Government Gazette A 179/8.11.2017), on "*agricultural parcels located in areas outside the Attica Basin and designated by the Department of Agriculture and Veterinary as agricultural land of high productivity, the installation of biomass power plants is permitted provided that the required quantities of raw materials come from agricultural, livestock or forestry holdings and at least 85% of these come from holdings which are less than thirty kilometers away*". On agricultural parcels located in areas outside the Attica Basin and designated by the Approved Zones of Residential Control as agricultural land of high productivity, "*the installation of biomass power plants up to 500 kW is permitted provided that the required quantities of raw materials come from agricultural, livestock or forestry holdings which are less than thirty kilometers away and the power plants are owned by natural or legal persons listed on the Register of Farmers and Rural Farms and installed within the Regional Unit, where their farms are located*".

Law no 4513/2018 (Government Gazette A 9/23.01.2018) provides that the Energy Community is an urban cooperative aiming to innovate in the energy sector, mitigate energy poverty and promote energy sustainability.[147] In this context, it is responsible for the management, collection, transport, treatment, storage and disposal of raw materials for the production of electricity from biomass. Law no 4546/2018 (Government Gazette A 101/12.06.2018) provides that the report on the promotion of RES should particularly refer to the biomass cascading principle, taking into consideration the regional and local economic and technological circumstances, the maintenance of the necessary carbon stock in the soil and the quality of soil and ecosystems. Finally, Law no 4643/2019 (Government Gazette A 193/3.12.2019) provides

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[146] Energy Regulatory Authority, *Action Report July 2000 - December 2002* (Gavrilidis Publications 2004).
[147] G. Dellis, 'From the Carnage of Pylos to Kassandra's Mine: The Sustainable Development: between law making of the judge and fiction of the theory' in *Honor of the 75 years of the Council of State* (Sakkoulas Athens - Thessaloniki 2004). G. Vassilopoulos (ed), *The Contribution of Jurisprudence to the Evolution of Environmental Law: Sustainable Development* (Ant. N. Sakkoulas Athens - Komotini 2009).

that the period for which the definitive connection offer from biomass power plants is valid should not exceed thirty months.

2.4.3 Regulatory administrative acts and circulars

The following is an indicative list of regulatory administrative acts and circulars that largely specify the aforementioned legislation:[148]

Presidential Decree 126/1986 (Government Gazette A 44/17.04.1986) "Procedure for granting the exploitation, maintenance and improvement of forested areas owned by the State and public sector entities to forestry cooperatives"

Joint Ministerial Decision 58751/2370 (Government Gazette B 264/15.04.1993) "Determination of measures and conditions for the reduction of atmospheric pollution from large combustion plants"

Joint Ministerial Decision 76802/1033 (Government Gazette B 596/19.07.1996) "Amending and supplementing Joint Ministerial Decision 58751/2370/93: Determination of measures and conditions for the reduction of atmospheric pollution from large combustion plants"

Ministerial Decision Δ6/Φ1/13129 (Government Gazette B 766/28.08.1996) "Determination of infringements and procedures for imposing sanctions on power plants"

Ministerial Decision Δ5-ΗΛ/Β/Φ.1/17951 (Government Gazette B 1498/8.12.2000) "Regulation on the licenses for production and supply of electricity"

Joint Ministerial Decision 29457/1511 (Government Gazette B 992/14.07.2005) "Determination of measures and conditions for the limitation of emissions of certain pollutants into the air from large combustion plants"

Joint Ministerial Decision ΕΥΠΕ/ΥΠΕΧΟΔΕ/104247 (Government Gazette B 663/26.05.2006) "Procedure for the preliminary environmental assessment and evaluation and approval process for the environmental terms and conditions of RES projects"

Joint Ministerial Decision ΕΥΠΕ/ΥΠΕΧΟΔΕ/104248 (Government Gazette B 663/26.05.2006) "Content, supporting documents and other information considering the

[148] V. Alexandropoulou, A. Gourzi and Ant. Koukouritaki, *Renewable Energy Sources* (Sakkoulas Athens - Thessaloniki 2014). Th. Fortsakis, *Energy Law* (Sakkoulas Athens - Komotini 2009). Ch. Hadjikonstantinou, *Renewable Energy Sources* (Sakkoulas Athens - Thessaloniki 2019). M. Karagiorgas, D. Zacharias and A. Kirkou, *Environmental Guide on Renewable Energy Sources* (WWF Athens 2010). M. Meng - Papantonis, *Energy Law* (Nomiki Bibliothiki Athens 2003). Th. Panagos, *The Legal Regime of the Energy Market* (Sakkoulas Athens - Thessaloniki 2012). N. Tsokanas, 'Renewable Energy Sources through the political texts and legal acts of EU and the related legal regime of Greece' (2004) 2 *Environment and Law* 184. K. Vatalis, *Collection of Legislation on Renewable Energy Sources* (Sakkoulas Athens - Thessaloniki 2010). Ibid, *Introduction to the Law of Electricity from RES* (Sakkoulas Athens - Thessaloniki 2007).

Preliminary Environmental Impact Study, the Environmental Impact Study and the relevant environmental studies of RES Projects"

Ministerial Decision Δ6/Φ1/5707 (Government Gazette B 448/3.04.2007) "Regulation on the licenses for production of electricity from Renewable Energy Sources and through high efficiency cogeneration"

Decision of RAE/20.12.2007 "Evaluation Guide on Energy Efficiency of CHP projects"

Decision of the Committee coordinating government policy in the field of Spatial Planning and Sustainable Development 49828 (Government Gazette B 2464/3.12.2008) "Adoption of a Specific Framework for Spatial Planning and Sustainable Development for Renewable Energy Sources and a Strategic Environmental Impact Study"

Ministerial Decision ΥΠΑΝ/Δ5/-ΗΛ/Γ/Φ1/15606 (Government Gazette B 1420/15.07.2009) "Definition of harmonized efficiency reference values for separate production of heat and electricity"

Ministerial Decision ΥΠΑΝ/Δ5/-ΗΛ/Γ/Φ1/15641 (Government Gazette B 1420/15.07.2009) "Laying down detailed rules considering the method of calculation of electricity through CHP and the efficiency of cogeneration"

Ministerial Decision ΑΥ/Φ1/17149 (Government Gazette B 1497/6.09.2010) "Type and content of agreement on the purchase of electricity produced from RES and through high-efficiency cogeneration"

Ministerial Decision ΑΥ/Φ1/19598 (Government Gazette B 1630/11.10.2010) "Decision on the intended proportion of installed capacity and the temporal distribution of various RES technologies"

Ministerial Decision YAPE/F1/24839 (Government Gazette B 1901/3.12.2010) "Guarantee for the signing of contracts considering the connection of power plants using RES and being exempted from the obligation to obtain a production license, to the Distribution System"

Ministerial Decision ΥΑΠΕ/Φ1/14810 (Government Gazette B 2373/25.10.2011) "Regulation on the licenses for electricity production from Renewable Energy Sources and through high efficiency cogeneration"

Document ΥΠΕΚΑ ΥΑΠΕ/Φ1/24650/2.11.2011 "Clarifications on the environmental authorization of power plants using biomass/biogas of a capacity ≤ 0.5 MW"

Circular 4 ΥΠΕΚΑ/1604.81/3.04.2012 "Environmental authorization of power plants and CHP plants using biogas from anaerobic biomass processing"

Supplementary Circular ΥΠΕΚΑ/199437/14.06.2012 "Clarifications on Circular 4/2012: Environmental authorization of power plants and CHP plants using biogas from anaerobic biomass processing"

Ministerial Decision 166640 (Government Gazette B 554/8.03.2013) "Additional environmental licensing obligations for power plants and CHP plants using biogas from anaerobic biomass processing"

Document ΥΠΕΚΑ/ΔΙΠΑ/176282/12.12.2014 "Clarifications on the classification of power plant projects using biomass, biogas and bio liquids of a capacity ≤ 0.5 MW"

Ministerial Decision ΥΠΕΝ/ΔΑΠΕΕΚ/30971/1190/2020 (Government Gazette B 1045/26.03.2020) "Addition of new categories of power stations from RES and HEC and determination of Reference Prices and amendment of Reference Prices set in Table 1 of case b of paragraph 1 of Article 4 of Law 4414/2016".

Chapter 3: Biomass to energy conversion technologies

3.1 Introduction

Biomass is a renewable energy source which can be used to produce electricity, heat and transport fuels. It accounts for roughly two thirds of renewable energy in the European Union (EU). Although biomass can come from many different sources, wood is by far the most common. Under EU legislation, biomass is "carbon neutral", based on the assumption that the carbon released when solid biomass is burned will be re-absorbed during tree growth.[149]

More specifically, as it is illustrated in figure 3.1 [150], trees absorb carbon dioxide from the atmosphere and convert it into biomass. When trees are burned they release the same amount of carbon dioxide into the atmosphere. Thus, if trees used as biomass are replanted, the new trees absorb the carbon dioxide released during the combustion. As a result, the carbon cycle theoretically remains in balance, and no extra carbon is added to atmosphere.

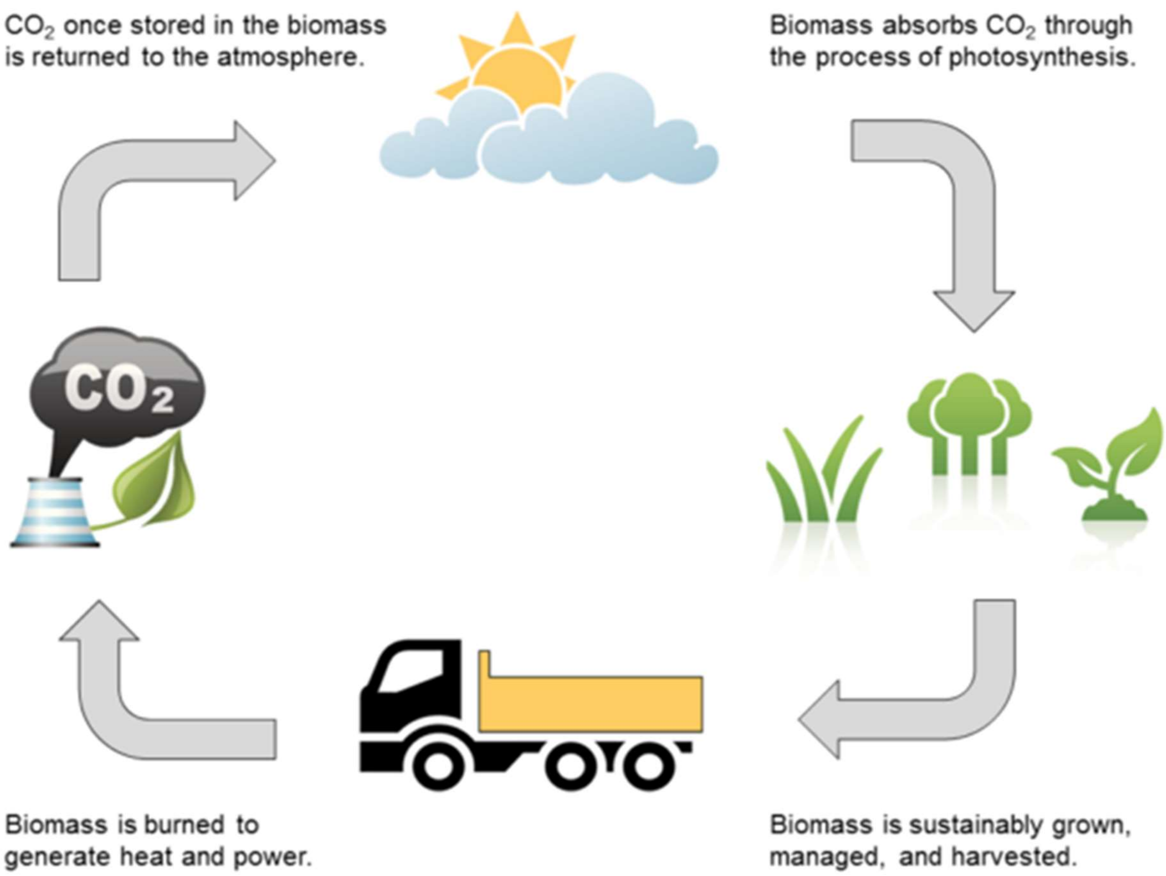

Figure 3.1 The carbon cycle of biomass

[149] Bourguignon D., Biomass for electricity and heating - Opportunities and challenges, Briefing September 2015, | European Parliamentary Research Service, https://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568329/EPRS_BRI(2015)568329_EN.pdf

[150]Biomass Compared to Fossil Fuels, Solar & Wind, https://www.viaspace.com/biomass_versus_alternatives.php

3.2 Definition of biomass

Biomass is an organic matter that has been in use since human beings started burning wood to make fires. It is a source of energy derived from plant material, urban garbage, and animal waste. It can regrow over a relatively short period of time. Biomass can be used directly through combustion or indirectly by converting it to biofuel.

Biomass is produced from solar energy by photosynthesis. Through the process of photosynthesis plants convert CO_2 from the air and water from the ground into carbohydrates, which on combustion gets back to CO_2 and water along with the release of solar energy absorbed during photosynthesis.[151]

According to Directive (EU) 2018/2001[152] of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast), in Article 2(24) - (28) were introduced the following definitions concerning biomass:

"Biomass" means the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin (Article 2(24));

Where:

"Agricultural biomass" means biomass produced from agriculture (Article 2(25));

"Forest biomass" means biomass produced from forestry (Article 2(26));

"Biomass fuels" means gaseous and solid fuels produced from biomass (Article 2(27));

"Biogas" means gaseous fuels produced from biomass (Article 2(28)).

3.3 Combined Heat and Power (CHP), Trigeneration and Polygeneration

Cogeneration (also known as combined heat and power, CHP) is the simultaneous production of electrical or mechanical energy (power) and useful thermal energy from a single energy stream such as oil, coal, natural or liquefied gas, biomass or solar.[153] The power generated is usually electricity, but can also be in other forms such as mechanical power for driving propeller, pumps, compressors, etc. Presently, industrial CHP power plants predominantly rely on natural gas, but biomass is becoming more important (13% share in total transformation input in 2017 and the second most used source).[154]

CHP production is a good example where the thermodynamic integration of processes leads inherently to higher effectiveness (up to 20%), fuel saving and therefore

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[151] Dipak K. and Sarkar, Termal Power Plant – Design and Operation, 2015 Elsevier Inc.

[152] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L2001

[153] Onovwiona HI, Ugursal VI. Residential cogeneration systems: review of the current technology. Renew Sustain Energy Rev 2006;10(5):389e431, https://doi.org/10.1016/j.rser.2004.07.005

[154] Malicoa I., Pereiraa R., Gonçalvesa A.,c, Sousaa A., Current status and future perspectives for energy production from solid biomass in the European industry, Renewable and Sustainable Energy Reviews Volume 112, September 2019, Pages 960-977, https://doi.org/10.1016/j.rser.2019.06.022

decrease of CO_2 emissions.[155] Furthermore, with the use of CHP systems is achieved a more reliable and secure energy supply.

In figure 3.2 is illustrated an example of comparison of a conventional power station and a boiler, and a CHP power plant. For 100 units of fuel, a CHP would typically produce around 30 units of electricity and 45 units of heat. To produce an equivalent level of heat and electricity, a conventional power station and boiler would need around 139 units of fuel, so CHP yields primary energy savings of around 39/139 or 28%.[156]

With limited available biomass resources, CHP power plants are gaining more and more importance, especially in countries with a high heat demand due to cold winters. For this reason, a considerable and growing share of the increasing electricity production from biomass is realized in CHP plants, depending on the frame conditions set by the respective government.[157]

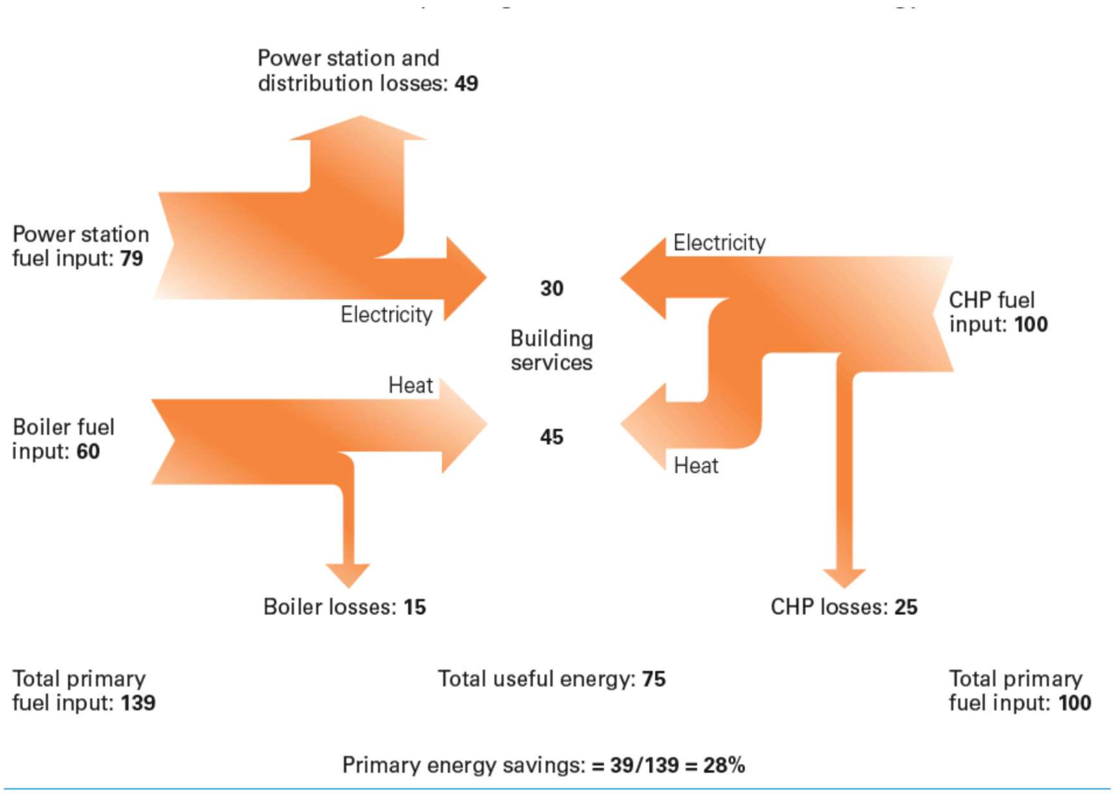

Figure 3.2 Energy savings through typical CHP to conventional sources of heat and power generation (shown in units of energy)

On the other hand, Trigeneration or Combined Cooling, Heat and Power system (CCHP) is one step ahead of cogeneration since it aims the simultaneous generation of

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[155] Liszka M, Malik T, Budnik M, Zie˛bik A. Comparison of IGCC (integrated gasification combined cycle) and CFB (circulating fluidized bed) cogenerationplants equipped with CO2 removal. Energy 2013;58:86e96., https://doi.org/10.1016/j.energy.2013.05.005

[156] Introducing combined heat and power, A new generation of energy and carbon savings, Technology guide, © Carbon Trust., Published in the UK: September 2010, https://www.theade.co.uk/assets/docs/resources/CarbonTrustCHPguide-Finalversion.pdf

[157]Meyers R., Encyclopedia of Sustainability Science and Technology, © Springer ScienceþBusiness Media, LLC 2012

electricity, useful heating and cooling from a single fuel source.[158] In addition to the heat processes, waste heat is used to produce cooling either by thermally driven heat pumps or desiccant systems.[159] As a result, with the application of trigeneration higher effectiveness, fuel saving and therefore decrease of CO_2 emissions could be achieved.

Finally, in a polygeneration system, besides the generation of power, heat and cooling, additional processes can be included into the system to make added-value products such as fuels, chemicals and fresh water, amongst others. In these type of systems, low grade heat can also be effectively used.[160] These systems can be a sustainable energy solution with higher efficiency and optimum resources' use since they allow efficient process integration with multiple inputs and outputs.[161]

3.4 Biomass to Energy Conversion Technologies

Biomass feedstocks are very diverse, which is reflected in a variety of conversion processes. In figure 3.3 are depicted the main routes of biomass to final products, such as heat, electricity, fuels and chemicals. Because some properties of raw biomass are not suitable for the respective conversion processes, it is often pretreated by an appropriate method, which can include size reduction, densification, drying and torrefaction.[162]

Factors that influence the choice of conversion process are: the type and quantity of biomass feedstock; the desired form of the energy, i.e. end-use requirements; environmental standards; economic conditions; and project specific factors. In many situations it is the form in which the energy is required that determines the process route, followed by the available types and quantities of biomass.[163]

Conversion of biomass to final products is executed by using three main process technologies: thermochemical, biochemical and chemical. Nowadays, the dominant conversion pathway for biomass is based on thermochemical methods. Within thermochemical conversion three main processes are available: combustion, gasification and pyrolysis. Thermochemical methods are less specific as concerns biomass chemical composition compared to the other methods and almost all types of biomass can be processed by these methods. Many different products such as heat, electricity, fuels and chemicals can be produced by these methods.

