Economics of Solid Biomass Heating in Germany

Master Thesis

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Abstract

Over the last 12 years the German energy market for new capacity has changed fundamentally. The energy supply is traditionally based on fossil fuels. These are increasingly being replaced by renewable energies including solid biomass/wood fuel driven heaters. In this paper economic fundamentals of this trend are discussed in three parts, one part on policies with effect on the solid biomass heating market, one on total market potential, and the last on the cost structure of biomass heating.

The first part encompasses an overview on policies and their current impact as well as an assessment of their future development. It is found that existing policies for the promotion of renewable energies have a crucial impact on the market. Promotion policies have to be continued or to be made more generous to achieve the German parliament's renewable energies targets.

In the second part potential demand for biomass heat is investigated for different sectors and in total. The analyses show that total potential demand generally exceeds potential resource supply. Thereof, Industrial process heating has the largest potential. Despite the fact that total demand for heating from residential buildings is declining, expansion of district heating will lead to increased demand for biomass in that sector.

In the third part costs of biomass heating under varying conditions are modeled. Analysis show that full load hours and heating size affect heating prices the most. Resources prices are also shown to be important, though less than the first two. Investor's return on equity and public subsidies affect heating prices only marginally but serve mostly to incentivize additional investments in the sector.

Preface

This thesis is part of the Master of Science in Energy, Natural Resources and the Environment at the Norwegian School of Economics (NHH) and accounts for 30 ECTS.

The purpose of this paper is to develop a better understanding of economics of contemporary solid biomass heating in Germany. Firing biomass for heating is an old technology which relative to fossil fuels declined in importance in the 20st century. Over the last 12 years, however, dynamics in the markets changed fundamentally in favor of renewable sources including biomass. With this thesis it is my target to contribute to sciences and society by improving the understanding of these new conditions by structuring current energy policies qualitatively and by providing a quantitative picture of cost drivers and the total market size for contemporary solid biomass heating.

I would like to thank my supervisor Johannes Mauritzen for his incredible support, academic guidance and constructive feedback throughout the writing process. Moreover, I appreciate the support from the C.A.R.M.E.N. institute for sharing their data. Finally, I am very grateful for all the feedback from my brother Andreas Brenner, family, friends and fellow students who have provided valuable insights to improve the quality of this thesis.

December 18, 2012

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Symbols

[EEG]	Renewable Energies Act
[KfW]	German Credit Institute for Reconstruction
[kW]	kilowatt
[kW_{el}]	kilowatt electric energy
[KWKG]	Preservation, Modernization and Cogeneration Act
[kW_{th}]	kilowatt thermal energy
[MW_{el}]	megawatt electric
[MW_{th}]	megawatt thermal
[ORC]	Organic Ranking Cycle
[REN]	renewables
[RES]	renewable sources
[RoE]	return on equity
[TWh]	terawatt hour

1 Introduction

Over the last 20 years market dynamics in the energy sector have changed fundamentally. With energy provision traditionally based on fossil fuels, EU energy strategies currently focus on the development of renewable sources. Germany is a frontrunner of this movement with the target to provide 20% of its energy and 30% of its electricity from renewable sources by 2020. Promoting the “Energiewende,” the transition from a fossil and nuclear energy supply to a local and renewable energy provision, ranks among the most prominent topics in German politics.

Solid biomass currently corresponds to 3.7% of primary energy or 40% of total renewable energy provision in Germany (BMWi, 2012). With 30% of the country covered by forests and 47% of agriculture land potential exists for increased use of biomass (DeStatis, 2010a, p.2). The purpose of this paper is to analyze the magnitude of these prospects by identifying total market size as well as economic aspects by modeling cost of biomass heating for different heaters under different conditions.

Depending on its application the costs of solid biomass can vary substantially. While electricity from biomass still requires heavy subsidies, solid biomass heating is competitive without external support. Moreover, solid biomass projects need to attain a certain size to become economical without major subsidies. Thus, research in this paper is focused on the economics of the most promising energetic application for Germany, the economics of thermal units in the range of 0.1-5 megawatt thermal [MW_{th}]. The economic analysis of these medium size solid biomass heaters encompasses three parts: Regulations and policies for biomass heating; total market potential for biomass heating; and the cost structure of biomass heating. The three parts are related by topic but can be read separated from one another.