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[158] Moussawi HA, Fardoun F, Louahlia-Gualous H. Review of tri-generation technologies: design evaluation, optimization, decision-making, and selection approach, Energy Convers Manag 2016;120:157–96, https://doi.org/10.1016/j.enconman.2016.04.085

[159] Segurado R., Pereira S., Correia D., Costa M. Techno-economic analysis of a trigeneration system based on biomass gasification, Renewable and Sustainable Energy Reviews 103 (2019), p. 503, https://doi.org/10.1016/j.rser.2019.01.008

[160] Murugan S, Horák B. Tri and polygeneration systems – a review. Renew Sustain Energy Rev 2016;60:1032–51., https://doi.org/10.1016/j.rser.2016.01.127

[161] Jana K, Ray A, Majoumerd MM, Assadi M, De S. Polygeneration as a future sustainable energy solution – A comprehensive review. Appl Energy 2017;202:88–111., https://doi.org/10.1016/j.apenergy.2017.05.129

[162] Ptasinski K., EFFICIENCY OF BIOMASS ENERGY, An Exergy Approach to Biofuels, Power, and Biorefineries, 2016 John Wiley & Sons, Inc, p.22

[163] McKendry P., Energy production from biomass (part 2): conversion technologies, Bioresource Technology 83 (2002) 47–54, p. 47-48. https://doi.org/10.1016/S0960-8524(01)00119-5

Furthermore, there is a fourth process within thermochemical conversion of biomass, called hydrothermal liquefaction of biomass, which is the thermochemical conversion of biomass into liquid fuels by processing in a hot, pressurized water environment for sufficient time to break down the solid bio polymeric structure to

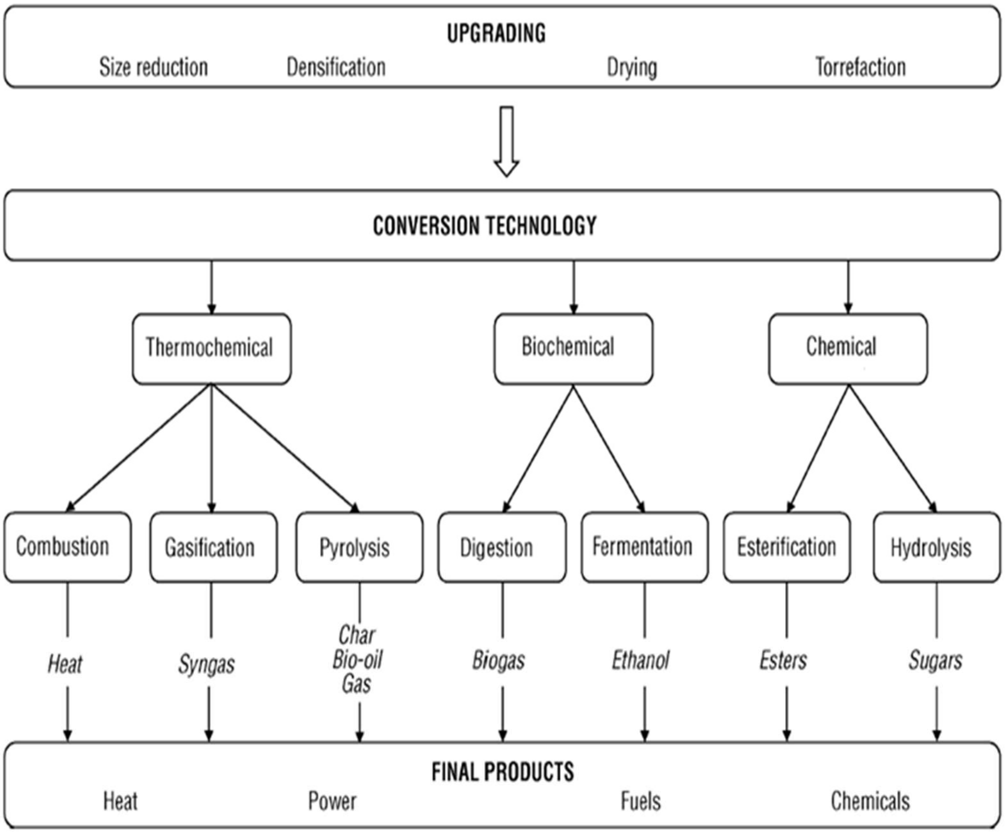

Figure 3.3 Main biomass conversion methods

mainly liquid components. The low operating temperature, high energy efficiency and low tar yield compared to pyrolysis is the key parameter that drives the attention of researchers on the liquefaction process.[164] In figure 3.5 [165]are summarized the main characteristics of the thermochemical processes.

Biochemical conversion process includes two available technologies, known as digestion and fermentation. Digestion is a chain of interconnected biological reactions in which organic matter is transformed into a gaseous mixture of methane, carbon dioxide, and small quantities of other gases, such as hydrogen sulphides, in an oxygen-free environment.[166] During the process, the biomass is converted by bacteria in an oxygen-free environment, producing a gas with an energy content of approximately

[164] Gollakota A., Kishore N., Gu S., A review on hydrothermal liquefaction of biomass, Renewable and Sustainable Energy Reviews Volume 81, Part 1, January 2018, Pages 1378-1392, https://doi.org/10.1016/j.rser.2017.05.178
[165] Pandey A., Bhaskar T., Stöcker M., Sukumaran R., RECENT ADVANCES IN THERMOCHEMICAL CONVERSION OF BIOMASS, Copyright © 2015 Elsevier B.V. All rights reserved., https://doi.org/10.1016/C2013-0-00403-3
[166] Yilmaz, S., and H. Selim. 2013. A review on the methods for biomass to energy conversion systems design, Renewable & Sustainable Energy Reviews, 25: 420–430, https://doi.org/10.1016/j.rser.2013.05.015

20%–40% of the lower heating value of the feedstock.[167] On the other hand, the fermentation of the sugars into alcohols, such as ethanol, includes biomass pre-treatment followed by fermentation of the sugars to ethanol then separation and purification to produce pure ethanol.[168] The efficiency of the biochemical conversion process is between 35%wt and 50%wt.[169]

Chemical processes are those processes that carry a change in the chemical structure of the molecule by reacting with other substances. Chemical conversion process includes esterification and hydrolysis.[170] An esterification reaction happens between an oil or a fat and an alcohol, usually of short length, in the presence of a catalyst and heating with the release of a mono-alkyl ester.[171] The resulting mono-alkyl ester shows characteristics similar to those of diesel derived from petrol, being then denominated as biodiesel.[172] On the other hand, with acid hydrolysis of lignocellulosic waste from agriculture and industry can be obtained fermentable sugars.[173]

3.4.1 Thermochemical Conversion Technologies

This study will focus on thermochemical technologies which are mainly used for the Combined Heat and Power (CHP) generation. In figure 3.4 [174] are depicted the main

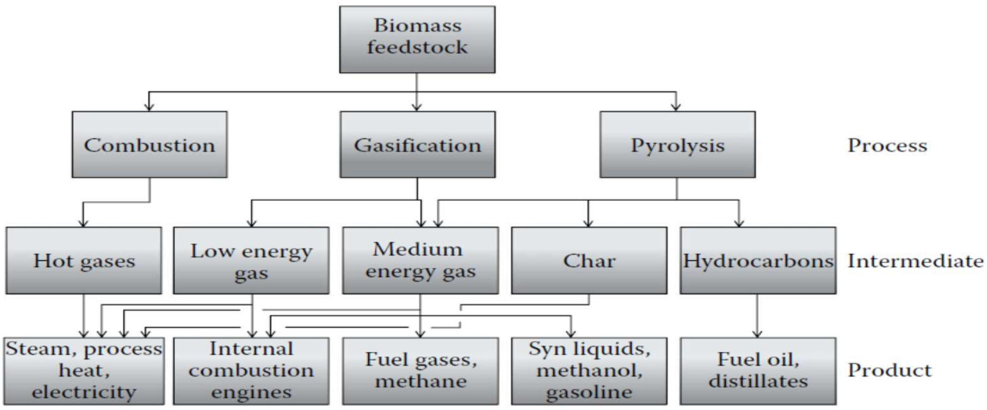

Figure 3.4 The main routes for the thermochemical conversion of biomass to power

[167] McKendry, P. 2002. Energy production from biomass (part 2): Conversion technologies, Bioresource Technology, 83: 47–54, https://doi.org/10.1016/S0960-8524(01)00119-5
[168] Ullah, K., Kumar Sharma, V., Dhingra, S., Braccio, G., Ahmad, M. and Sofia, S. 2015. Assessing the lignocellulosic biomass resources potential in developing countries: A critical review. Renewable and Sustainable Energy Reviews, 51, 682–698, https://doi.org/10.1016/j.rser.2015.06.044
[169] Singh, N. R., Delgass, W. N., Ribeiro, F. H. and Agrawal, R. 2010. Estimation of liquid fuel yields from biomass. Environmental Science and Technology, 44, 5298–5305, DOI: 10.1021/es100316z
[170] F. Cherubini, The biorefinery concept: using biomass instead of oil for producing energy and chemicals, Energy Convers. Manage. 51 (2010) 1412–1421, https://doi.org/10.1016/j.enconman.2010.01.015
[171] Sílvio Vaz Jr., Biomass and Green Chemistry, Building a Renewable Pathway, Springer International Publishing AG 2018, https://doi.org/10.1007/978-3-319-66736-2
[172] Knothe G (2016) Biodiesel and its properties. In: McKeon T, Hayes T, Hildebrand D, et al (eds) Industrial oil crops. Academic Press, New York, p 474; Chapter 2, pp 15–42, https://doi.org/10.1016/B978-1-893997-98-1.00002-6
[173] Swaaij W., Kersten S., and Palz W., Transformations to Effective Use BIOMASS POWER for the World, 2015 by Taylor & Francis Group, LLC, CRC Press
[174] Cheng J., Biomass to Renewable Energy Processes Second Edition, CRC Press, 2018 by Taylor & Francis Group, p. 384.

routes for the thermochemical conversion of biomass to power, fuels and chemicals. Thermochemical methods of conversion have major advantages as these methods

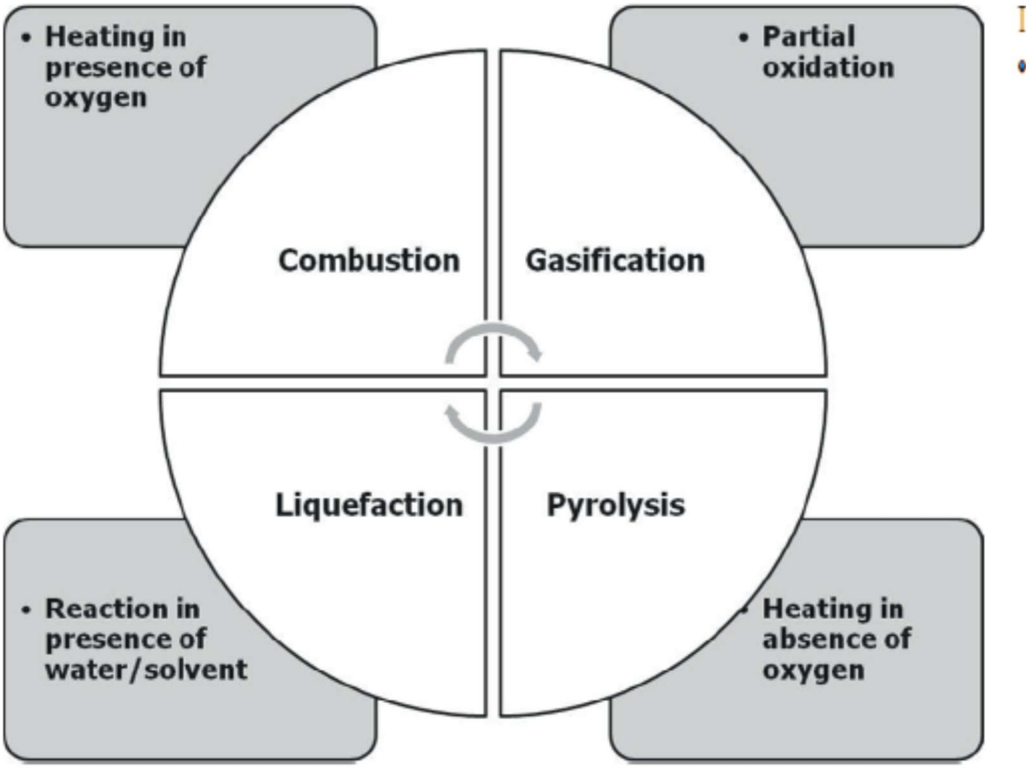

Figure 3.5 The main characteristics of Thermochemical methods of conversion

utilize the entire biomass. This eliminates the cost and energy input of pretreatment whether in the form of acid hydrolysis, enzyme hydrolysis, or various other methods.[175]

3.4.2 Combustion

Combustion is a mature technology that has been successfully applied in industry for many decades. Combustion is the heating of any biomass material in the presence of oxygen. In figure 3.6 [176] are depicted the main reactors that can be used for combustion of biomass.

Grate firing, which is often called "fixed-bed" technology, is the oldest firing principle used in boilers. The typical operating principle in the grate firing of biomass fuels differs from that of coal. Sloped grates are typically used for biomass fuels (see figure 3.7). They can be static or mechanically activated. Although originally invented

[175] Pandey A., Bhaskar T., Stöcker M., Sukumaran R., RECENT ADVANCES IN THERMOCHEMICAL CONVERSION OF BIOMASS, Copyright © 2015 Elsevier B.V. All rights reserved., https://doi.org/10.1016/C2013-0-00403-3

[176] Pandey A., Bhaskar T., Stöcker M., Sukumaran R., RECENT ADVANCES IN THERMOCHEMICAL CONVERSION OF BIOMASS, Copyright © 2015 Elsevier B.V. All rights reserved., https://doi.org/10.1016/C2013-0-00403-3

as a coal-firing technology spreader stoker combustion is particularly suited to biomass combustion and is typically used in boilers up to 150 MWth.[177]

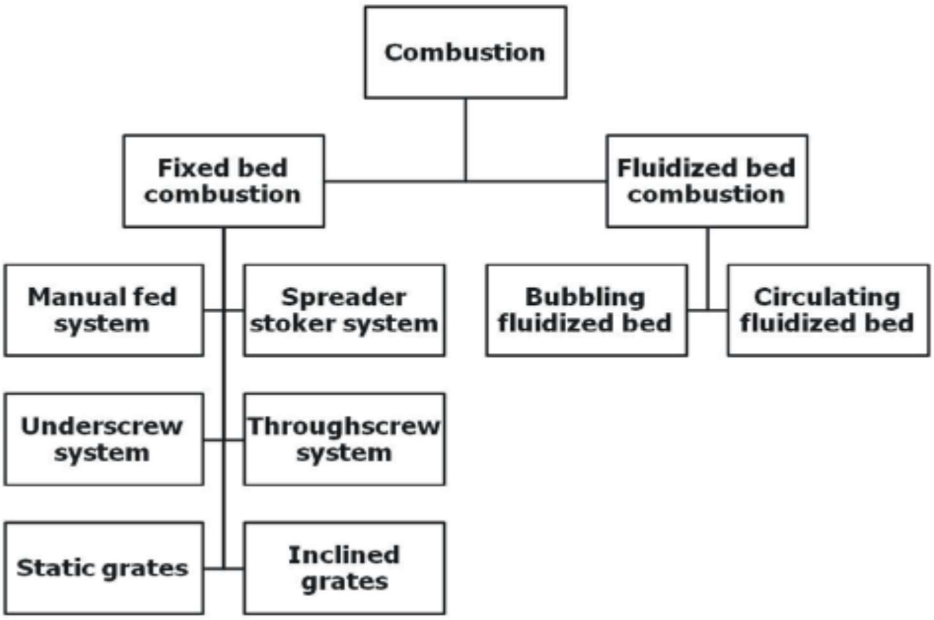

Figure 3.6 Main reactors for combustion of biomass

Fluidized bed combustion is used widely for biomass fuels. Two fluidized bed combustion technologies are available: bubbling fluidized bed (BFB) and circulating fluidized bed (CFB). Both are proven technologies. BFB boilers are often preferred in

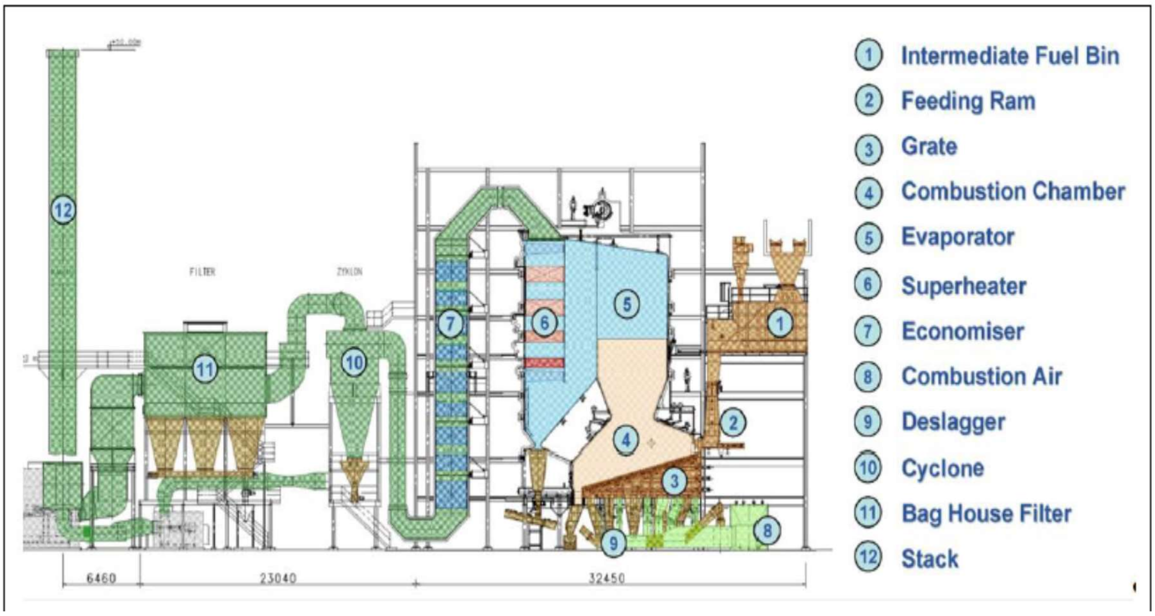

Figure 3.7 Water-cooled vibrating moving grate system with sloped grate boiler for biomass

[177] Lecomte T., Ferrería de la Fuente J., Neuwahl F., Canova M., Pinasseau A., Jankov I., Brinkmann T., Roudier S., Sancho L., Best Available Techniques (BAT) Reference Document for Large Combustion Plants, 2017, JRC SCIENCE FOR POLICY REPORT,

small-scale applications, with fuels having low heating value and high moisture content. CFB boilers are normally used in larger applications.[178]

3.4.3 Gasification

Gasification, among other thermochemical conversion methods, is marked as a prominent route for generating a clean and less polluting intermediate gas for high efficiency power generation.[179] With this process biomass is converted to a gaseous product, termed as producer gas or product gas, which consists mainly of CO, H_2, CO_2 and CH_4, as well as other hydrocarbon species. The gasification process operates at temperatures from 700 to 1200 °C. [180] Gasification takes place with the presence of agents such as O_2, air, steam and CO_2 or their mixtures.

There are two types of gasification: common gasification of biomass is a partial oxidization process by air or pure oxygen. [181] Another type of gasification in a supercritical aqueous environment is called HTG; biomass is gasified to syngas and methane under supercritical and nonoxidative conditions.[182] Different categories of gasification with their working conditions and products are summarized in figure 3.8.[183]

Process	**Working conditions**	**Products**	**Heating value (MJ/m^3)**
Partial oxidation with air	700°C–900°C; ST atm	CO, CO_2, H_2, CH_4, N_2, tar	~5
Partial oxidation with oxygen	700°C–900°C; ST atm	CO, CO_2, H_2, CH_4, tar	~10–12
HTG	≥ 370°C; ≥ 22 MPa	CO, CO_2, H_2, CH_4, tar	~15–20

ST atm refers to standard atmospheric pressure.

Figure 3.8 Categories of gasification

[178] Converting Biomass to Energy, A Guide for Developers and Investors, © 2017 International Finance Corporation, http://documents.worldbank.org/curated/en/451461502956339912/pdf/118738-WP-BioMass-report-06-2017-PUBLIC.pdf

[179] AlNoussa A., McKaya G., Al-Ansari T., A comparison of steam and oxygen fed biomass gasification through a techno-economic-environmental study, Energy Conversion and Management, Volume 208, 15 March 2020, 112612, p. 13., https://doi.org/10.1016/j.enconman.2020.112612

[180] Shusheng Pang, Advances in thermochemical conversion of woody biomass to energy, fuels and chemicals, Biotechnology Advances, Volume 37, Issue 4, July–August 2019, Pages 589-597, https://doi.org/10.1016/j.biotechadv.2018.11.004

[181] Zhang Jiajun and Zhang Xiaolei, The thermochemical conversion of biomass into biofuels, Elsevier 2019, p. 352, https://doi.org/10.1016/B978-0-08-102426-3.00015-1

[182] Toor SS, Rosendahl L, Rudolf A. Hydrothermal liquefaction of biomass: a review of subcritical water technologies. Energy 2011;36:2328_42. Available from: https://doi.org/10.1016/j.energy.2011.03.013.

[183] Bridgwater AV. Renewable fuels and chemicals by thermal processing of biomass. Chem Eng J 2003;91:87102. Available from: https://doi.org/10.1016/S1385-8947(02)00142-0.

Technologies used for gasification can broadly be classified into four groups; fixed bed or moving bed gasification, fluidized bed gasification, entrained bed gasification, and plasma gasification. For biomass gasification are used mainly two types of reactors: fixed bed gasifiers and fluidized bed gasifiers.[184]

Fixed bed gasifiers are the oldest type and are used for small scale applications up to 10 MW. Therefore, fixed bed gasifiers are mostly used for decentralized power generation using biomass. In fixed bed gasifiers, different reaction zones are separated. On the other hand, in fluidized bed gasifier drying, pyrolysis, oxidation, and reduction zones are not apparent at any specific region of the gasifier. Fluidized bed gasifiers are suitable for small to medium scale (500 kW to 50 MW) application. Although the fluidized bed gasifiers are used for gasification of both coal and biomass, they are becoming more popular for biomass gasification due to lower gasification temperature of biomass compared to coal.[185]

After expensive cleaning processes, the gas produced by gasification can be used directly without any further chemical transformation, for example, in an engine, a gas turbine, or even a fuel cell to provide heat and/or electricity. Alternatively, the gas can undergo a subsequent synthesis process to be converted into a liquid or gaseous biofuel with clearly defined properties (e.g., Fischer-Tropsch diesel, synthetic natural gas (biomethane), hydrogen) for an easy use within the transportation sector, for example.[186]

3.4.4 Pyrolysis

Pyrolysis is another thermochemical technology capable of transforming lignocellulosic biomass into high value products. The term pyrolysis is very self-explanatory in its root, deriving from the Ancient Greek words pyro (πυρ) meaning heat and lysis (λύσις) meaning rupture. Pyrolysis is mainly associated with thermal decomposition of organic compounds, as they are heated in the absence of oxygen or any other reactive element. As shown in figure 3.9 [187], pyrolysis processes are usually classified in two categories depending on the target product: solid charcoal in slow pyrolysis and liquid oils in fast pyrolysis.[188]

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[184] Warnecke R., Gasification of biomass: Comparison of fixed bed and fluidized bed gasifier, Biomass and Bioenergy 18(6):489-497 · June 2000, https://doi.org/10.1016/S0961-9534(00)00009-X

[185] Loha C., Karmakar M., Chatterjee P., Gasifiers: Types, Operational Principles, and Commercial Forms, Springer Nature Singapore Pte Ltd. 2018, p.64-65 and 69-70.

[186] Kaltschmitt Martin, Energy from Organic Materials (Biomass) – A Volume in the Encyclopedia of Sustainability Science and Technology, Second Edition, Springer 2019, P.360-361.

[187] Haggerty A., Biomass Crops: Production, Energy and the Environment, 2011 by Nova Science Publishers, Inc., p.5.

[188] San Miguel G, Makibar J. and Fernandez-Akarregi A., Conversion of Wood into Liquid Fuels: A Review of the Science and Technology Behind the Fast Pyrolysis of Biomass, Advances in Building Energy Research 7:1-88 · October 2011

Process		Product yields (wt%)			Conditions	Enthalpy
		Liquid	Char	Gas		
Pyrolysis	Slow	15-25	30-40	30-40	Low temperature (300-600°C). Long vapor residence time (> 1 min) Inert atmosphere	Endothermic/ Exothermic
	Fast	60-75	10-15	15-30	Moderate temperature (450-500°C). Short vapor residence time (< 2 sec) Inert atmosphere	Slightly endothermic
Gasification		0-5	5-10	85-95	Very high temperature (850-1000°C). Mildly oxidizing conditions	Endothermic
Combustion		0	0-5	95-100	High temperatures (700-850°C). Highly oxidizing conditions.	Highly exothermic

Figure 3.9 Typical product yields, reaction conditions and enthalpy in the pyrolysis of biomass, compared against combustion and gasification technologies

The pyrolysis of biomass faces challenges in terms of biofuel application owing to unfavorable properties of bio-oil, such as high acidity as well as high water and alkali metal contents, which makes such bio-oil difficult to exploit as fuels. These properties can also make downstream conversion to valuable chemicals more difficult.[189] Pyrolysis research is receiving more attention with new organizations beginning research in the area at a rapid rate.[190]

3.5 Combustion Commercial Technologies

One of the most important aspects for plant owners is whether the chosen technology is commercial and proven, as this is crucial for securing a reliable and stable production of electricity and/or heat/steam. The use of proven and commercial technology is also very important for the financial viability and robustness of the project and thus affects the possibilities for securing financing.[191]

In figure 3.10 [149] is illustrated the current development status of biomass conversion technologies, including the five technologies that are proven and commercial. The selection of the technology that will be applied for each case is a complicated procedure that depends on many parameters such as investment cost, type of biomass, size of power plant, thermal power consumption, etc.

However, the very early and most important selection relates to the moisture content in the fuel. If the fuel is very wet, usually above 60 to 65 percent, the calorific

[189] Clark J., Luque R., Matharu A., Green chemistry, biofuels, and biorefinery, Annu. Rev. Chem. Biomol. Eng. 3 (2012) 183–207, DOI: 10.1146/annurev-chembioeng-062011-081014
[190] Pandey A., Bhaskar T., Stöcker M., Sukumaran R., RECENT ADVANCES IN THERMOCHEMICAL CONVERSION OF BIOMASS, Copyright © 2015 Elsevier B.V. All rights reserved., https://doi.org/10.1016/C2013-0-00403-3
[191] Converting Biomass to Energy, A Guide for Developers and Investors, © 2017 International Finance Corporation, http://documents.worldbank.org/curated/en/451461502956339912/pdf/118738-WP-BioMass-report-06-2017-PUBLIC.pdf

value of the biomass is too low for combustion and a biogas plant is the only relevant option, unless drying of the fuel is considered.[192]

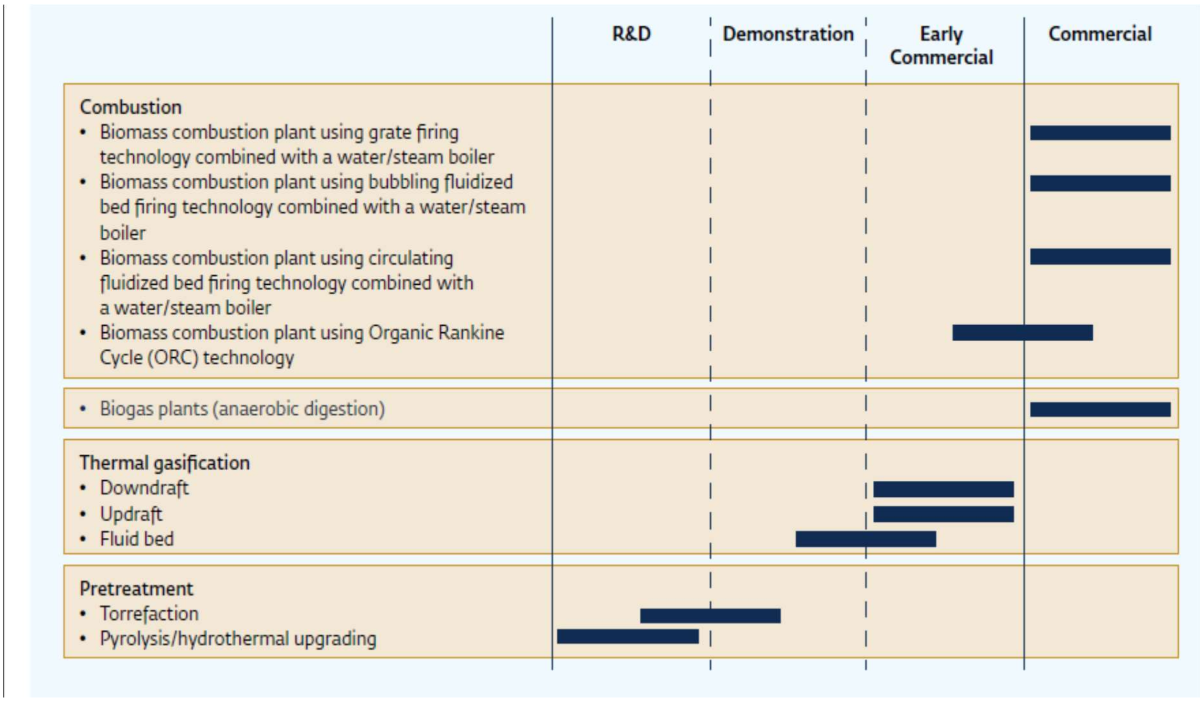

Figure 3.10 Overview of biomass conversion technologies and their current development status

Furthermore, as concerns the capacity of the biomass power plants in figures 3.11 and 3.12 [193] are illustrated the appropriate technologies depending on the electrical capacity. As it derives from the above-mentioned figures overlap might occur between

Technology	1–5 MWe	5–10 MWe	10–40 MWe
Grate technology	X	X	X
Bubbling fluidized bed (BFB) technology		X	X
Circulating fluidized bed (CFB) technology			X

Source: COWI.

Figure 3.11 Steam-cycle Technologies according to Size

Range	1–5 MWe (4–20 MWth)	5–10 MWe (20–40 MWth)	10–40 MWe (40–160 MWth)
Combustion plants using a water/steam boiler (steam technology)	X	X	X
Combustion plants using ORC technology	X	X	n.a.
Biogas technology	X	n.a.	n.a.

Source: COWI.

Figure 3.12 Overview of Technologies and Plant Sizes

[192] Converting Biomass to Energy, A Guide for Developers and Investors, © 2017 International Finance Corporation, http://documents.worldbank.org/curated/en/451461502956339912/pdf/118738-WP-BioMass-report-06-2017-PUBLIC.pdf
[193] COWI A/S, https://www.cowi.com/

groups for specific capacities. Finally, for the steam-cycle technologies the grate technology is best fit for the case of loose biomass.

3.6 Pros and cons of biomass

3.6.1 Pros

The use of biomass is characterized by many benefits. One of the most important advantage of Biomass is that is a renewable, abundant and sustainable form of energy. The use of biomass for energy production contributes to the reduction of CO_2 emissions since it is considered "carbon neutral". This happens because biomass has absorbed during its life equal quantity of CO_2 to the amount emitted when burned, provided that biomass is entirely renewed, and that cut and renewed biomass absorbs equal amounts of CO_2.[194]

In addition, by using biomass is reduced the dependency on fossil fuels like oil and gas, and every country can utilize its own biomass resources.[195] Thus, it is promoted the decarbonization of energy sector. Furthermore, by this way is reduced the dependence of countries on imports of fossil fuels and as a result the respective savings could be invested for biomass related business development or other activities.

The high Volatile Matter (VM) content (especially combustible VM) and low initial ignition and combustion temperatures are among the greatest advantages of biomass for thermochemical conversion because they are criteria for the highly reactive nature of this fuel[196].

Due to the low content of biomass in sulfur (S), the SO_2 emissions are lower in comparison with the related emissions of fossil fuels. However, in a complicated supply system of biomass production, this advantage may be eliminated because of fossil fuels usage in these systems (for biomass cultivation, harvesting, preparation and transportation stages)[197].

The low nitrogen (N) content in biomass (especially for wood and woody biomass)[198] is a big advantage due to decreased NO_X and ammonia (NH_3) emissions,

[194] Fotiadis M., The Greek Biofuel market: Trends, prospects and challenges, Thesis for MSc Energy, 2016, p. 16, Pireaus.
[195] Biomass Combined Heat and Power Catalog of Technologies, U.S. Environmental Protection Agency and Combined Heat and Power Partnership, U.S. EPA, 2007, https://www.epa.gov/sites/production/files/2015-07/documents/biomass_combined_heat_and_power_catalog_of_technologies_v.1.1.pdf
[196] Demirbas A. Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues. Prog Energ Combust 2005;31:171–92, https://doi.org/10.1016/j.pecs.2005.02.002
[197] Petrou E. and Pappis C., Biofuels: A Survey on Pros and Cons, Energy and Fuels, 2009, 23, p. 1062-1064, Pireaus, DOI: 10.1021/ef800806g
[198] Vassilev S, Baxter D, Andersen L, Vassileva C. An overview of the chemical composition of biomass. Fuel 2010; 89: 913–33, https://doi.org/10.1016/j.fuel.2009.10.022

acid precipitation, ozone pollution, photochemical smog and corrosion problems during thermochemical conversion.[199]

Biomass can be used for electricity generation in the same plants that are burning fossil fuels with minor retrofits. Thus, power plants that are planned to phase out could be used for biomass burning. Furthermore, biomass is suitable for co-firing in existing fossil fuel burning power plants, minimizing thus the total emission of GHG and other pollutants.

The usage of biomass for energy generation could significantly contribute to the reduction of dumping waste in landfills. Furthermore, with this way would be created fuel from products that otherwise should be discarded.

Biomass is widely available and can be found almost anywhere. Due to this fact distributed small scale CHP plants could be constructed and as a result the security of energy supply would be enhanced. Furthermore, job opportunities at all the stages of biomass production (cultivation, preparation, transportation, processing, etc.) would be created. Especially, growing biomass corps could help to boost local economies, decrease unemployment and improve the quality of air.

Another advantage of biomass is that it can be used in many forms such as solid (briquettes, pellets, wood, sewage, industrial wastes etc.), liquid (biodiesel, bioethanol, etc.) or gaseous (methane, hydrogen, etc.). Thus, the applications of biomass for energy production are unlimited.

3.6.2 Cons

While the advantages of biomass energy are plenty, there are also some shortcomings. There are some drawbacks of biomass energy utilization compared to fossil fuels: heterogeneous and uneven composition, lower calorific value and quality deterioration due to biodegradation.[200] The lower calorific value of biomass than most coal is in part due to the generally higher moisture content and in part due to the high oxygen content.[201]

Seasonal/annual fluctuation in biomass supply, due to its biological nature and environmental diversity, is another important drawback.[202] Thus, costly big storehouses should be constructed for its storage. Moreover, the cost of biomass is higher than the respective of fossil fuel.

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[199] Vassilev S, Vassileva C, Vassilev V. Advantages and disadvantages of composition and properties of biomass in comparison with coal: An overview. Fuel 2015; JFUE 9280: p. 13, https://doi.org/10.1016/j.fuel.2015.05.050

[200] Sadrul Islam A. K. M. and Ahiduzzaman M., Biomass Energy: Sustainable Solution for Greenhouse Gas Emission. AIP Conf. Proc. 1440, 23 (2012); p. 27, DOI: 10.1063/1.4704200

[201] Demirbas A. Combustion characteristics of different biomass fuels. Progress in Energy and Combustion Science 30 (2004) 219–230, p.228, https://doi.org/10.1016/j.pecs.2003.10.004

[202] IEA-ETSAP and IRENA, Biomass for Heat and Power:, Technology Brief, 2015, https://www.irena.org/publications/2015/Jan/Biomass-for-Heat-and-Power

To grow the plants and trees for biomass is required a lot of space. In many cases this leads to widespread deforestation and to extinctions of species of wildlife. Furthermore, the biomass cultivation many times is competitive with the cultivation of food corps, requires huge quantities of water and leads to sharp rise in food commodity prices quickly accompanied by food riots in the cities of many developing countries.[203]

Direct combustion of any carbon-based fuel like biomass leads to air pollution similar to that from fossil. As it was analyzed in previous section 3.6.1, the SO_2 and NO_x emissions of biomass are significantly lower than the respective of fossil fuels. However, due to the high contents of some toxic and potentially toxic Trace Elements (TEs) such as Ag, Be, Cd, Cl, Cr, Cu, Mn, Ni, Se, Zn, others in biomass, and especially those with unfavourable modes of occurrences, are among the most serious disadvantages during biomass conversion.[204] It was found that the thermochemical conversion of biomass can increase the negative TE impacts because significant amounts of TEs (As, Cd, Cr, Cu, Ni, V and Zn) that have been mobilized from geochemically stable sources are remobilized during biomass conversion.[205] Another negative impact concerning the supply chain of solid biofuels production is heavy metal (Pb, Hg, etc.) and dioxin emissions. This problem is mainly related with Refused Derived Fuels (RDFs) used as a fuel (but even with virgin biomass under certain conditions) and constitutes a conflict of interest between the various stakeholders.[206]

Transporting waste from forestry and industry to a biomass plant also carries a significant carbon footprint from the petroleum used by transportation. This release of greenhouse gases may be a secondary environmental impact from biomass energy generation, but it's important nonetheless.[207]

3.7 References of biomass CHP power plants

Herein below are summarized data for many CHP biomass burning power plants that have similar characteristics with the one under study in the techno-economic assessment that is presented in Chapter 4.

Table 3.1 References of biomass CHP power plants

Name of Plant	Technology	Electrical power (MWe)	Thermal power (MWth)	Total efficiency	Year of Construction
Pärnu, ESTONIA	Steam turbine	24	45+5	N/A	2009

[203] HLPE (2013), Biofuels and food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, p.55, Rome, Italy

[204] Vassilev S, Vassileva C, Baxter D. Trace element concentrations and associations in some biomass ashes. Fuel 2014;129: p.292–313, https://doi.org/10.1016/j.fuel.2014.04.001

[205] Reijnders L., Conditions for the sustainability of biomass based fuel use. Energy Policy 2006;34:863–76.

[206] Petrou E. and Pappis C., Biofuels: A Survey on Pros and Cons, Energy and Fuels, 2009, 23, p. 1064, Pireaus, DOI: 10.1021/ef800806g

[207] Negative Effects of Biomass, https://sciencing.com/negative-effects-biomass-19624.html.

Fortum Tartu, ESTONIA	Steam turbine	25	50+15	N/A	2009
Częstochowa, Poland	CFB	64.5	120	N/A	2010
Iisalmi, Finland	BFB	14.7	30	93%	2002
Kotka, Finland	BFB	17	56	90%	2003
Savonlinna, Finland	BFB	17	53	86%	2003
Kokkola, Finland	BFB	20	50	89%	2002
Härnösand, Sweden	BFB	11.7	26+7	106%	2002
Hudiksvall, Sweden	Grate	13	36	82%	1992
Kristianstad, Sweden	CFB	13.5	35	87%	1994
Lycksele, Sweden	CFB	14	28	84%	2001
Karlstad, Sweden	CFB	20	55+20	108%	1992
Fynsvaerket, Denmark	Grate	35.2	85	102.30%	2006
Maribo-Sakskøbing, Denmark	Grate	9.7	20	89%	1999
Siauliai, Lithuania	Grate	9.8	40	101%	N/A
Boras Energi, Sweden	CFB	10	40	89%	2004
Gallivare Energi, Sweden	N/A	8	34	85%	2010
Lycksele, Sweden	N/A	16	51	91%	2000
Funsverket, Denmark	Grate	35	86	N/A	2009
Wittgenstein, Germany	N/A	8	30	70%	2009
N/A : Not Available,	References [208,209,210,211]				

[208] Sipilä K., Pursiheimo E., Savola T., Fogelholm C., Keppo I. & Ahtila P., SmallScale Biomass CHP Plant and District Heating, Copyright © VTT 2005

[209] Biomass Combined Heat and Power Catalog of Technologies, U.S. Environmental Protection Agency and Combined Heat and Power Partnership, U.S. EPA, 2007, https://www.epa.gov/sites/production/files/2015-07/documents/biomass_combined_heat_and_power_catalog_of_technologies_v.1.1.pdf

[210] Paul Lako, Biomass for heat and power, ETSAP Energy Technology Systems Analysis Programme, , IEA ETSAP - Technology Brief E05 - May 2010, p. 2., https://iea-etsap.org/E-TechDS/PDF/E04-CHP-GS-gct_ADfinal.pdf

[211] Thorin E., Sandberg J., Jinyue Yan J., Combined Heat and Power, https://doi.org/10.1002/9781118991978.hces021

Chapter 4: Extensive Techno-Economic Assessment of a Biomass CHP power plant to supply with District Heating Energy the city of Amynteon

4.1 Introduction

In this chapter we will study the feasibility of a biomass Combined Heat and Power (CHP) power plant that will supply with thermal energy the District Heating Network (DHN) of Amynteon city located in the Florina regional unit of Macedonia, Greece.