Policies and regulations are determining for the economics of biomass heating. For instance, subsidies, fuel quotas or banning of certain technologies shift the economics of different energy sources in favor of one or the other. Thus the first part of the paper introduces readers to the limits and opportunities of the German biomass market and its prospects under condition of current German policies. Among others it is found that policies for the promotion of renewable energies have to be continued or to be made more generous to achieve the German parliament’s targets for the extension of renewable energies.

The second part of the paper investigates total market size for medium size solid biomass heating units. Technological aspects and a required minimum size of 100-500 kW for operating the heaters economically limit its market potential. Considering these limits the market size is modeled with a bottom up model. Potential demand for the main costumer groups of biomass heating is determined group by group and summing these leads to the total potential. The analyses show the total potential demand exceeds the potential supply.

In the third part a model is developed to analyze the cost structure of solid biomass heating under different economic circumstances. Input parameters of the model are investigated individually and where needed, supplementing models are built to simulate the input factors. Major findings of the model are that cost of heat from solid biomass is especially sensitive to changes in full load hours and the unit size. With a difference of 30% between the highest and lowest potential future fuel price, resource prices also have a crucial impact on the economics of biomass heaters. Return on equity does not affect the heat cost significantly. The chapter analyzes among others investment cost, resource prices, return on equity and the effects of regional subsidy schemes.

2 Solid biomass heating regulations and policies

The German energy market is highly regulated. Multiple policies, as subsidies, feed-in tariffs, renewable quotas, and building standards affect the market and economic attractiveness of energy projects. In this chapter these regulations and acts with respect to medium size biomass heating units (0.1 MW-5 MW) are discussed.

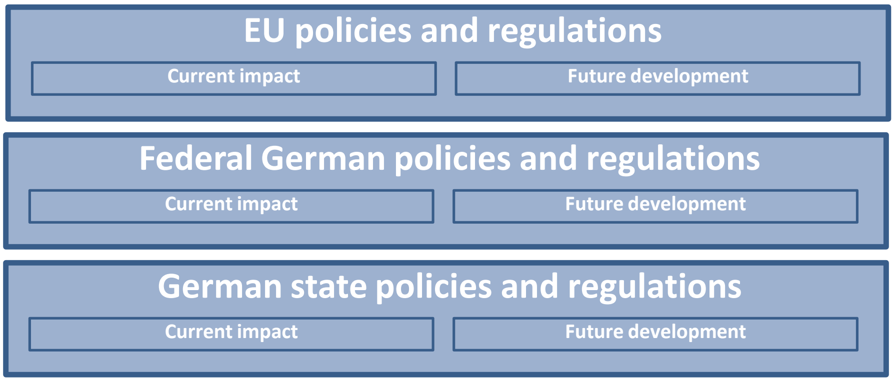
The chapter has two targets: First, given that policies determine the economic environment of the bioenergy sector, important policies and regulations are discussed and summarized to introduce readers to the opportunities and limits of the solid biomass market. Second, the future development of these policies and regulations are investigated to determine prospects of the sector.

Insights from analyzes for the first target are summarized in a table in the conclusion. The table shows policies with their current effects and the magnitude of these effects for the bioenergy market. The table indicates that the most crucial policies for the bioenergy market are the following:

- EU regulation EG/2010/31 and its related federal policies that require all buildings from 2020 onwards to fulfill zero energy standards
- The German cogeneration act which subsidizes district heating grids
- The German EEG renewable energies act which subsidizes biomass cogeneration
- Energy taxes which indirectly foster biomass heating
- Regional subsidies which lower the equity requirement for heating infrastructure investors

For meeting the second target, determining the prospect of the solid biomass heating sector, historical as well as contemporary developments of German policies are compared to government targets. The analyses show that as of recently, most targets had been achieved and therefore existing targets had been revised to become more ambitious. If these targets are also to be met, existing policies need to remain in place and sometimes to be reinforced.

The chapter is structured along the three institutional layers with the right to set policies affecting the bioenergy market: the EU level, the federal German level, the state level. Generally EU laws have precedent over German laws, which in turn have precedent over state and local laws. For instance, if the EU adopts a renewable energies quota the federal level can only adopt its own quotas within the framework set by the EU and the states can only adopt own regulations that are in compliance with both EU and federal policies. Thus, discussion begins with EU policies, followed by federal and finishing with state level policies and regulations.