At the beginning, are estimated the thermal loads that are required by the DHN of Amynteon during the heating season. Following, is estimated the electrical power of the CHP power plant. Then, is executed a technical study concerning the technology of the power plant and the supply of biomass. Afterwards, is analyzed the regulation framework during all the stages of the Project (construction, commissioning, Commercial Operation, Acceptance Tests, etc.). Furthermore, an extensive economic assessment including sensitivity analysis of various key parameters of the Project is executed, taking into consideration the updated data of the Greek Energy Market. Finally, an optimization study for maximizing the Internal Rate of Return (IRR) of the CHP plant's investment by installing a Thermal Energy Storage (TES) system in parallel with the CHP plant is executed.

4.2 Current status of Amynteon's DHN

The biomass CHP plants connected to DHN are considered a very good opportunity in order to increase the RES into energy systems. Indeed, large CHP plants combine high conversion efficiency, high availability and low operation costs. From an environmental point of view, the use of biomass allows a significant reduction of CO_2 emissions compared to the use of fossil fuels due to their low emission levels.[212]

Nowadays, the Municipal District Heating Company of Amynteon (DETEPA) operates a District Heating Production System (DHPS) supplying thermal energy to Amynteon city and the villages Filotas and Levaia with thermal energy produced with co-generation in the Amynteon – Filotas PPC lignite fired power plant. The capacity of this DHPS is 25 MWth. The thermal energy is produced by steam extraction from Unit I or II and subsequent condensation of the steam in a heat exchanger, through which the District Heating (DH) water is circulated. The DH water is supplied at the exit of DHPS at 120^{o}C and returns form the city at 70^{o}C. The flow rate of the DH water is 427 m^3/h.[213]

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[212] Klass DL. Biomass for Renewable Energy, Fuels, and Chemicals [Internet]. Elsevier Science; 1998. Available from: https://books.google.be/books?id=udDHC3Ss7DAC

[213] Public Power Corporation, Contract DMKT 11 85 301, Amynteon S.E.S. Units I/II, Supply and Installation of equipment for District Heating Energy supply 25 MWth.

The Amynteon – Filotas lignite fired power station will be soon phased out. Thus, an alternative way to supply with thermal energy the DHN of city of Amynteon shall be realized. For this purpose, in this chapter the option of installation of a CHP biomass plant to cover the thermal energy requirements of the existing DH system will be studied.

4.2.1 Suggested position of the plant

The Biomass CHP Project will be built next to existing Amynteon – Filotas power station, which consists of two units with a generation capacity of 300 MW each and is in Municipality of Amynteon belonging to Florina regional unit of Macedonia, Greece. In this way, it will take advantage of the existing infrastructures in order to be connected to the electrical and DH networks. In addition, this area is reached by railway network which could be used for the supply of the CHP plant with biomass. Moreover, PPC has obtained a Production License from the Regulatory Authority of Energy (RAE) for the specific project.

4.3 Form of energy used

The primary form of energy to be used by the CHP Project will be the renewable energy of biomass, which will be transformed into electricity and thermal energy through a steam turbine and a generator. Biomass will be supplied to the CHP power plant from the area of West Macedonia and would be straw of cereal and corn, timber from forests, residues from forests and by-products of agricultural industries. Furthermore, biomass energy corps such as cardoons, miscanthus and sweet sorghum shall be used.

4.4 Installed thermal power of the CHP station

According to Municipal District Heating Company of Amynteon (DETEPA), the peak thermal load of the DHN is 40 MWth. This load corresponds to the simultaneously operation of all thermal energy consumers (1900 buildings) connected to DHN. Since the DHN will be extended and new connections with thermal energy consumers will be realized, it is anticipated that the peak thermal load could be reach the value of 50 MWth in the future.[214] However, due to the fact that already has been installed a heat storage system comprising two tanks of volume 600 m^3 each with a capacity up to 70 MWth and maximum loading/unloading rate up to 9 MWth/h belonging to the municipality of Amynteon, the design thermal energy supplied from the CHP power plant to the DHN shall be considered equal to 45 MWth.

4.5 Technology of the CHP station

The technology that will be applied shall be proven, commercial and suitable for the raw material of biomass, as well as the amount of power generated by the CHP power plant. While, several CHP technologies are available nowadays in the market, since a solid fuel would be used, those options are considerably reduced. Based on

214 http://detepa.gr/texnika-stoixeia/

comparative data from similar projects and on extensive search through bibliography sources, it derives that for a CHP that produces thermal power around 45 MWth, the generated electrical power should be around 20 MWe. In figure 4.1 [215]are depicted data

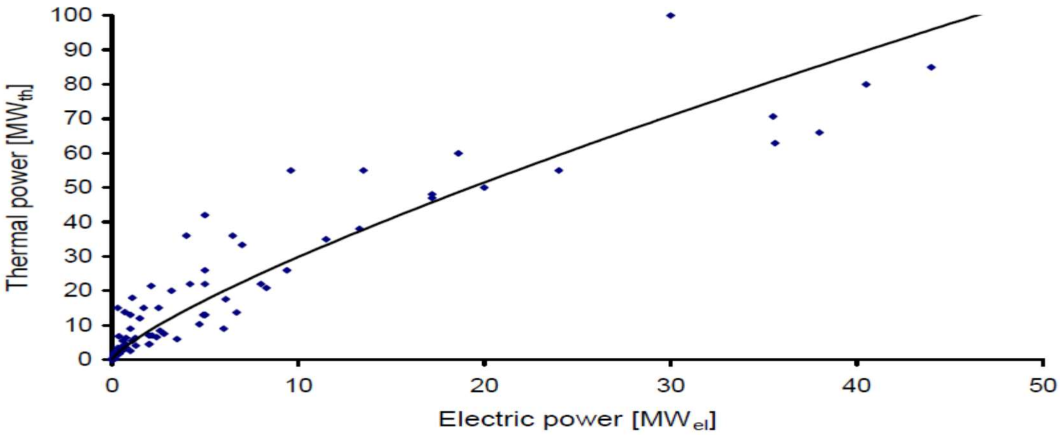

Figure 4.1 Electric and thermal of the solid biomass CHP plants with less than 50 MWel

concerning electrical and thermal power of several CHP power plants with installed electrical power up to 50 MWe.

As it was analyzed herein above in paragraph 3.5, the technologies suitable for solid biomass with humidity less than 60% are the following: a) combustion plant using grate firing technology combined with a water/steam boiler, b) combustion plant using circulating fluidized bed firing technology combined with a water/steam boiler, and c) combustion plant using circulating fluidized bed firing technology combined with a water/steam boiler. For the capacity of the CHP power plant in Amynteon and for the type of biomass that is available in the area of West Macedonia (including loose biomass), the technology of biomass using grate firing combustion boiler[216] and a steam extraction turbine connected to a generator is the most appropriate.

4.6 Description of the CHP plant

The implementation of the project will help to increase the share of energy produced from RES in Greece and the corresponding decrease of production from conventional thermal units. This will contribute to the fulfillment of Greece's commitments to the EU in terms of increasing electricity production from RES.

The main access routes to the site of the CHP power plant Amynteon are already existing and no significant additional work is required. In addition, the existing facilities will be used for the connection to DHN and electrical grid. Furthermore, the area of

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[215] Biomass Cogeneration Network, BIOCOGEN, Grant agreement ID: ENK5-CT-2001-80525, Solid biomass cogeneration, Johanneum Report, http://www.cres.gr/biocogen/solid_biomass.htm

[216] Renewable Energy Technologies: cost analysis series, Volume 1: Power Sector, Biomass for Power Generation, June 2012, IRENA, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-BIOMASS.pdf

about 30.000 m^2, which required for the construction of the power plant and the storage of biomass[217] is available close to existing power plant of PPC.

The main principle of operation of the CHP power plant is that the energy produced by the combustion of biomass in the boiler will be converted to kinetic energy in a turbine which will be connected to a generator. Thus, the kinetic energy will be converted to electricity. In addition, part of the remaining thermal energy will be extracted in the form of superheated steam from the turbine and will be transferred to the water of the DHN. In figure 4.2 [218] is illustrated a simplified scheme of a steam CHP power plant.

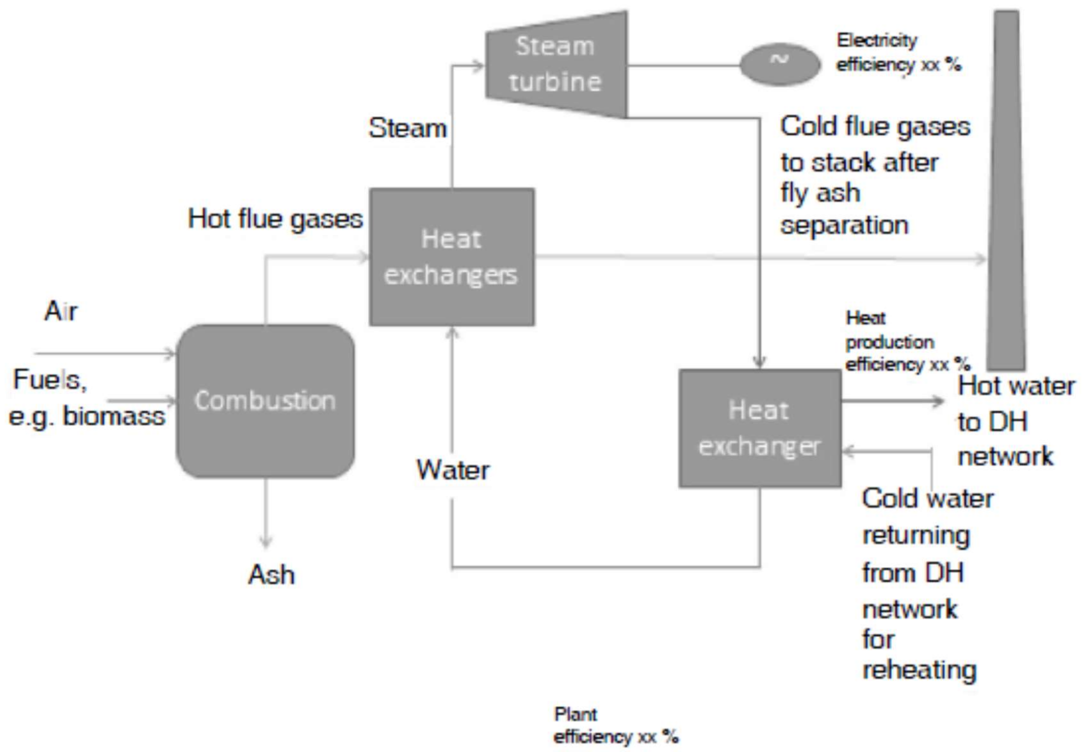

Figure 4.2 Simplified scheme of a steam power plant cogenerating power and heat for DH

The biomass from the storage area of the plant will be transferred via belt conveyors to the preparation system, where it will pre-crushed. Then, the biomass will be transferred via belt conveyors to the mills of the plant, where it will be further minimized the size of fuel. Afterwards, biomass will feed the burners that are located at the surfaces of the boiler.

The boiler that will be selected will be of Grate-fired technology. These types of boilers have been used for long time for combustion of solid fuels and the grate can be designed for various biomass types. In grate-fired boilers, biomass is fed on a fixed or

[217] Biomass Combined Heat and Power Catalog of Technologies, U.S. Environmental Protection Agency and Combined Heat and Power Partnership, U.S. EPA, 2007, https://www.epa.gov/sites/production/files/2015-07/documents/biomass_combined_heat_and_power_catalog_of_technologies_v.1.1.pdf

[218] Swaaij W., Kersten S., and Palz W., Transformations to Effective Use BIOMASS POWER for the World, 2015 by Taylor & Francis Group, LLC, CRC Press

mechanical grate that can have a sloping structure to facilitate the moving of biomass during combustion. The biomass is fed on the grate and air is fed through and on top of the grate. Biomass ash is removed from the end or the bottom of the grate.[219]

Biomass will be combusted inside the boiler and the produced heat will be transported through heat exchangers such as economizers, evaporators, super heaters and re-heaters to the water cycle. Thus, superheated steam will be produced, which will be directed to the inlet of the steam turbine. In the steam turbine the energy of steam is transformed to kinetic energy rotating its shaft, which is coupled with the shaft of the generator. As a result, the kinetic energy of the turbine is converted to electricity through the generator.

Furthermore, part of the superheated steam directed to the turbine is extracted at intermediate stages and send to steam-water heat exchangers where the water of the DHN of the city is heated. For the case of DHN of Amynteon the water is returned from the city at 70^0C and heated at 120^0C in the above-mentioned heat exchangers.

The flue gases produced during the combustion of biomass in the boiler will be directed through ducts to the chimney of the power plant. In order the emissions of the plant to comply with the EU Emissions limits, the flue gas cleaning systems that are analyzed in paragraph 4.9 will be installed upstream the chimney.

The CHP plant in Amynteon will operate automatically and will be capable of remote monitoring and control through a Distributed Control System (DCS). In order to achieve this mode of operation all the necessary equipment for the operation, control and protection of the plant will be installed. The CHP plant will be connected to the network via a step-up transformer.

The main systems of the CHP power plant are listed herein below:

- Biomass reception and storage.
- Biomass handling and preparation.
- Biomass crushing and boiler feeding system.
- Grate technology boiler including water-steam cycle.
- Cooling tower and cooling system.
- Ash removal and disposal system.
- Flue gas cleaning systems.
- Chimney.
- Electrical systems.
- Generator.
- Sub-station.
- Grid connection.
- Instrumentation and control (I&C) system.
- Distributed control system (DCS) automation.

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[219] Koskelainen, L., Saarela, R., Sipilä, K. (2006). Kaukolämmön Käsikirja/District Heating Handbook (in Finnish), Energiateollisuus ry. ISBN 952-5615-08-1.

In figure 4.3 [220] is depicted the general layout of a CHP plant located in Pakistan.

Figure 4.3 General Layout of Straw-fired Power Plant with Storage Facility located in Pakistan

4.7 Installed power of the CHP station

As concerns, the electric power of the CHP, it will be selected in order that when the plant operates at full load and cogeneration mode to be able to supply the DHN with the maximum required thermal load of 45 MWth. In addition, in the economic assessment that follows, a sensitivity analysis regarding the values of the efficiencies of the CHP plant will be executed.

From extended bibliography search [221] it derives that for biomass burning CHP plants with technology and size similar to the one under investigation in this study (>20 MWe), the net electrical efficiency of the plant when it generates only electricity will be around 33,5% and when it operates in cogeneration mode the electrical net efficiency and the net thermal efficiency will be around 22% and 63% respectively. Thus, when the plant shall operate in cogeneration mode and at full load producing thermal power about 45 MWth, the total efficiency will be around 85%. If the required thermal power shall be reduced, then the cogeneration efficiency of the power plant will be reduced accordingly.

Considering the efficiencies of the above paragraph, the net electrical power of the CHP plant, when it generates only electricity, is calculated herein below:

*Electrical power of CHP = 45 MW * 33,5/63 = 23,929 MWe (electricity-only mode)*

This value is close to the value of 20 MWe, which is considered the optimal size of the biomass CHP plants taking into account the optimal size of the biomass sourcing area (< 50km) and the number of truck loads per day (< 50).[222]

[220] Converting Biomass to Energy, A Guide for Developers and Investors, © 2017 International Finance Corporation, http://documents.worldbank.org/curated/en/451461502956339912/pdf/118738-WP-BioMass-report-06-2017-PUBLIC.pdf

[221] Renewable Power Generation Costs in 2017, IRENA 2018, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf

[222] Paul Lako, Biomass for heat and power, ETSAP Energy Technology Systems Analysis Programme, , IEA ETSAP - Technology Brief E05 - May 2010, p. 2., https://iea-etsap.org/E-TechDS/PDF/E04-CHP-GS-gct_ADfinal.pdf

When the CHP operates at full load in cogeneration mode the thermal power will be 45 MWth and the net electrical power will be equal to:

*Electrical power of CHP = 22,86 MW * 22/32 = 15,714 MWe (cogeneration mode)*

When the CHP plant will generate only electrical power, it will supply the grid with 23,929 MWe at full load. On the other hand, when it operates in cogeneration mode the electrical power supplied to the grid will be decreased and the thermal power supplied to DHN will be increased. This will happen because the flow of the extraction steam from the steam turbine to the heaters of the DHPS will be increased when the thermal energy requirements of the DHN will be increased and as a result the power transmitted to the generator of the CHP will be decreased accordingly. As it is illustrated in Figure 4.4[223], it could be assumed without significant error that the electrical power produced is inversely proportional to the thermal power of the CHP. Thus, the formula for calculating the electrical power of the CHP operating in cogeneration mode for a given thermal power is as follows:

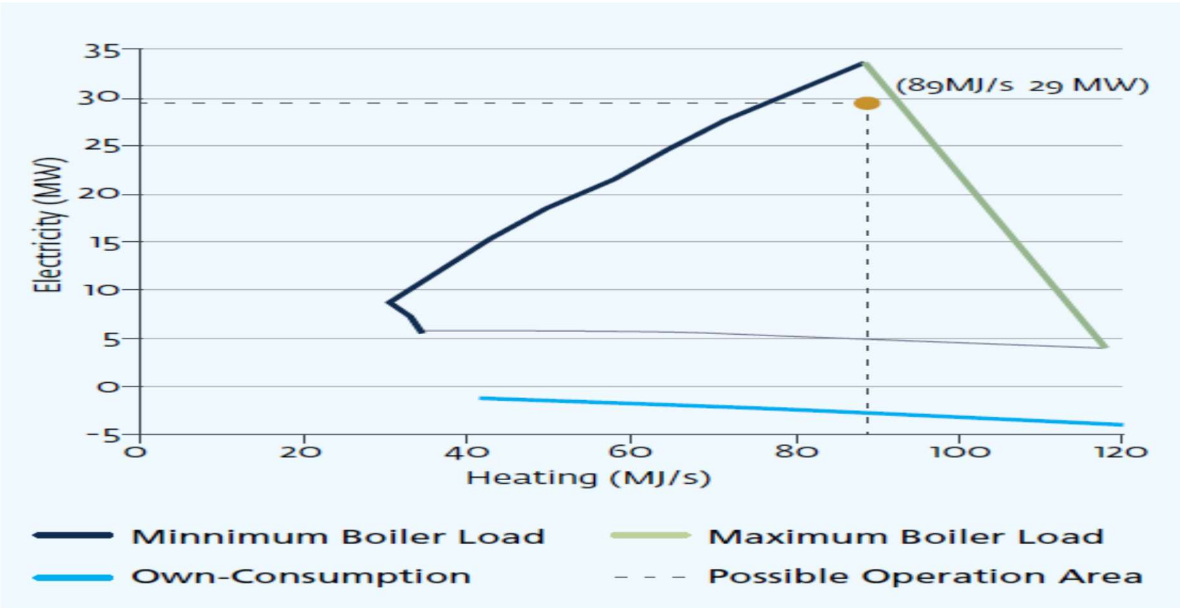

Figure 4.4 PQ-diagram showing Power Output on the vertical axis and Heating Output on the horizontal axis

Electrical Power = -0,18254(Thermal Power) + 23,929 (MWe) (formula 4.1)*

In figure 4.5 is depicted the Electrical Energy and Thermal Energy produced by the CHP plant operating at full load and for different thermal load demand by DHN.

[223] Converting Biomass to Energy, A Guide for Developers and Investors, © 2017 International Finance Corporation, http://documents.worldbank.org/curated/en/451461502956339912/pdf/118738-WP-BioMass-report-06-2017-PUBLIC.pdf

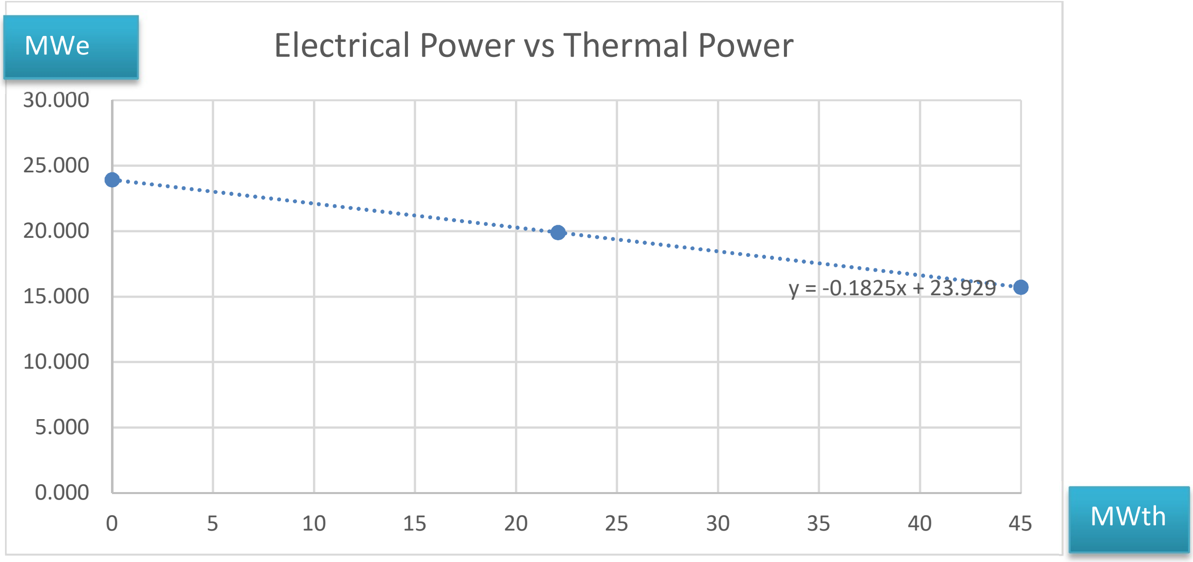

Figure 4.5 Electrical Energy and Thermal Energy produced by the CHP operating at full load

Furthermore, in figure 4.6 are depicted the efficiencies (n) of cogeneration, electricity generation and thermal power production for various thermal loads.

4.8 Energy study

In this part will be presented the energy study for the calculation and documentation of the electric and thermal energy produced by the CHP Plant.

The District Heating Network (DHN) of Amynteon operates from 15th October till 15th May. The thermal load is not steady and fluctuates. For the calculation of the annual thermal load of DHN of Amynteon, will be used available data from the operation of

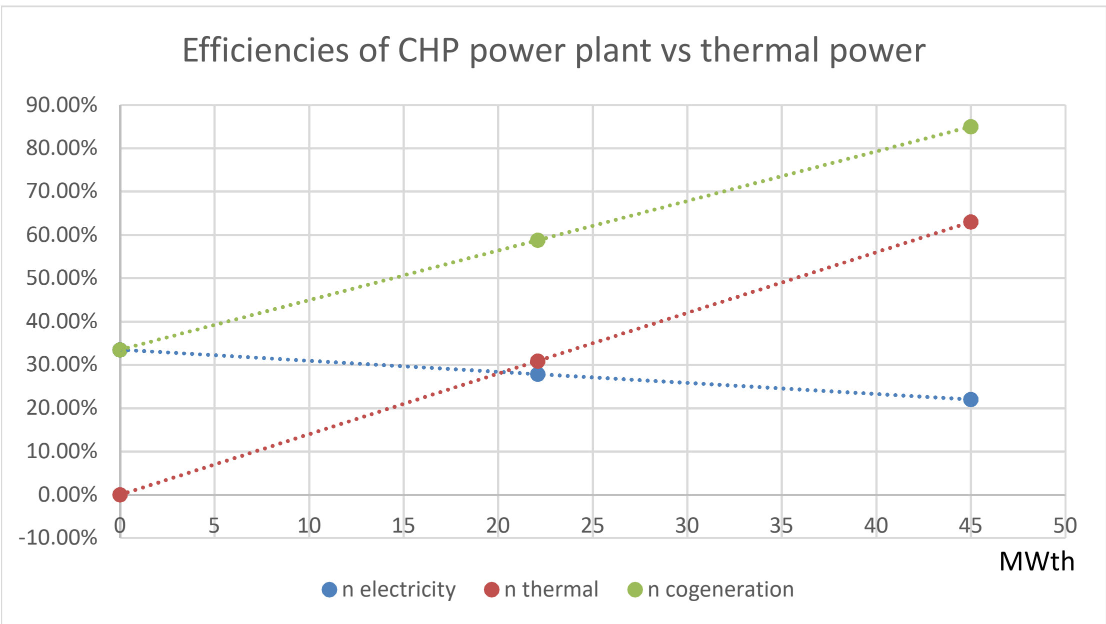

Figure 4.6 Efficiencies of the CHP power plant in Amynteon

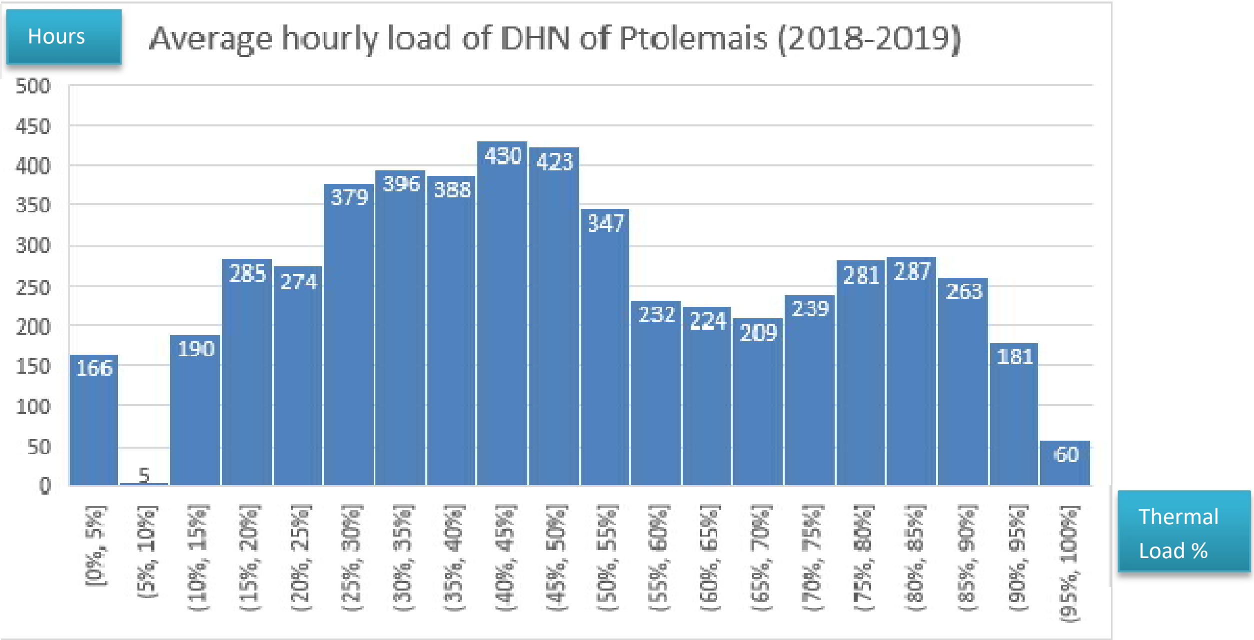

Figure 4.7 Average hourly load of DHN of Ptolemais

the DHN of the city of Ptolemais for the heating season 2018-2019[224], which is located very close to Amynteon (about 20 km distance) and has similar climate. In figure 4.7 are depicted the hours during the heating season for various average hourly loads of the DHN. Furthermore, in figure 4.8 is depicted the hourly average load of the DHN for the coldest day of the heating season 2018-2019, which was the 16th of January 2019. From this chart, it derives that for the coldest day the thermal load of DHN fluctuated between around 80% and 100% of the maximum load. Moreover, in figure 4.9 is illustrated the hourly average load of the DHN for a day with medium thermal load (15th November

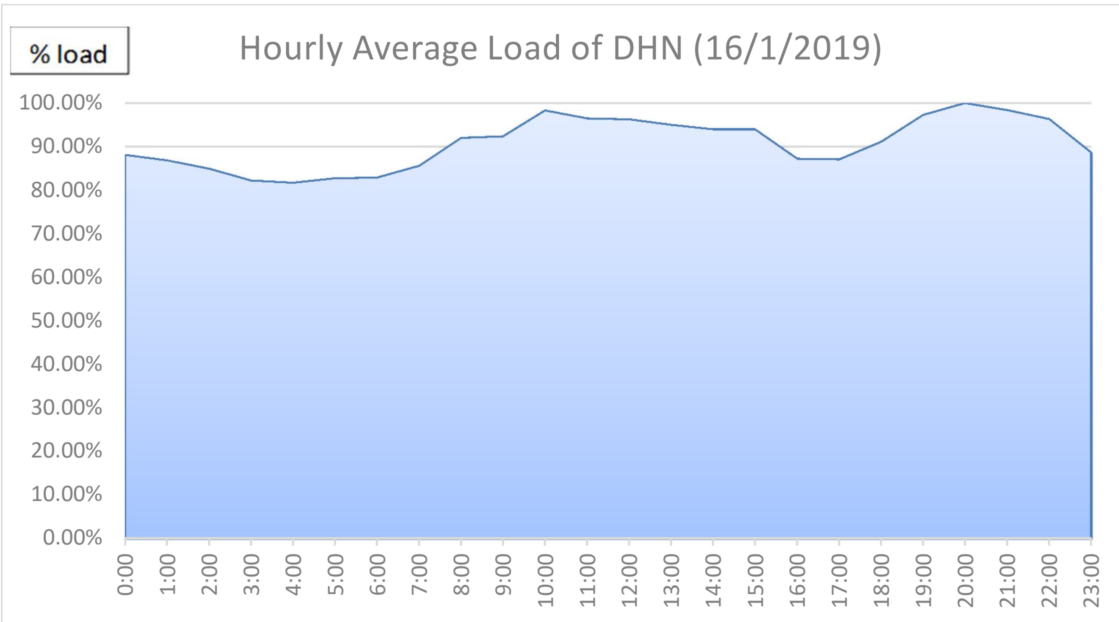

Figure 4.8 Hourly average Load of DHN (16/1/2019)

[224] Data from the DCS system of Kardia SES, Units III-IV that supply with thermal energy the DHN of the city of Ptolemais.

2018). For this date, the thermal load of DHN fluctuated between around 40% and 65% of the maximum load. Taking all the above into consideration, it comes that the thermal load of the DHN fluctuates both during each day and during the thermal period.

As it derives from integration of chart depicted in figure 4.7 the average hourly

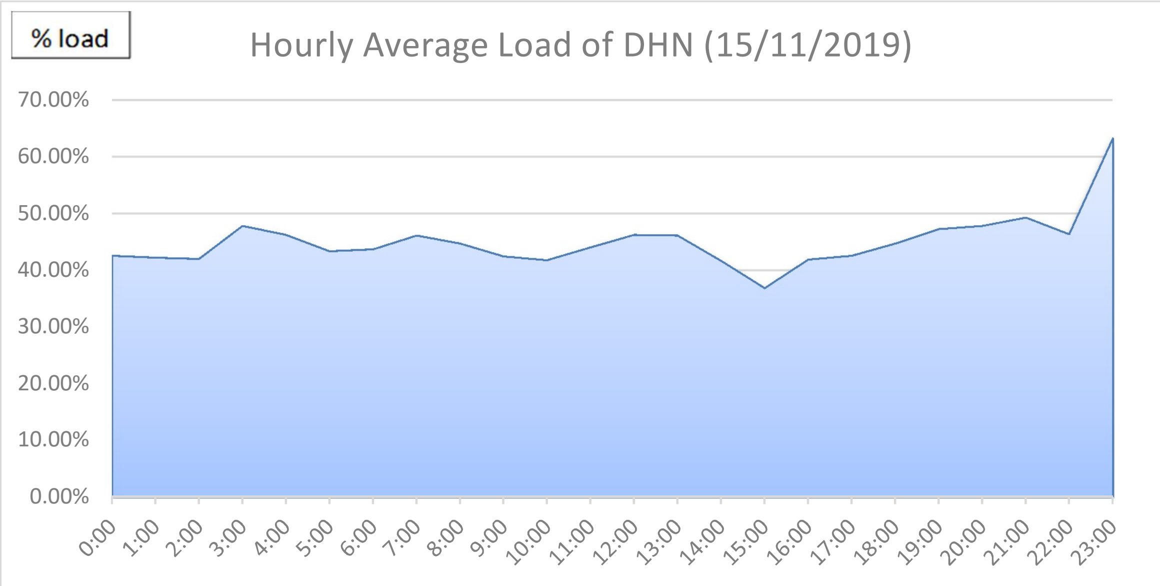

Figure 4.9 Hourly average Load of DHN (15.11.2019)

load of the DHN during the whole heating season is 49,08% of the maximum thermal load. As a result, it is estimated that the average hourly thermal load of the DHN of city of Amynteon for the heating season would be equal to:

*45 MWth * 49,08 % = 22,086 MWth*

Thus, the total thermal energy required by the DHN for the whole heating season that lasts 7 months would be:

*22,086 MWth * 24 * 30 * 7 = 111.313,44 MWth or* ***111,313 GWh***

When the CHP plant of Amynteon operates, it will produce either electrical power or both electrical power and thermal power. Thus, the CHP plant during the heating period that lasts 7 months each year will produce both electrical power and thermal power and for the rest 5 months it will generate only electrical power.

The electrical power generated by the CHP when it produces thermal power equal to 23,929 is calculated according to formula 4.1 as follows:

*Electrical Power = -0,18254*22,086 + 23,929 = 19,897 MWe*

The efficiency of cogeneration for this mode of operation of the CHP is calculated herein below:

$n_{cogeneration}$=(22,086+19,897)*33,5/23,929=58,78%

Thus, it derives that the average cogeneration efficiency of the CHP plant during the heating season shall be only 58,78%, while the CHP could achieve a cogeneration efficiency equal to 85% when it would produce thermal energy 45 MWth and electrical energy 15,714 MWe.

The availability of CHP plant is anticipated to be 95 %.[225] Furthermore, the TSO shall be given priority connection to the grid for the respective station since it is a CHP plant burning biomass. Furthermore, it is assumed that the maintenance of the plant will not take place during the heating season, because the supply of thermal energy to the DHN is very important and crucial for the local community. Therefore, the electrical energy generated annually during the heating season is estimated to be as follows:

*Electrical Energy per heating season=19,897 * 24 * 30 * 7 = 100.281 MWh =*

=100,281 GWh

Taking into account the availability of the CHP plant, the electrical power generated annually from 16th May till 15th October is estimated to be as follows:

*Electrical Energy for rest of the year = 23,929 * (24* 30 *5-(24*360*0.05)) = 75.806 MWh=*
= 75,806 GWh

Thus, the electrical energy generated by the CHP plant during a year would be **176,087 GWh**.

4.9 Installation of environment protection systems to comply with EU Emissions limits

The CHP power plant burning biomass will emit various air pollutants. Since this power plant will be set in operation after 18.08.2021, it will be only allowed to operate with a permit that specifies the conditions for operation, and it is obliged to use the Best Available Techniques (BAT).[226] In Chapter 10.2.2 of this Reference Document are summarized the conclusions for the combustion of solid biomass and/or peat and are defined the permissible maximum emissions levels (BAT-AELs).

In order to define the emission levels the combustion plant total rated thermal input (MWth) should be calculated:

*Total Rated Thermal Input = 23.929*100/33,5 = 71,429 MWth*

Therefore, for the CHP power plant in Amynteon the emission levels accrue according to the respective tables of Chapter 10.2.2 of BAT for total Rated Thermal Input in the range of 50-100 MWth. Taking all the above into consideration, the net electrical efficiency, as well as the emission limits for the CHP power plant are summarized in Table 4.1

[225] Biomass Combined Heat and Power Catalog of Technologies, U.S. Environmental Protection Agency, 2007, https://www.epa.gov/sites/production/files/2015-07/documents/biomass_combined_heat_and_power_catalog_of_technologies_v.1.1.pdf

[226] Best Available Techniques (BAT) Reference Document for Large Combustion Plants. Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control) http://publications.jrc.ec.europa.eu/repository/bitstream/JRC107769/jrc107769_lcp_bref2017(1).pdf

Table 4.1 BAT-associated net electrical efficiency and emission levels (BAT-AELs) for the CHP power plant in Amynteon		
Net electrical efficiency	33,5	%
NOx (yearly average)	150	mg/m³ (N.dry @6%O2)
CO indicative	250	mg/m³ (N.dry @6%O2)
SO2 (yearly average)	70	mg/m³ (N.dry @6%O2)
HCl (yearly average)	7	mg/m³ (N.dry @6%O2)
HF (yearly average)	1	mg/m³ (N.dry @6%O2)
Dust (yearly average)	5	mg/m³ (N.dry @6%O2)
Hg (average over the sampling period)	5	μg/m³ (N.dry @6%O2)

In order to achieve the levels indicated in Table 4.1 the CHP power plant must be equipped with the flue gas cleaning systems referred in Table 4.2. The investment cost for the installation of the respective systems will be taken into account for the calculation of the total investment cost of the Project.

Table 4.2 Flue gas cleaning systems	
Description	Technique
Reduction of NO_X, N_2O and CO emissions to air	Low-NOX burners (LNB) and installation of Selective catalytic reduction (SCR) system
Reduction of SO_X, HCl and HF emissions to air	Wet flue-gas desulphurisation (wet FGD)
Reduction of dust and particulate-bound metal emissions to air	Electrostatic precipitator (ESP)
Reduction of mercury emissions to air	Fuel choice, and co-benefit from techniques of SCR and wet FGD applied for NOx and SOx reduction respectively

4.10 Biomass supply and storage

Securing good quality feedstock at affordable prices over a plant's lifetime is a key issue for biomass power projects. This comes mainly from fluctuations in biomass supply availability, seasonally or annually, so that setting up long-term supply contracts may not be easy. Seasonal fluctuation depends on the type of feedstock and developers need to consider installation of storage facilities or combination with another type of feedstock that has a different supply season. Yearly fluctuations also relate to annual changes in production and market demand for agricultural commodities. Most food and fiber crops are grown and sold on an annual basis, often for widely varying commodity prices.[227]

The operation of the CHP will require annually around 135.000 tons of biomass. For this reason, agricultural crop residues, such as straw of cereal and corn, timber from forests, residues from forests and by-products of agricultural industries could be used as fuel. Furthermore, biomass could be produced by cultivation of energy corps such as cardoons, miscanthus and sweet sorghum. The yield of the latter cultivations is between 1 and 2 tons per year for an area of 1000 m^2.[228] All these cultivations are suitable for the area of West Macedonia, where the CHP plant will be constructed. In addition, the combination of the above-mentioned energy cultivations could ensure supply of biomass to the power plant during all the year since their harvest is done in different periods.

The raw material of biomass will be gathered in large storehouses in the area of West Macedonia. Then it will be transferred by trucks for storage to the respective area adjacent of the new CHP plant. The business of biomass production, preparation, processing, transportation and storage will create several hundreds of jobs and will boost the local economy.

4.11 Economic Assessment

In this part of the chapter is presented an extensive Economic Assessment of the investment concerning the implementation of CHP Amynteon, with an installed electrical power of 23,929 MWe and thermal power 45 MWth, which consists the base case scenario. Furthermore, a sensitivity analysis regarding the values of the main figures that influence the profitability of the CHP power plant's investment will be executed.

The study includes the analysis of the main macroeconomic variables that affect the profitability of the particular investment, as well as the main assumptions about the operation of the CHP Power Plant. A major effort in presenting this study is the proof that the proposed investment has secured finance and certain economic indicators and could create the conditions and the required cash flows to finance a range of similar investment proposals in other Greek cities where DHN of similar thermal loads requirements could be installed.