Graph 1

2.1 EU level regulations and policies

Following EU policies and regulations in respect to solid biomass heating are discussed. When the EU adopts new policies, regions and member states have to comply with these. Nevertheless, the EU is strongly limited in its right to set policies (see appendix 1). It can only adopt rules that fall in the realm of environment protection but not directly in the realm of energy markets. For instance, it can adopt minimum quotas of renewable energies in the energy mix as a measure of environmental protection but it cannot adopt rules on energy taxes or prescribe how to achieve the quota as for instance through feed-in tariffs or green certificates. Thus, the effects of EU policies are generally weak and limited to set frameworks within which federal law has to be developed. Over the past 15 years the EU used its rights to install three important frameworks: renewables electricity/efficiency standards, emissions trading mechanisms, and renewable heating/housing efficiency quotas.

Renewable electricity/efficiency standards

In 2001 the first important EU level renewable energies acts was adopted, EG/2001/77. The act sets a quota for EU member states to jointly achieve 12% of energy provision from renewable sources. This directive was revised several times since and resulted in the 20-20-20 targets. The 20-20-20 directive obliges member states to jointly achieve a 20% increase in energy efficiency, a 20% reduction of CO_2 emissions, and 20% energy provision from renewable sources by 2020. These targets are to be achieved mostly by implementing measures on the federal state level that eventually lead to the contribution required from the EU by that particular member state. For the heating market these targets imply different outcomes. Achieving the 20% efficiency target means less energy consumption and thus a smaller market, whereas the other two targets will increase demand: The 20% provision from renewable sources and the 20% decline in greenhouse gas emissions will both lead to a replacement of fossil sources with renewables. Thus, generally the demand for related technologies will increase.

Emission Trading Scheme

In 2003, EC/2003/87 was adopted, the directive on the greenhouse gas emission trading scheme [ETS]. Following the Kyoto commitments from 1997, the EU enacted individual emission targets for its member states in 2002. To simplify achieving these targets the European Trading Scheme was installed. Now member states auction their emissions rights to organizations which again can trade these on exchanges. The aim of this policy is to reduce emissions where it is the cheapest. For instance old eastern German coal plants can easier be renovated than modern western German plants.

For the heating market, emissions trading implies an indirect support for renewable (and nuclear) energy sources. However, for medium sized heating units the effects of the ETS are insignificant. The ETS only affects "combustion installations with a rated thermal input exceeding 20 MW" (Annex I, 2003/87/EC). The main effect for such heating units is therefore indirect. Big consumers replace existing fuels with renewables and thus become new participants on the demand side in the solid biomass market.

Renewable heating/housing efficiency quotas

Regulations directly regulating the heating market were adopted in 2009 as EG/28/2009. Due to directive EG/28/2009 EU member states must install some kind of federal regulation that forces newly constructed and significantly renovated buildings to be heated with a minimum quota of renewable energies (EG/28/2009 Art.13 Abs.4). Minimum quotas mean one can either install a purely renewable heating system or a system with fossil energy sources that is supported by renewable systems (e.g. a joint system combining natural gas heater with solar radiation systems). In case of geothermal and biomass as renewable heating source a joint system is usually more expansive than a pure system. Thus a major share of new and significant renovated buildings is going to have only renewable systems. Moreover, for district heating grids this implies that they must be fueled by renewable sources to a minimum of what the quota requires if they want new and renovated buildings to be connected to the grid.

One year after installing the renewables quota system, in 2010, the EU adopted directive EG/2010/31 on building efficency standards. EG/2010/31 requires Member States to enact policies that from 2020 onwards generally all new buildings fulfill "nearly zero energy standards" (Art. 9 Abs.1 lit.). According to Art.2 a EG/2010/31 "nearly zero-energy building' means a building that has a very high energy performance […]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby." For the heating market EG/2010/31 and its zero energy standards implies that insulation standards will increase significantly and therefore demand for warming and cooling of all kind of houses will decline. It also implies that remaining heating energy demand will increasingly be covered by renewable sources.

EU conclusion

All three EU regulations have minor direct effects on the energy market. They are, however, very important to estimate the future development of renewable energy laws on member state level. The 20-20-20 targets lead to replacement of fossil through renewable energy sources. If Germany would not yet comply it would have to enforce existing federal law giving stronger support to alternative energy sources. The emission trading scheme profits renewable heating in the long term but has a small impact on below 20 MW heating units since these are exempted from purchasing carbon credits even if they are operated with fossil fuels. Most crucial might be the zero energy standards. As will be shown in the next chapter, federal law was and still needs to be significantly strengthened to comply to the regulation. Thus, demand for heating energy will significantly decline in the residential sector and new units will increasingly be based on renewable and thus also biomass fuels.