[227] Biomass for Heat and Power Technology Brief, IEA-ETSAP and IRENA© Technology Brief E05 – January 2015, https://irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA-ETSAP_Tech_Brief_E05_Biomass-for-Heat-and-Power.pdf

[228] Ενεργειακές καλλιέργειες για την παραγωγή υγρών και στερεών βιοκαυσίμων στην Ελλάδα, CRES, http://www.cres.gr/cres/files/xrisima/ekdoseis/ekdoseis_GR8.pdf

4.11.1 Business environment and long-term policy

The development of RES is a key priority of EU policy aiming for the protection of the environment and the security of energy supply. The implementation of CHP power plant in Amynteon will contribute to increase the share of energy produced from RES in Greece and the corresponding reduction of generation from thermal units. This will help to the fulfillment of Greece's commitments to increase electricity production from RES and increase energy efficiency by promoting cogeneration.

However, the construction of a biomass burning CHP power plant is an economic investment and therefore must be examined also with strict financial criteria and indicators to prove the feasibility and cost-effectiveness of the power plant. Considering the fact that CHP power plants investments require large amounts of money and have an economic lifetime of at least 30 years[229], during which they demand significant operating and maintenance costs, the business plans of these projects should present the company's prospects and economics on a long-term basis in order that the feasibility of such investments can be assessed.

Taking all the above into consideration, as well as the fact that according to the respective legal framework the validity of the production license is 25 years and the duration of the energy trading contract is for at least 20 years, the present economic assessment examines the cash flows for 25 years. In addition, a brief analysis will be executed for the results of economic assessment taking into consideration the cash flows only for 20 years, which is the minimum period that the feed in tariffs of electricity prices are guaranteed.

4.11.2 Legal Environment and Permits

According to legal environment for the certain CHP biomass burning Power plant with installed electric power higher than 1 MWe the following are required[230]:

- A Production Licence.
- An Approval of Environmental Terms (ΕΠΟ), which is provided following the submission of respective application accompanied with an Environmental Impact Assessment (ΜΠΕ).
- Application for the Connection Offer to TSO, who approve the topographical diagrams of the connection.
- Installation Licence.
- Building Linence.
- A connection to the grid Contract.
- A Trading Contract.
- Temporary connection for Testing Operation following the respective application to TSO. If it is achieved unrestricted operation of 15 days, then

[229] Paul Lako, Biomass for heat and power, ETSAP Energy Technology Systems Analysis Programme, , IEA ETSAP - Technology Brief E05 - May 2010, p. 2., https://iea-etsap.org/E-TechDS/PDF/E04-CHP-GS-gct_ADfinal.pdf
[230] Legal Sources on Renewable Energy, http://www.res-legal.eu

TSO issues a Certificate of successful completion of tests (YA.13310/2007, Government Gazette B'1153, Article.14).

- Operation Licence.

4.11.3 Investment cost

The investment cost of biomass-based CHP and power generation depends upon several parameters such as the feedstock used (e.g. wood, straw, waste, etc.), the boiler technology (VG, BFBC, or CFBC); the capacity of the plant (MWe) and the kind of plant service (CHP or solely power generation).[231]

The investment cost for CHP power plant in Amynteon was assumed to be 3.500 €/kWe based on real offers of equipment by construction companies, on comparative data from the construction of similar projects, and on extensive search through bibliography sources.[232,233, 234] However, because the range of cost for various biomass CHP power plants is wide, a sensitivity analysis will be executed for various investment costs.

In the above mentioned investment cost are not included any expenses for purchase of land for the installation of the plant, since next to existing Amynteon – Filotas power station, there is available the area required for the CHP power plant, which is owned by PPC.

Taking all the above into consideration, the total investment for the base case scenario is calculated equal to 23.929 kWe * 3.500 €/kWe ≈ 83.750.000 €. In detail, the costs that will be incurred are as follows:

Table 4.3

List of Material and Prices

Description of equipment	Percentage of total cost	Cost (€)
Mechanical equipment	65%	54.000.000
Electrical equipment	9%	7.500.000
I&C equipment (Instrumentation and Control)	3%	2.700.000
Water & Chemical Processes	2%	1.800.000

[231] Paul Lako, Biomass for heat and power, ETSAP Energy Technology Systems Analysis Programme, , IEA ETSAP - Technology Brief E05 - May 2010, p. 4.

[232] COST-COMPETITIVE RENEWABLE POWER GENERATION: Potential across South East Europe, IRENA 2017, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Cost competitive_power_potential_SEE_2017.pdf

[233] Paul Lako, Biomass for heat and power, ETSAP Energy Technology Systems Analysis Programme, , IEA ETSAP - Technology Brief E05 - May 2010, p. 2., https://iea-etsap.org/E-TechDS/PDF/E04-CHP-GS-gct_ADfinal.pdf

[234] I. Malico, R. Nepomuceno Pereira, A.C. Gonçalves, A.M.O. Sousa, Current status and future perspectives for energy production from solid biomass in the European industry, Renew. Sustain. Energy Rev. 112 (2019) 960e977, https://doi.org/10.1016/j.rser.2019.06.022

Civil works	11%	9.500.000
Testing and commissioning	1%	900.000
Spare Parts	4%	3.200.000
Other Services	5%	4.150.000
Grand total price for the CHP power plant	100%	83.750.000

4.11.4 Time Schedule of the Project

The time required from the signing of the Contract of the Project till the operation of the CHP power plant is estimated to be around 2-2,5 years[235]. The first year are issued the relative permits, is executed the basic design of the CHP power plant, is ordered the main equipment and begin the excavations at site. During the second year are executed the foundations and the rest civil works and the erection of mechanical, electrical and I&C equipment. Afterwards, follows the commissioning, the cold tests, the hot tests and the operation of the power plant.

Taking all the above into account, as well as comparative data from the construction of similar projects, it derives that the first year it will be paid about 10% of the total budget of the Project, while the rest 90% will be paid during second year. At the end of second year, the power plant will start operating, producing thermal and electrical power, and receiving revenues.

4.11.5 Financial investment scheme

The financing of the proposed investment is projected to be 70% through a long-term bank loan and 30% through owner equity. The financial scheme for the implementation of the investment and the basic terms of financing the loan are summarized in the tables 4.4 and 4.5.

Table 4.4 Financial Investment Scheme		
	Euro (€)	**%**
Owner Equity	25.125.000	30,0%
Loan	58.625.000	70,00%
Subsidy	0	0,00%
Total cost of the Project :	**83.750.000**	**100,0%**

Table 4.5 Basic conditions for the granting of Long-term bank loan	
Loan	58.625.000 €
Interest Rate	5,00%
Loan Duration	15
Way of Payback	Annual Equivalent Installments

[235] Renewable Energy Technologies: cost analysis series, Volume 1: Power Sector, Biomass for Power Generation, June 2012, IRENA, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-BIOMASS.pdf

In this study, for reasons of simplification we assume that the loan will be disbursed at the end of the first year following the signing of the Contract for the construction of the CHP power plant (year 0) and the payment of the first installment of the loan will start a year after the loan disbursement during the first operation of the plant (year 1). The payback of the loan is made in equal installments at the end of each year, out of the company's profits after the deduction of income tax. In Table 4.6 are illustrated the main data of the loan for the base case scenario.

Table 4.6 Pay off loan

YEAR	INTEREST (A) (€)	NSTALLMENT (B) (€)	(ANNUAL INSTALLMENT (€)
0			
1	2.931.250	2.716.817	5.648.067
2	2.795.409	2.852.657	5.648.067
3	2.652.776	2.995.290	5.648.067
4	2.503.012	3.145.055	5.648.067
5	2.345.759	3.302.308	5.648.067
6	2.180.644	3.467.423	5.648.067
7	2.007.273	3.640.794	5.648.067
8	1.825.233	3.822.834	5.648.067
9	1.634.091	4.013.975	5.648.067
10	1.433.392	4.214.674	5.648.067
11	1.222.659	4.425.408	5.648.067
12	1.001.388	4.646.678	5.648.067
13	769.054	4.879.012	5.648.067
14	525.104	5.122.963	5.648.067
15	268.956	5.379.111	5.648.067
TOTAL	**26.095.000**	**58.625.000**	**84.720.000**

4.11.6 Key macroeconomic figures taken into consideration

Herein below are analyzed the key macroeconomic figures considered in this economic assessment. More extensive reference is made to three of the most basic macroeconomic figures used in this study that are expected to affect the cost-effectiveness of the investment, namely the inflation measured by the Consumer Price Index (CPI), the tax rate and the depreciation.

Although the evolution of the CPI is expected to be downward in the coming years, as it is clear from the requirements set by the European Union for the countries participating in Economic and Monetary Union, it was considered that the inflation will be 0,5% throughout the life of the investment. Furthermore, in the current economic assessment a sensitivity analysis concerning inflation will be executed.

The tax rate will be considered equal to 25%, since it has legislated gradually decrease of corporate tax rate and more specifically for the corporates' incomes after 2022 the relative tax rate will be 25%.

The depreciation will be considered equal to 5%, according to respective legislation and the discount rate equal to 7%.

4.11.7 Price of electrical and thermal power

According to the recent legislative framework (Ministerial Decision ΥΠΕΝ/ΔΑΠΕΕΚ/30971/1190/2020 - ΦΕΚ 1045/Β/26-3-2020)[236] for setting up the new RES support mechanism, the Reference Price of electrical energy from biomass has been amended. More specifically, while according to Article 4 of Law 4414/2016 the Reference Price of electricity generated by combustion of biomass in power stations with installed power higher than 5 MW was 140 €/MWh, the latter Reference Price has been decreased to 133 €/MWh. This amendment is valid for the respective power plants that will start operating after 01.01.2022. Because according to the time schedule of the Project, the CHP power plant in Amynteon will set in operation after 01.01.2022, a Reference Price equal to 133 €/MWh will be considered, for which is not foreseen an annual adjustment and therefore a zero increase in the selling price of electricity will be taken into account.

In Greece operate four DHN systems that are supplied with thermal energy produced in lignite fired power stations belonging to PPC. These systems are located in cities of Megalopolis, Kozani, Ptolemais and Amynteon and belong to municipalities of the respective cities. The price that the thermal energy is sold by PPC to the municipal companies is about 10 €/MWh, while the citizens of the cities buy the thermal energy at a price around 40 €/MWh[237]. Furthermore, considering the current prices of oil and Natural Gas (NG), it is calculated that the cost only of the fuel for producing thermal energy for heating buildings with boilers costs about 75 €/MWh for the case of oil and about 50 €/MWh for the case of NG. Taking all the above into account, in this study we will assume a price of selling the thermal power to the municipal company operating the DHN at least equal to the calculated value that Internal Rate of Return (IRR) of the investment of CHP power plant is higher than the respective IRR for the case of operating the power plant in electricity-only generation mode. The investment cost of the power plant for the case of the electricity-only generation plant will be assumed equal to 3.400 €/kWe, since the District Heating Production System (DHPS) will not be included in the scope of supply of the construction. Furthermore, a sensitivity analysis

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[236] Ministerial Decision ΥΠΕΝ/ΔΑΠΕΕΚ/30971/1190/2020 - ΦΕΚ 1045/Β/26-3-2020, http://www.et.gr/idocs-nph/search/pdfViewerForm.html?args=5C7QrtC22wHUdWr4xouZundtvSoClrL8-11WGLkYj8YliYHTRwL0-OJInJ48_97uHrMts-zFzeyCiBSQOpYnTy36MacmUFCx2ppFvBej56Mmc8Qdb8ZfRJqZnsIAdk8Lv_e6czmhEembNmZCMxLMteQBLo1yfqr3wAQssIF0UVVis_xuHanDrsaOeWw0pxg4

[237] Markogiannakis G., ALTERNATIVES TO THE DISTRICT HEATING SYSTEMS OF W. MACEDONIA - The case of Ptolemaida, WWf, July 2016, https://coaltransitions.org/publications/alternatives-to-the-district-heating-systems-of-w-macedonia/

will be executed concerning the price of thermal energy, which influence the revenues of the investment. For the thermal energy price is foreseen an annual adjustment according to CPI.

4.11.8 Assumptions concerning operation of CHP power plant

In the market are available various types of biomass characterized by different properties, net calorific value and price. As it was described in paragraph 4.10 in the CHP power plant of Amynteon will be burnt mainly biomass produced in West Macedonia. For the economic assessment it will be assumed that the average net calorific value of biomass will be equal to 15.500 kJ/kg[238] and its price will be equal to 90 €/ton[239,240] delivered at CHP power plant. Moreover, as concerns biomass price, a sensitivity analysis will be executed. For the price of biomass is foreseen an annual adjustment according to CPI.

Operation and maintenance (O&M) refer to the fixed and variable costs associated with the operation of biomass-fired power generation plants. Fixed O&M costs consist of labour, scheduled maintenance, routine component/equipment replacement (for boilers, feedstock handling equipment, etc.), insurance, etc. Variable O&M costs include non-biomass fuels costs, ash disposal, unplanned maintenance, equipment replacement and incremental servicing costs.[241] The annual operation and maintenance (O&M) cost (fixed and variable) of the CHP power plant according to extensive literature review[242,243] will be assumed to be equal to 4% of initial investment cost. Furthermore, due to the timely and correct maintenance of the equipment, it will be assumed that the efficiency of the power plant will not be decreased through the whole life of the Project.

Given that carbon released when solid biomass is burned will be re-absorbed during tree growth, Greenhouse Gas emissions (GHG) associated with biomass combustion are treated preferentially. GHG emissions from using biomass for electricity generation do not fall under the EU Emissions Trading Scheme (EU ETS)[244]. Therefore, in this economic assessment free CO_2 allowances will be considered.

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238 Renewable Energy Technologies: cost analysis series, Volume 1: Power Sector, Biomass for Power Generation, June 2012, IRENA, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-BIOMASS.pdf

239 Eleftheriadis I., Cost of wood biomass production from forests, CRES, www.biomasstradecentreii.eu

240 Prislan P., Krajnc N., Jemec T., Piškur M., MONITORING OF WOOD FUEL PRICES IN SLOVENIA, AUSTRIA, ITALY, CROATIA, ROMANIA, GERMANY, SPAIN AND IRELAND, Report No. 6, March 2014, Biomass Trade Centre, http://www.biomasstradecentreii.eu/scripts/download.php?file=/data/upload/Wood_fuel_prices_in_2014_I_report_no_6_final.pdf

241 Renewable Energy Technologies: cost analysis series, Volume 1: Power Sector, Biomass for Power Generation, June 2012, IRENA

242 Mott MacDonald, Costs of low-carbon generation technologies, May 2011, Committee on Climate Change, http://www.coiim.es/Comisiones/Energia/Descargas/Costs%20of%20low-carbon%20generation%20technologies_UK.pdf

243 Biomass Combined Heat and Power Catalog of Technologies, U.S. Environmental Protection Agency and Combined Heat and Power Partnership, U.S. EPA, 2007, https://www.epa.gov/sites/production/files/2015-07/documents/biomass_combined_heat_and_power_catalog_of_technologies_v.1.1.pdf

244 https://www.emissions-euets.com/carbon-market-glossary/976-biomass

4.11.9 Summarizing the data of base case scenario

Taking all the above into consideration, in Table 4.7 are summarized the main macroeconomic figures and assumptions considered in the present economic assessment, which affect the cost-effectiveness of the investment.

Table 4.7 Main macroeconomic figures and assumptions for the base case scenario	
Capital	
Type of Plant	CHP biomass burning
Installed electrical power	23,929 (MWe)
Installed thermal power	45 (MWth)
Investment cost for CHP power plant	3.500 (€/kWe)
Total investment cost of CHP power plant	83.750.000 (€)
Investment cost for electricity-only generation power plant	3.400 (€/kWe)
Total investment cost of electricity-only generation power plant	81.360.000 (€)
Revenues	
Availability of power plant	95%
Operating hours for electricity generation	3.168 (hours/year)
Operating hours in cogeneration mode	5.040 (hours/year)
Produced Electrical Energy annually	176,087 (GWh)
Produced Thermal Energy annually	111,313 (GWh)
Price of electrical energy	133 (€/MWh)
Expenses	
Biomass Lower calorific	15.500 (kJ/kg)
Biomass price delivered at CHP power plant	90 (€/ton)
Biomass quantity	136.170 (tons/year)
Operation and Maintenance cost	4% of initial investment
Financing	
Loan	70%
Duration of Loan	15 (years)
Loan interest	5%
Owner Equity	30%
Key macroeconomic figures	
Economic Assessment duration	25 (years)

Inflation	0,5%
Tax rate	25%
Depreciation	5%
Discount rate	7%

4.12 Results of Economic Assessment

4.12.1 Base case scenario

For the base case scenario, if the power plant in Amynteon operates in electricity-only mode, the Internal rate of Return (IRR) was calculated equal to 9,9%. Afterwards, for cogeneration mode it was calculated that in order that the IRR to be equal to 9,9%, the price of the thermal power should be equal to 26,96 €/MWth. Therefore, the thermal price should be sold to DHN at a price higher than 26,96 €/MWth, in order the power plant to be preferable to operate in cogeneration mode. Considering the above-mentioned data, the financial indicator Internal Rate of Return (IRR), the economic indicator Net Present Value (NPV) and the Weighted Average Cost of Capital (WACC) of the investment for the CHP power plant are as depicted in Table 4.8.

Table 4.8 Results for Base Case Scenario		
WACC	4,73%	
Thermal Energy Price	26,96 €/MWth	
	25 years evaluation	**20 years evaluation**
NPV	45.331.915 €	33.167.922 €
IRR	9,9%	9,17%

WACC is the average after-tax cost of a company's capital sources and a measure of the interest return a company pays out for its financing[245]. Since for the base case scenario the IRR is much higher than WACC, it is concluded that for the specific investment it could be covered the financing. Furthermore, after 25 years the present value of the cumulative net cash flows of the Project will be equal to 45.331.915 €. The payback period was calculated equal to 12 years. Taking all the above into consideration, it derives that the construction and operation of the CHP power plant in Amynteon is an attractive investment, with marginal profits. In figure 4.10 are depicted the cumulative net cash flows of the Project. In addition, the variable cost of electricity was calculated equal to 65,24 €/MWh and the total cost of electricity equal to 83,94 €/MWh.

[245] https://www.investopedia.com/ask/answers/062714/whats-difference-between-weighted-average-cost-capital-wacc-and-internal-rate-return-irr.asp

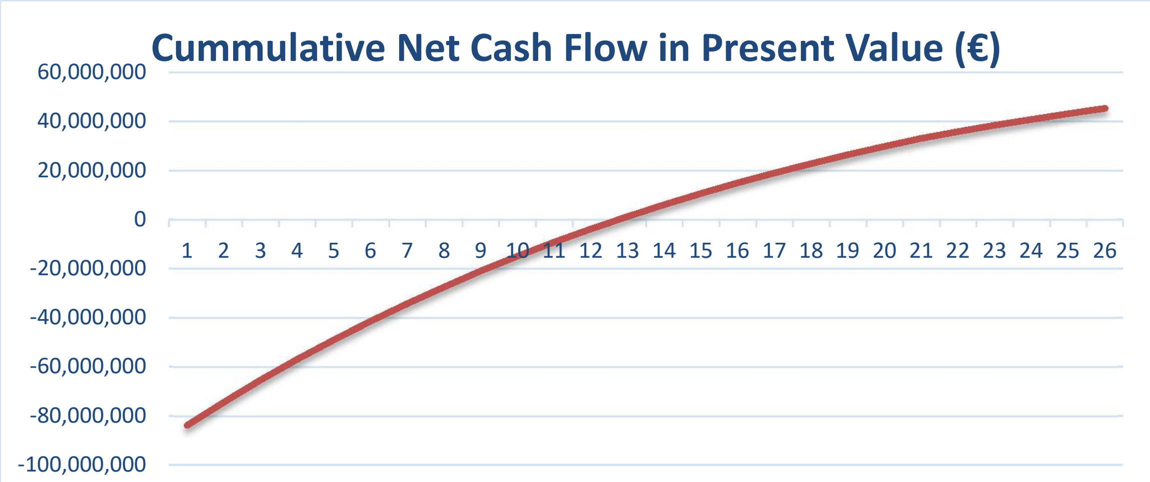

Figure 4.10 Cumulative Net Cash Flow of the Project in Present Value

The above-mentioned results concerning the Project's profitability were very conservative since the price of thermal energy was assumed equal to 26,96 €/MWth in order that the IRR of the power plant to be equal for both cases of electricity-only mode and cogeneration mode. For this reason, in Table 4.9 are depicted the values of IRR and NPV for higher prices of thermal energy. Moreover, an extensive sensitivity analysis will be executed recording among other parameters and the price of thermal energy.