2.2 Federal level regulations and policies

Out of the three institutional layers with right to set energy policies the federal state of Germany has by far the most extensive competences to set policies (see appendix 1.1). It has the right to regulate every field of energy policy and is only constrained by compliance with EU framework regulations discussed previously. Equipped with these far-reaching rights for energy policy setting, federal German energy policy changed fundamentally over the last 20 years.

For most of the 20th century, energy policy remained relatively unchanged but in recent times there passes almost no year without the adoption of an important new act on the energy sector or at least the revision of another (BMWi, 2010). The high level of political activity makes the market environment very complex with multiple regulations affecting the heating market. Of major significance for the solid biomass heating market are five types of policies and regulations discussed following: energy taxes, the cogeneration act, the renewable energies act, heating ordinances including the renewables heating act, and preferred loan mechanisms.

2.2.1 Heating and construction ordinances

This chapter shows that energy efficiency regulations will lead to a declining room heating consumption and at the same time an increasing demand for bioenergy heating.

Regulation on energy efficiency of buildings has a long tradition in Germany with first rules adopted in 1977. Nowadays there exist ordinances the insulation efficiency of buildings as well as on the fuels to be used for heating. Over time these regulations were adjusted and minimum insulation requirements became more demanding. In particular over the last 12 years the regulation was revised leading to significant stricter insulation standards.[1] The EU's building efficiency directive which requires all new buildings erected in 2020 or later to fulfill nearly zero energy efficiency standards is a main driver for the stricter building efficiency rules. Despite of the multiple revisions over the last 12 years, the current standard still allows for about 50 kW/a and m^2 of energy consumption in new buildings wherefore

[1] Interested readers may find more information on the topic in appendix 2

federal regulations will have to be enforced further to comply to the EU's zero kW/a standards by 2020 (EnEV 2009, EnEV 2012).

To complement the efficiency standards in 2009 the renewables energies heating act was installed [EEWärmeG]. Simplified the act requires that at new and significantly renovated buildings heating energy must be to a certain share from solar or geothermal sources or at least 50% from solid biomass.[2] The quantitative target of the EEWärmeG act is to increase the energy share of renewable energy for heating and cooling from 10.4% in 2010 to 14% in 2020 (see appendix 2).

Given the new efficiency standards new buildings will have a very small energy demand and total room heating is going to decline in the future. Because of the renewable energies heating act the remaining energy will be covered by renewable sources. In contrast to residential buildings insulation is often too expansive for industrial buildings. Regulation, however, also requires these to either meet high insulation standards or to cover their heat demand by renewable sources.[3] Thus, a major share of new industrial and renovated buildings will cover their energy demand by renewable resources instead of improving the building insulation. Out of the renewable heating sources, solar and geothermal can only provide sufficient energy for single buildings but can, by technical constraint,[4] not supply district heating grids. The only remaining renewable energy source is biomass, which therefore faces a prosperous future in the district heating market.

2.2.2 KfW bank loan and subsidy program

Through the German development bank, the German Credit Institute for Reconstruction (KfW), the government provides low interest loans for renewable energies projects – called KfW loans. These loans make it attractive to build new biomass heating systems by four mechanisms: by easing access to financing, by providing low interest rates, by providing generous payback terms, and by issuing direct subsidies on certain types of projects.

In respect to solid biomass heating, KfW loans are available for three project categories:

[2] Interested readers may find more information on the topic in appendix 2
[3] Instead of by installing very efficient insulation one can also comply to the regulations by increasing the share of renewable heating above the 50% level from the EEWärmeG (EnEV §3 Abs.3).
[4] The amount of energy that can be extracted from solar rays and soil is usually much smaller than demand in district heating grids.

1. Large (>100 kW) biomass heating units
2. Biomass based cogeneration units < 2 MW_{th} with main focus on heat instead of electricity provision
3. District heating grids fueled by renewable resources

For all three types of investment one can apply for a preferential loan by the KfW bank. The bank then usually provides the entire loan sum. This eases access to credits since private banks might not be interested in financing such projects. The exact rate on the loan depends on the investment rating of the project but usually lies significantly (e.g. 1-2%) below what private banks would ask for (KFW, 2012).[5] Energy production as well as district heating infrastructure is usually highly leveraged and 70-80% debt ratio are usual. Moreover, terms for preferential loans state that upon request the payback starts in period three. This reduces risk for investors significantly as the entire cash flow from the first two years can be allocated as dividend to the equity investors.