Table 4.9 Results for Base Case Scenario and variation of thermal energy price

WACC	4,73%				
Thermal Energy Price (€/MWth)	26,96	28	29	30	35
NPV (€) (25 years evaluation)	45.331.915	46.648.763	47.918.953	49.189.143	55.540.092
NPV (€) (20 years evaluation)	33.167.922	34.317.477	35.426.301	36.535.126	42.079.249
IRR (%) (25 years evaluation)	9,9	10,04	10,17	10,30	10,93
IRR (%) (20 years evaluation)	9,17	9.31	9,44	9,58	10,25

As it is derives from Table 4.9, when the thermal energy is sold at a price equal to 35 €/MWth, which is much lower than the variable cost of producing the same amount of energy by burning alternative fuels such as Natural Gas (NG), Liquefied Petroleum Gas (LPG), Diesel, etc., the IRR of the CHP plant is 10,93% and the NPV is 55.540.092 €. Therefore, since the price of electricity is guaranteed in order to proceed to the installation of the CHP plant, the investor shall ensure that the thermal energy will be sold at price higher than 30 €/MWth.

Finally, as it was mentioned herein above in paragraph 4.11.7, the feed-in tariff for electricity generated by biomass was 140 €/MWh and decreased to 133 €/MWh last April (2020). For the base case scenario, if it is assumed that the feed-in tariff is equal to 140 €/MWh, then the IRR is 11,26% and the NPV is 58.727.786 €. Taking all the above into consideration, it concludes that the new feed-in tariff prices for electricity generated by biomass influenced negatively the attractiveness of such Projects.

4.12.2 Sensitivity Analysis

A sensitivity analysis was performed to determine which variables had the largest impact on the CHP power plant's profitability. The sensitivity analysis adjusted investment costs, operating costs, cost of biomass, calorific value of biomass, feed-in tariff of electricity, the price of thermal power and the consumption of thermal energy by DHN. Each variable was individually adjusted by +5%, -5%, +10%, -10%, +15%, –15%, +20% and –20% and the effect on the project's profitability was recorded. Especially for the feed-in tariff of electricity the variable was adjusted only for years between 21 and 25 because for the first 20 years of the investment a feed-in tariff equal to 133 €/MWh is guaranteed.

The sensitivity analysis recorded the influence of the variation of the above-mentioned parameters to IRR and NPV. In figure 4.11 is depicted the tornado diagram

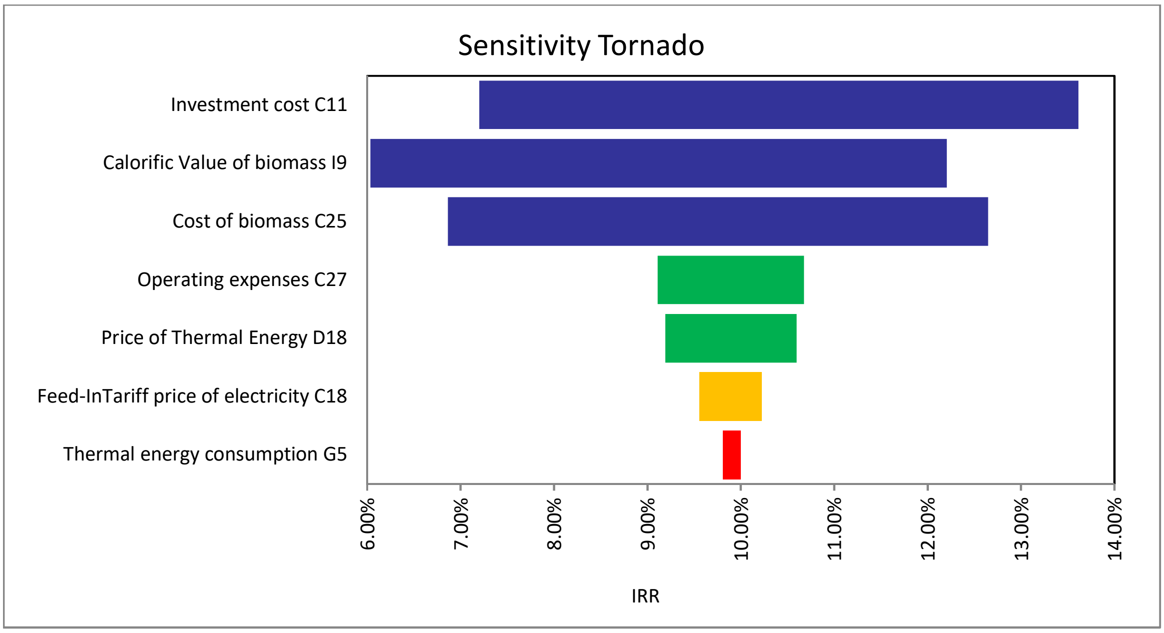

Figure 4.11 Tornado diagram of the sensitivity analysis for IRR

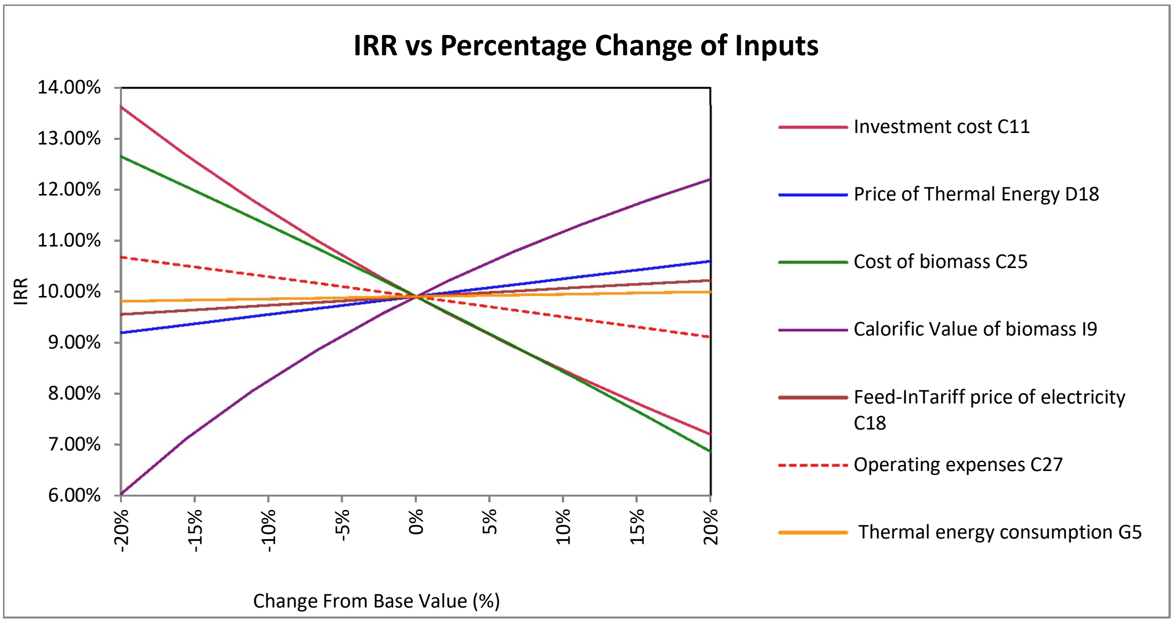

Figure 4.12 IRR vs Percentage Change of Inputs

of the sensitivity analysis for IRR. Furthermore, in Figure 4.12 is depicted the influence of these parameters to IRR. The results of the sensitivity analysis showed that the IRR of the Project was most affected by investment cost, calorific value of biomass and cost of biomass in that order. The next important variables were operating expenses, price of thermal energy and feed-in tariff of electricity, but with significantly lower influence on IRR than investment cost, calorific value of biomass and cost of biomass. Finally, the least important parameter was the thermal energy consumption by DHN.

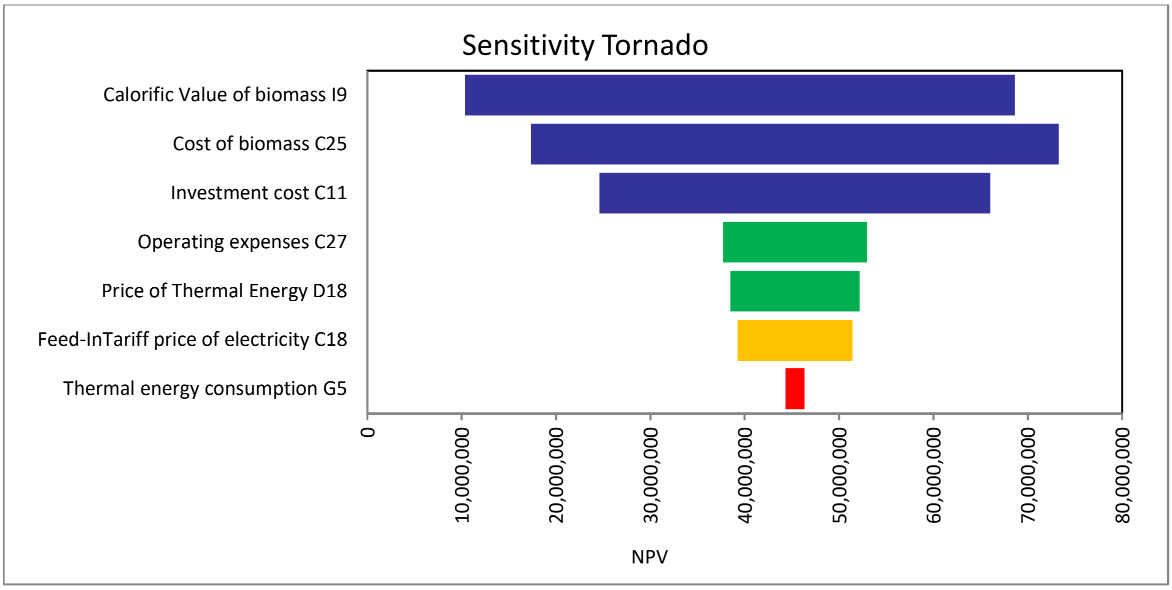

Figure 4.13 Tornado diagram of the sensitivity analysis for NPV

On the other hand, as concerns the sensitivity analysis on NPV, in Figure 4.13 is depicted the respective tornado diagram. Furthermore, in Figure 4.14 is depicted the influence of the variation of recorded parameters on NPV. The results of the sensitivity analysis showed the project's NPV was most affected by calorific value of biomass, cost of biomass and investment cost. As it derives from the analysis the order that the latter three parameters influence IRR and NPV is different. The next important variables were operating expenses, price of thermal energy and feed-in tariff of electricity, but with significantly lower influence on NPV than calorific value of biomass, cost of biomass and investment cost. Finally, the least important parameter was the thermal energy consumption by DHN.

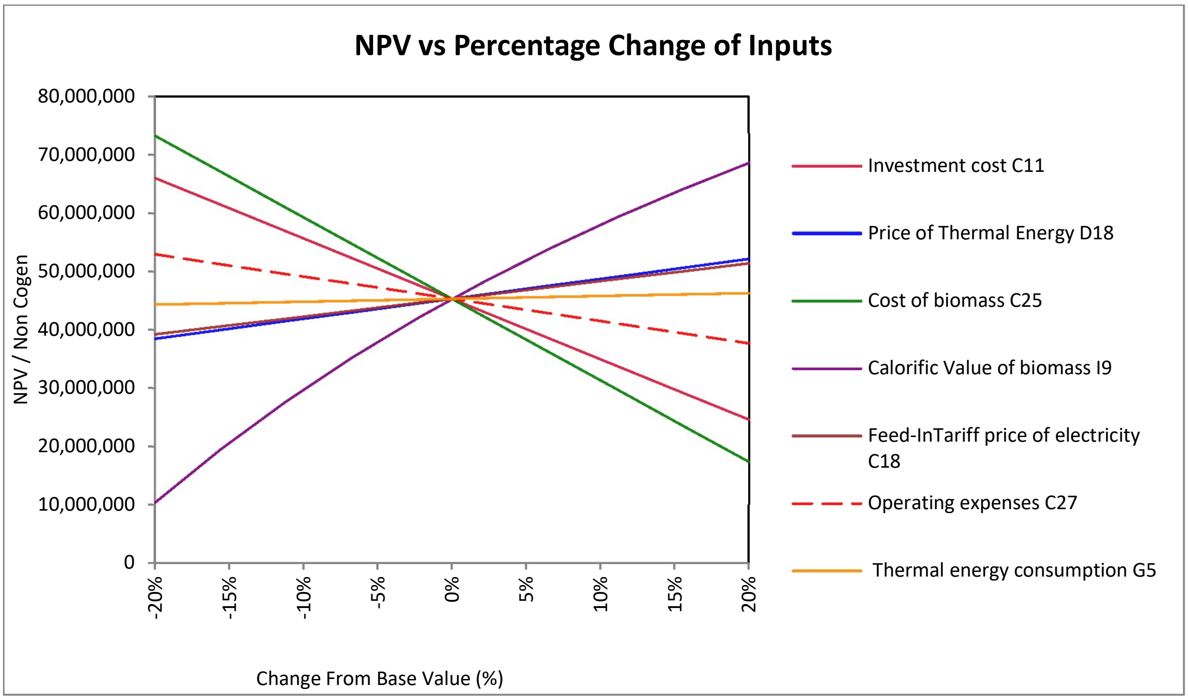

Figure 4.14 NPV vs Percentage Change of Inputs

In conclusion, the most important parameters that influence the profitability of the investment of the CHP power plant are investment cost, calorific value of biomass and cost of biomass. Investment cost would be defined during the submission of offers by the construction companies and as a result is a parameter that is under control. As concerns the calorific value and the price of biomass, their uncertainty could be significantly decreased by signing long term contracts with the suppliers of biomass that will include strict technical specifications regarding quality of biomass. Furthermore, from the sensitivity analysis it derives that the profitability of the investment is achieved for a wide variation of recorded parameters (-20%, +20). Thus, it was calculated that even with an investment cost equal to 4200 €/kWe the IRR is equal to 7,2% and the NPV is equal to 24.612.449 €. Furthermore, if the price of biomass is equal to 108 €/ton, the IRR is equal to 6,86% and the NPV is equal to 17.363.126 €.

4.12.3 Sensitivity analysis concerning efficiencies of CHP power plant

A sensitivity analysis was also performed to determine how the electrical efficiency in electricity-only mode and the electrical and thermal efficiency in cogeneration mode of the CHP power plant influence the profitability of the investment. In Figure 4.15 is depicted the sensitivity tornado of the efficiencies of the plant and of the parameters recorded in paragraph 4.12.2 for comparison. As it derives the electrical efficiency in electricity-only mode and in cogeneration mode influence significantly the profitability of the Project. This happens mainly due to the value of the feed-in tariff for electricity (133 €/MWh). However, the values of the efficiencies that were taken into account for this economic assessment have been achieved in commercial level by plants of this type and could be guaranteed by the Contractor of the Project, binding him by terms of rejection and penalties, and as a result the risk of the profitability of the investment due to their variation is significantly low.

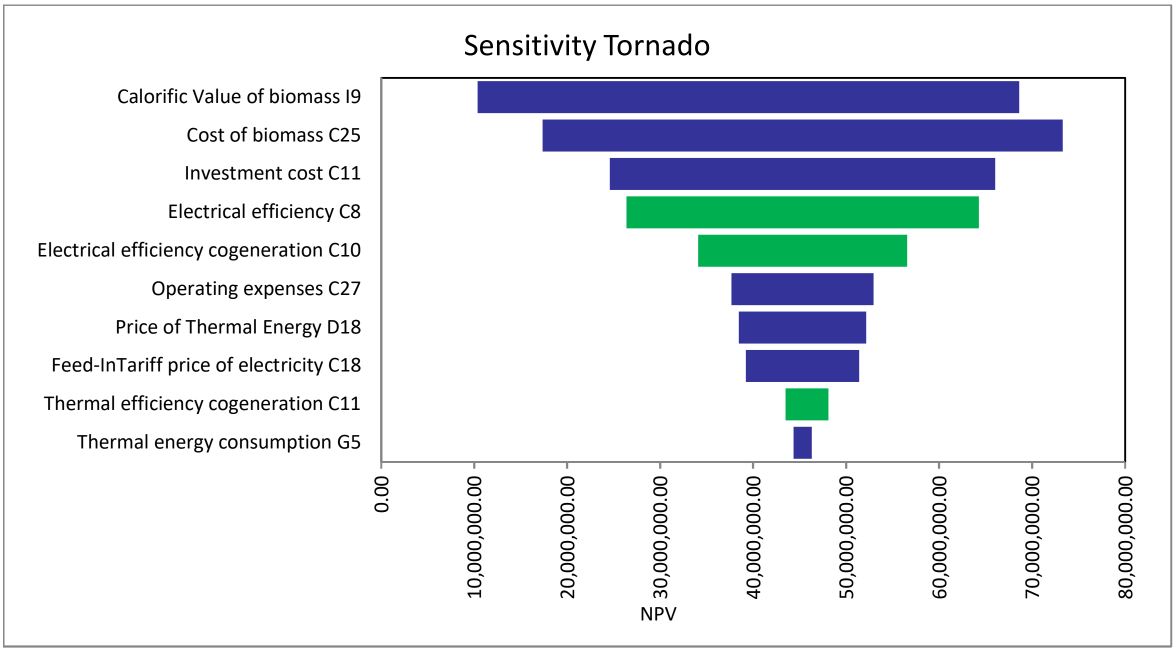

Figure 4.15 Tornado diagram of the sensitivity analysis for NPV

4.12.4 Other options to increase investment's profitability

The CHP power plant under study shall operate only 7 months per year in cogeneration mode to supply with thermal energy the DHN. For this reason, it shall be examined the possibility to utilize the produced generated thermal energy throughout the year in order to increase the profitability of the investment. Towards this direction could help the supply of energy during summer for District Cooling purposes, as well as the installation of hydroponic greenhouse units in the area of Amynteon. With this way parallel financial activities such as agriculture could be developed. In table 4.10 are illustrated the IRR values for the case that the thermal energy demand extends to more than 7 months and for various thermal energy prices.

Table 4.10 IRR values for the case that the thermal energy demand extends to more than 7 months			
	IRR		
Number of Months	Price of thermal energy 27 €/MWth	Price of thermal energy 30 €/MWth	Price of thermal energy equal to 35 €/MWth
7	9.90%	10.30%	10.93%
8	9.97%	10.42%	11.14%
9	10.04%	10.54%	11.34%
10	10.10%	10.66%	11.55%
11	10.17%	10.78%	11.75%
12	10.23%	10.89%	11.95%

On the other hand, the average cogeneration efficiency of the CHP power plant was calculated equal to 58,78%, while it could achieve cogeneration efficiency equal to 85%. This happen because the power plant will be designed to provide the peak thermal energy of 45 MWth, while the average thermal energy during heating season is 22,086 MWth. Therefore, the extension of the storage system of thermal energy of the DHN network could contribute to the increase of the average cogeneration efficiency. For this reason, an optimization study shall be executed in section 4.12.5 taking into account the investment cost of the thermal energy storage system and the increase in cogeneration efficiency.

Furthermore, the installation of a flue gas condenser that would increase either the production of thermal energy or the total net efficiency of the CHP power plant could be investigated. This condenser should cool furthermore the flue gases upstream the stack and this energy could be transferred either to the condensate of the unit, or to the DHPS. A feasibility study concerning the profitability of this investment could be executed.

Finally, ash, which is a by-product of biomass burning, could be used in the cement's and fertilizer's industry. This will help to the increase of the profitability of the investment and the development of parallel financial activities.

4.12.5 Optimization of Thermal Energy Storage (TES) system's capacity

The Thermal Energy Storage (TES) is a system, which can store heat or cold for later use under different conditions, such as temperature, location or storage tank.[246] There are a number of TES types, such as sensible heat storage (hot water accumulator

[246] Cabeza L. F., Martorell I., Miró L., Fernández A. I., Barreneche C., 2015, Introduction to thermal energy storage (TES) systems, Advances in Thermal Energy Storage Systems, 1–28, https://doi.org/10.1533/9781782420965.1

tanks), latent heat storage and thermochemical storage. Hot water accumulator tanks are widely used in European DH systems at the moment.[247]

In this study is examined the feasibility of installation of hot water accumulator tank in order to cope with the peak thermal loads of the DHN. As it is illustrated in figure 4.7 only 60 hours per heating season the thermal load demand is higher than 95% of its peak value. Furthermore, 181 hours per heating season the thermal load demand is between 90% and 95% of its peak load. However, these high values of thermal energy demand appear during successive days.

In order to dimension the capacity of the hot water accumulator a statistical analysis was executed. Therefore, for various maximum thermal loads of the CHP plant it was calculated the required capacity of the TES, in order that uninterrupted supply with thermal energy of the DHN to be achieved. As it is illustrated in figure 4.16 the required capacity of the TES system increases significantly when the installed thermal capacity of the CHP plant is lower than 40,5 MWth.

An optimization model was defined using the @Risk built-in program for Excel. For each thermal load between 35 and 45 MWth and a step equal to 0,05 was calculated the required thermal capacity of the TES in order that uninterrupted supply with thermal energy of the DHN to be achieved. Then was calculated the investment cost of

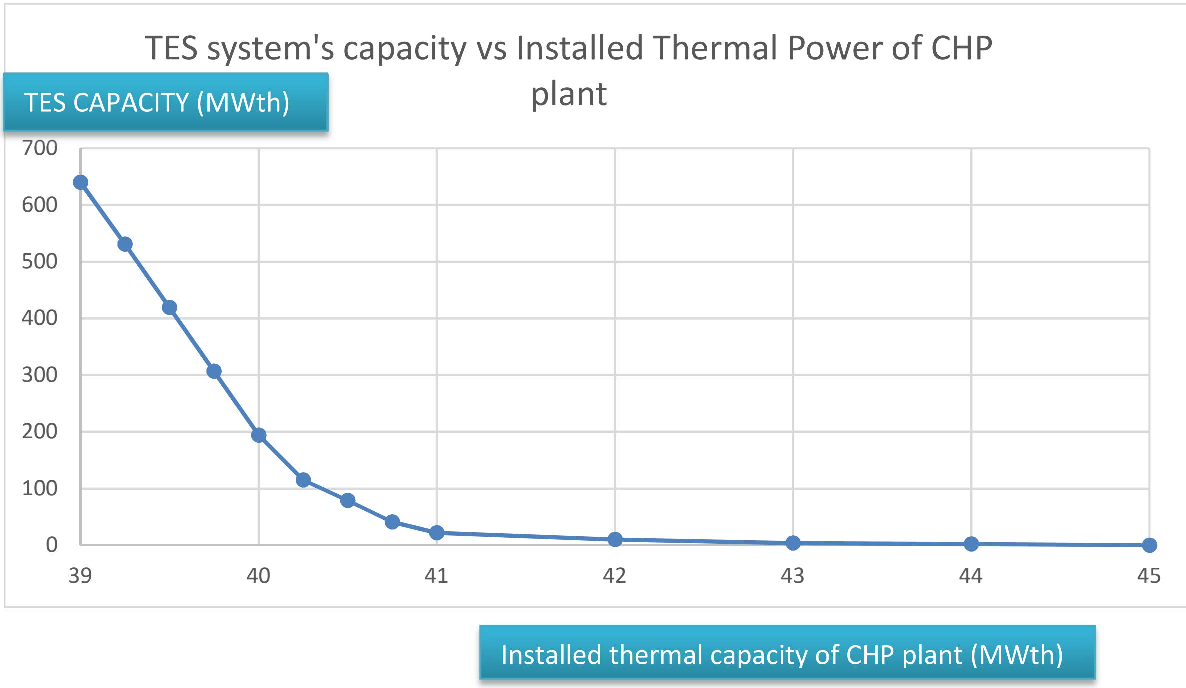

Figure 4.16 TES system capacity vs Installed Thermal Power of CHP plant

[247] Volkova A., Latõšov E., Andrijaškin M., Siirde A., Feasibility of Thermal Energy Storage Integration into Biomass CHP-Based District Heating System, CHEMICAL ENGINEERING TRANSACTIONS, VOL. 70, 2018, https://www.researchgate.net/publication/326835993_Feasibility_of_Thermal_Energy_Storage_Integration_into_Biomass_CHP_-Based_District_Heating_System

the TES by assuming that the installation cost of each 10 MWth of storage capacity is equal to 70.000 €[248]. The target of the optimization study was to define the TES system's capacity that maximized the IRR of the CHP plant's investment. In figure 4.17 is depicted the optimization procedure of Project's IRR.

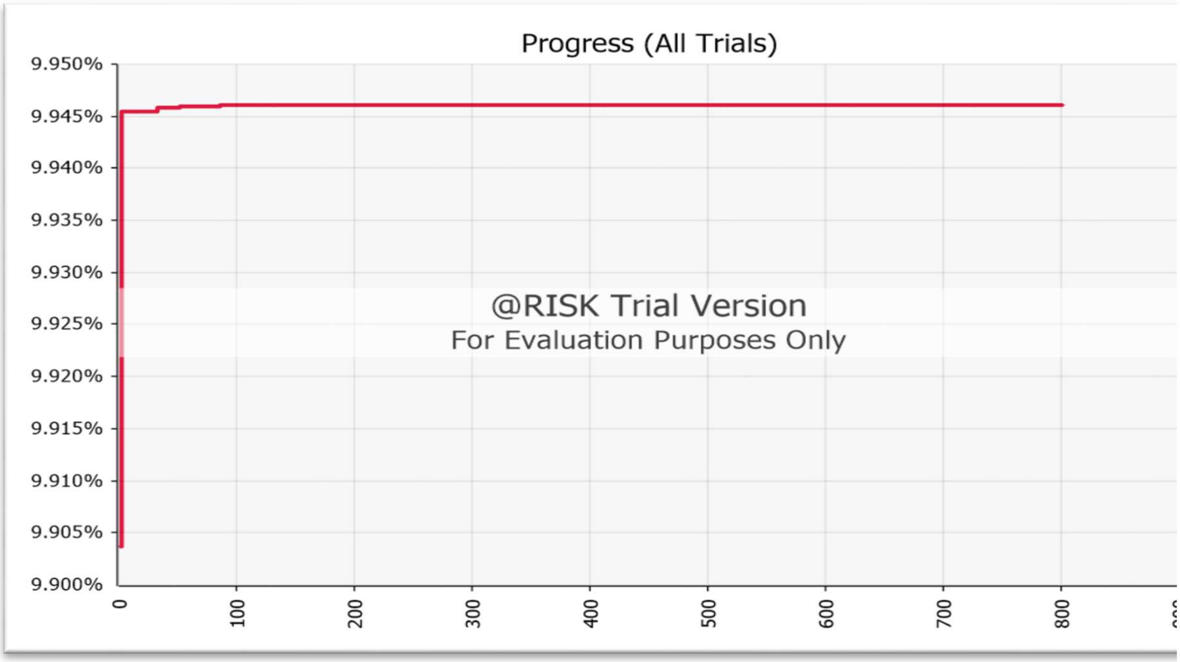

Figure 4.17 Optimization procedure of TES

The results of this analysis are summarized in Table 4.11. As it concludes, the IRR of the optimized solution is not significantly higher than the base case scenario. However, with the installation of the TES system the thermal energy requirements of the DHN could be covered with a CHP plant with significantly lower installed electrical and thermal capacity. In addition, the investment cost is significantly lower (about 8 million €) and the average cogeneration efficiency of the CHP plant is 61,48% instead of 58,78% for the base case scenario. To sum up the installation of a TES system with capacity around 50 MWth on one hand could marginally increase the profitability of the investment, but on the other hand the benefits that analyzed herein above could be achieved.

Table 4.11 Results of optimization study for TES's capacity

	Base case scenario	Optimization scenario
IRR (%)	9,90	9,95
TES capacity (MWth)	0	48,275
Installed Thermal Energy of CHP plant (MWth)	45	40,65

[248] Δημοτική Επιχείρηση Τηλεθέρμανσης Πτολεμαΐδας (ΔΕΤΗΠ) http://www.tpt.gr/images/stories/teuxos/megala-erga.pdf

Installed Electrical Energy of CHP plant (MWe)	23,929	21,615
Average cogeneration efficiency (%)	58,78	61,48
NPV (€)	45.331.915	41,379,585
Investment cost (€)	83.750.000	75.687.959

4.12.6 Pros of CHP power plant

The construction of the CHP power plant in Amynteon that will supply with DH thermal energy the city is characterized by several key advantages that are summarized, as follows:

- Increase of energy security due to burning of domestic fuel.
- Currency savings and local redistribution of several million Euros per year due to substitution of oil for heating.
- Increase of penetration of RES.
- The CO_2 emissions reduction will be about 150.000 tons/year.
- Lower pollutant emissions in comparison with existing technologies.
- The investment will create employment opportunities during all the phases of the Project. Thus, during construction, hundreds will be employed at manufacturing industries and at site. Afterwards, about 25 employees will work at the power plant. Furthermore, hundreds of people will work along the chain of preparation, processing, storage and supply of biomass to the power plant.
- The life quality of citizens will be upgraded.
- The domestic heating will be cheaper 30% - 50% than oil equivalent cost.
- Support and opportunities for sustainable regional development.

4.12.7 Threats

As it was analyzed in the previous paragraphs for the base case scenario the IRR and the NPV of the CHP power plant are equal to 9,9% and 45.331.915€, respectively. However, since this investment is studied for a period of 25 years and many parameters might change, herein below are examined the main threats for the profitability of the Project.

GHG emissions from using biomass for electricity generation do not fall under the EU Emissions Trading Scheme (EU ETS). This assumption has been taken into consideration for the economic assessment. However, it is possible in the future the GHG emissions either for the transportation of biomass to the power plant, or during biomass burning at the power plan to be considered under the EU ETS. Especially for the case of biomass transportation, for which is most likely the GHG emissions to be taken into account under EU ETS in the future, due to the capacity of the CHP power plant and the fact that biomass will be supplied from the area of West Macedonia, this risk is significantly low for the specific investment.

The feed-in tariff of the electricity generated by biomass burned power plant is possible to be decreased in the future. The value of 133 €/MWh is guaranteed for the first 20 years of operation of the power plant. Furthermore, in the sensitivity analysis of paragraph 4.12.2, it was calculated that the influence of feed-in tariff of electricity it is not significant to the profitability of the Project under the condition that the guaranteed price will be decreased 20 years after the commercial operation of the Project.

The price of biomass is possible to be increased in the future. Towards this direction could contribute the fact that other biomass power plants would be constructed in the area. As it was analyzed in the sensitivity analysis, the influence of biomass price to the profitability of the investment is high. Thus, in order to cope with this threat, long term contracts with strict terms concerning price and quality of biomass shall be signed with the suppliers of biomass.

Moreover, the regulating framework is possible to change in the future. Thus, the emissions limits or the technical requirements concerning the efficiencies of CHP power plants might be stricter. In this case a retrofit or upgrade of the power plant might be required.

The price of thermal power might change in the future. As it was analyzed herein above, the price of thermal energy that was taken into account for the economic assessment is significantly lower than the alternative cost that accrue for the case of burning alternative fuels such as NG, LPG and diesel oil. In addition, the sensitivity analysis concluded that the influence of thermal energy price to the profitability of the investment is not significant. Moreover, the profitability of the power plant is guaranteed even in the case that it would operate in electricity-only mode.

Chapter 5: Summary and Conclusions

5.1 Conclusions

The purpose of this thesis is to review the application of biomass for CHP in Europe. An extensive literature review in Chapter 1 revealed that although studies on the thermodynamic and economical assessment of biomass CHP plants and the respective regulatory framework for many European countries are wide spread in literature, the respective analysis for Greece is very limited. Furthermore, the installed capacity of biomass CHP plants in Greece is extremely limited too. Taking all the above into consideration, as well as the fact that in the cities of Kozani, Ptolemais, Amynteon and Megalopolis are operating District Heating Networks (DHN), which are supplied with thermal energy from lignite fired power plants that will be phased out in the next years, it was concluded that there is a need to examine the application of CHP plants to supply with thermal energy the DHN of cities located in Greece.

Firstly, it was analyzed the policy framework concerning biomass and cogeneration from it in Europe and Greece. Bioenergy is the main source of renewable energy (59,2% in 2016) in the EU and plays a significant role in achieving the 2030 and beyond targets for sustainable development. Support schemes on the promotion of renewables and more specifically for biomass are intended to cover the gap between costs of energy (electricity or heat) and revenues. The main support schemes for the promotion of renewable energy are feed-in tariff (FIT), feed-in premium (FIP), Quota (tradable green certificates) and Tender/Auctions.

Furthermore, the Legal Regime for biomass was studied. An extensive analysis was executed at the beginning for EU's regulatory framework. Since biomass tends to become central pillar of the European Union's energy policy, the latter has set up a number of rules - both hard and soft law - in order to provide the supporting legal framework for the promotion of biomass and become a global leader in the field of renewable energy sources. The promotion of biomass culminated in 2009, when Directive 2009/28/EC (RED-I) was published pursuant to article 194 of the Treaty on the Functioning of the European Union, which lays the specific legal basis for the field of energy, based on shared competences between the European Union and the Member States. Moreover, in November 2016, the European Commission published its "*Clean Energy for all Europeans*" initiative. As substantial part of this package, the Commission adopted a legislative proposal for a recast of the Renewable Energy Directive. Directive (EU) 2018/2001 (RED-II) entered into force on 24 December 2018, Member States have to transpose it into national law by 30 June 2021 and it shall be applied from 1 July 2021 onwards. The most important however, is that Directive RED-II includes, for the first time, updated and mandatory sustainability and GHG emissions saving criteria for both biofuels used in transport and bio-liquids, and solid and gaseous biomass fuels used for heat and power. Finally, numerous non-binding legal instruments concerning biomass have been issued in the context of the European Commission and the European Parliament.

In addition, a specific legal framework recognizing the benefits of cogeneration has been introduced, based on common definitions and methodologies and establishing the principles as to how the Member States could support the technology in question. The Directive 2004/8/EC aimed to increase energy efficiency and improve security of supply by creating a framework for promotion and development of high efficiency cogeneration of heat and power, based on useful heat demand and primary energy savings in the internal energy market, taking into account the specific national circumstances especially concerning climatic and economic conditions. On the other hand, the Directive 2012/27/EU repealed the Directive 2004/8/EC. More specifically, it provides that Member States shall adopt policies which encourage the due taking into account at local and regional levels of the potential of using efficient heating and cooling systems, in particular those using high-efficiency cogeneration. Furthermore, numerous Delegating Regulations and non-binding legal instruments have also issued concerning cogeneration from biomass. Finally, as concerns the pollutant emissions from industrial installations, the Directive 2010/75/EU of the European Parliament and the Council on industrial emissions (IED) is the main EU's regulating instrument.

On the other hand, as concerns Greece, distinctive feature of the legislation on electricity from RES, in particular biomass, and through CHP, in the first instance, was the complexity exacerbated by the high number of laws applying at the same time and the numerous amendments. A number of Law regarding biomass are analyzed in Chapter 2 that were issued in order to harmonize and incorporate the EU's legislation to the domestic Legal Regime. Moreover, a list of regulatory administrative acts and circulars that largely specify the aforementioned legislation is presented.

In chapter 3 is presented why biomass is considered as "carbon neutral" and are analyzed the terms cogeneration, trigeneration and polygeneration. Furthermore, are presented the main biomass to energy conversion processes and special reference is made to the proven and commercial ones. In addition, are named the main advantages and disadvantages of biomass. Among main advantages are included that it contributes to CO_2 emissions reduction, it decreases the dependency on fossil fuels, it emits lower pollutants than fossil fuels, it is widely available and it can be used in many forms. On the other hand, the main disadvantages of biomass are that its supply is characterized by seasonal fluctuation, it is required a lot of space for its cultivation and storage, sometimes has increased heavy metal concentration and dioxin emissions, and that transporting waste from forestry and industry to a biomass plant also carries a significant carbon footprint. Finally, a number of CHP biomass plants worldwide are presented.

In chapter 4 is presented an extensive techno-economic assessment of a biomass CHP plant in Amynteon, which will supply with thermal energy the respective DHN of the city. For the capacity of the CHP power plant in Amynteon and for the type of biomass that is available in the area of West Macedonia (including loose biomass), the technology of biomass using grate firing combustion boiler and a steam extraction turbine connected to a generator was selected. Through an energy study was selected the installed electrical and thermal power of the plant. Then, the main parameters of the techno-economic assessment were selected.

Firstly, it was calculated for the base case scenario, that in order the power plant to be preferable to operate in cogeneration mode than in electricity-only mode, the thermal energy should be sold at a price higher than 26,96 €/MWth. For the marginal case that the thermal energy price was 26,96 €/MWth, the IRR of the Project was calculated equal to 9,9% and the respective NPV equal to 45.331.915 €. Furthermore, the payback period was calculated equal to 12 years. In case that the thermal energy price is increased to 35 €/MWth, which is a price much lower than the variable cost of producing the same amount of energy by burning alternative fuels such as NG, LPG, Diesel, etc., the IRR of the CHP plant is 10,93% and the NPV is 55.540.092 €.

The feed-in tariff for electricity generated by biomass was 140 €/MWh and decreased to 133 €/MWh last April (2020). For the base case scenario, if it is assumed that the feed-in tariff is equal to 140 €/MWh, then the IRR is 11,26% and the NPV is 58.727.786 €. Taking all the above into consideration, it concludes that the new feed-in tariff prices for electricity generated by biomass influenced negatively the attractiveness of such Projects. However, considering the new feed-in tariffs (133€/MWe), it is concluded that the relative investment could achieve marginal profits under the condition that a price of thermal energy higher than 30 €/MWth could be ensured.

Furthermore, a sensitivity analysis was performed to determine which variables had the largest impact on the CHP power plant's profitability. The sensitivity analysis adjusted investment costs, operating costs, cost of biomass, calorific value of biomass, feed-in tariff of electricity, the price of thermal power and the consumption of thermal energy by DHN. Each variable was individually adjusted by +5%, -5%, +10%, -10%, +15%, –15%, +20% and –20% and the effect on the project's profitability was recorded. The results of the sensitivity analysis showed that the IRR of the Project was most affected by investment cost, calorific value of biomass and cost of biomass in that order. The next important variables were operating expenses, price of thermal energy and feed-in tariff of electricity, but with significantly lower influence on IRR than investment cost, calorific value of biomass and cost of biomass. Finally, the least important parameter was the thermal energy consumption by DHN.

A sensitivity analysis was also performed to determine how the electrical efficiency in electricity-only mode and the electrical and thermal efficiency in cogeneration mode of the CHP power plant influence the profitability of the investment, which concluded that the electrical efficiency in electricity-only mode and in cogeneration mode influence significantly the profitability of the Project.

Moreover, there were examined other options to increase the investment's profitability. An option is the supply of energy during summer for District Cooling purposes, as well as the installation of hydroponic greenhouse units in the area of Amynteon, which will be supplied with thermal energy produced in the CHP plant. It was calculated that if the thermal energy demand was extended for the whole year and it was sold at a price equal to 35 €/MWth, then the IRR would be equal to 11,95%.

Another option is the installation of a TES system, which would help towards the increase of the cogeneration efficiency of the CHP plant and the profitability of the investment. Other options to increase profitability of investment is the installation of a flue gas condenser upstream stack and the disposal of ash produced during combustion of biomass to cement's and fertilizer's industry.

An optimization study, was also executed to examine the feasibility of installation of hot water accumulator tank in order to cope with the peak thermal loads of the DHN. The target of this study was to define the TES system's capacity that maximized the IRR of the CHP plant's investment. The IRR of the optimized solution is not significantly higher than the base case scenario (9,95% instead of 9,90%). However, with the installation of the TES system the thermal energy requirements of the DHN could be covered with a CHP plant with significantly lower installed electrical and thermal capacity. In addition, the investment cost is significantly lower (about 8 million €) and the average cogeneration efficiency of the CHP plant is 61,48% instead of 58,78% for the base case scenario.

Finally, there were analyzed the main advantages of the CHP plant, which included increase of energy security, currency savings, increase of RES installed capacity, CO_2 emissions reduction, employment opportunities and cheaper domestic heating. On the other hands, there were analyzed the main threats of this Project, which included the following possibilities for the future:

- GHG emissions to be taken into account under EU ETS,
- Feed-in tariffs of electricity to decrease,
- Biomass price to increase and,
- The regulating framework to change.

Among the above mentioned threats, it was concluded that the most serious one is the possibility that the biomass price shall be increased in the future. In order to cope with this threat, long term contracts with strict terms concerning price and quality of biomass shall be signed with the suppliers of biomass.

5.2 Future work

This study examined the feasibility of the installation of a biomass CHP plant that will supply with thermal energy of 45 MWth the DHN of Amynteon. Similar studies could be executed and for other Greek cities such as Kozani (140 MWth), Ptolemais (100 MWTh) and Megalopolis (10 MWth), which are supplied with DH thermal energy from lignite fired power plants that will be phased out in the next years. Furthermore, such studies could be executed and for smaller cities located in North Greece that are not connected to DHN.

Finally, it would be useful to execute an optimization study that would examine the installation of a flue gas condenser that would increase either the production of thermal energy or the total net efficiency of the CHP power plant in Amynteon. This condenser should cool furthermore the flue gases upstream the stack and this energy could be transferred either to the condensate of the unit, or to the DHPS.