In addition to these preferential loan conditions, investors receive direct subsidies on their projects as shown in Table 1. The direct subsidy amounts to as much as 8% on the heating unit and 15-30% on the grid. This constitutes a crucial incentive for investors since solid biomass energy infrastructure usually requires only 20-30% equity contribution (C.A.R.M.E.N., 2011).

	Biomass heating unit	**District heating grid**
Subsidy	20 EUR/ kW installation	60-80 EUR/ m
Subsidy as % of total cost	8%	22-50%
Subsidy cap	50’000 EUR	1’000’000 EUR
Source	KfW, 2012	Hartmann et al., 2011, p. 68; KfW, 2012

Table 1 KfW subsidy as percent of total investment

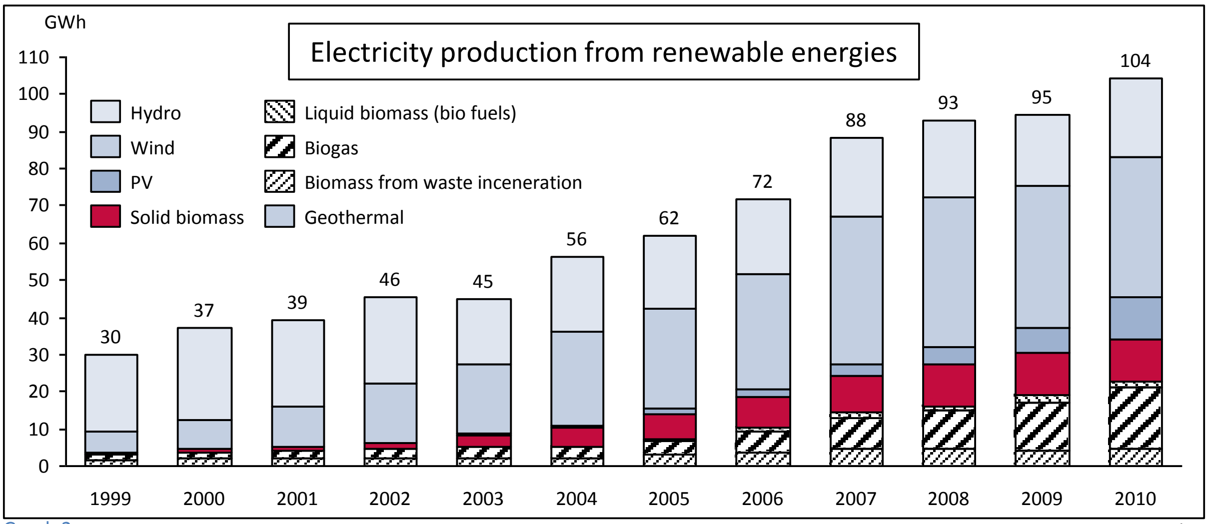
As shown the KfW program constitutes an important subsidy for the spread of biomass heating. It relieves investors almost entirely from risk for building district heating grids but also increases profitability of biomass heating units by lowering interest rates by about 1-2% as well as by issuing up to 50’000 EUR of direct subsidies. It is very likely that similar terms remain also in the future as the system was installed in 2000 and little was changed up to date.

[5] For instance, rates for investors with a probability of a default within one year between 0.1 and 2% would receive fixed interest rates on biomass projects in the range of ~2 to 4% over 10 years (KFW, 2012).

2.2.3 Renewable Energies Act (EEG)

Following it is shown that renewable electricity and thus also solid biomass electricity production will increase and that the increase is met by small cogeneration units which are substitutes for pure biomass heaters.

The EEG act is the act on promotion of electricity from renewable sources. It was enacted in 2000 to promote electricity production from renewable sources. Simplified the act guarantees investors a fixed feed-in tariff over 20 years for the production of renewable electricity. Therefore, they receive higher returns than possible with regular electricity sales and can much easier plan their future returns. Graph 2 shows development of renewable electricity since adoption of the act.



Graph 2

Source: BMU, 2011b

As shown, production from all renewable sources including solid biomass increased strongly over that period. As written in law by the act, the government has to undertake further measures to continue that growth.[6] Renewables are planned to make 50% of electricity in Germany coming from 17% in 2010.

Generally all biomass fueled and EEG subsidized electricity units are cogeneration units.[7] Therefore, the positive development of the bioelectricity market is crucial for the heating

[6] Coming from 6.4% in 2000, in 2010 renewable energies already contributed 17% of total German electricity production (BMU, 2011). The quantitative target written in the EEG act is to increase the share further up to 35% by 2020, 50% by 2030, 65% by 2040 and 80% by 2050 (As §1 Abs.2 EG2009).

[7] 95% of all EEG subsidized biomass power plants also produce heat used for heating or industrial processes (DBFZ, 2011b, p. 20)

market. It supplies already about 1% of all heat in Germany nowadays. [8] As analyzes in appendix 3 show conditions improved significantly in favor of biomass heating/electricity cogeneration instead of pure electricity production. The newest version of the EEG act subsidizes only cogeneration but no pure electricity production. This means all new plants will also have some kind of a heat costumer. Moreover, as the government targets to increase the share of renewable energies, the number of solid biomass cogeneration units will also increase.

Another crucial change in the newest version of the law was cancellation of recycled wood as potential fuel. As explained in appendix 3, this cancellation and the cogeneration requirement indirectly result in new cogeneration units to be relative small (< 5 megawatt electric [MW_{el}]). Summarized, biomass electricity production is to grow while additional capacity must be cogeneration and thus also produce heat. These cogeneration units are going to be primarily small units.

2.2.4 Cogeneration act

Following it is shown that electricity production will increasingly come from cogeneration. Biomass will be responsible for the majority of greenfield cogeneration (power plant) capacity and increase its share as power source for additional district heating grids.

Cogeneration requires less energy than separated electricity and heat production, a favorable attribute from an energy security point of view. Primarily for this reason[9] the German government promotes preservation of existing construction of additional cogeneration capacity through direct subsidies. The German parliament set the target to increase electricity from cogeneration to 25% by 2020 coming from a level of 15.4% in 2010 (Federal Government of Germany, 2011, p. 1; §1 KWKG). These targets are to be achieved through two support mechanisms, one for cogeneration units and the other for district heating grids.

[8] The German biomass research institute estimates that in 2010 biomass cogeneration provided already 14.1 TWh or 1% of the German heat energy consumption[8] (BMU, 2011; DBFZ, 2011a, p. 20).

[9] When the act was enacted in 2000 in its first version another crucial factor was to protect public utilities. A lot of cogeneration units belong to public utilities and were threatened of severe financial losses from low energy prices in the late 90s (Lobo, 2011, p. 225). The direct subsidy, however, made operation of these units more economically.

KWK subsidies for cogeneration units

The cogeneration (KWKG) 2009 act's subsidies mechanism is complex with different fees for different categories. Simplified the mechanism works as a direct subsidy issued on produced electricity from cogeneration and independent of the input fuel. Generally the subsidy should compensate for expenses required for building costly heat distribution infrastructure.

This subsidy, however, is insufficient to promote construction of greenfield[10] fossil fuel cogeneration capacity (Seefeldt, Mellahn, Rits, & Wetzel, 2011, p. 29). It only guarantees continued operation or expansion of existing fossil fuel cogeneration capacity. Therefore greenfield cogeneration capacity comes primarily from biomass (p. 30-31).[11] This implies that as long as the KWKG production capacity subsidy is not made more favorable the EEG subsidized biomass capacity continues to dominate greenfield projects.

KWK cogenerating subsidies for district heating grids

Often potential heat consumers are not directly connected to power stations wherefore district heating grids need to be constructed. The government subsidizes construction of these grids through the KWKG cogeneration act. These subsidies make investments in such infrastructure very favorable from an investor's point of view. Direct subsidies are that high that the investor has to provide almost no equity to build such grids.[12] At new built district heating grids sponsored by the act, biomass cogeneration has already a market share of 18% (Seefeldt et al., 2011, p. 42). As explained in detail in appendix 4, the act also promotes that biomass as fuel for district heating grids will be growing in the future.

2.2.5 Energy taxes and the eco tax reform

Duties on energy consumption have a long standing tradition in Germany beginning with the tolls on petrol in 1879 (BMF, 2012). From then until 1999 the tax and its successors had

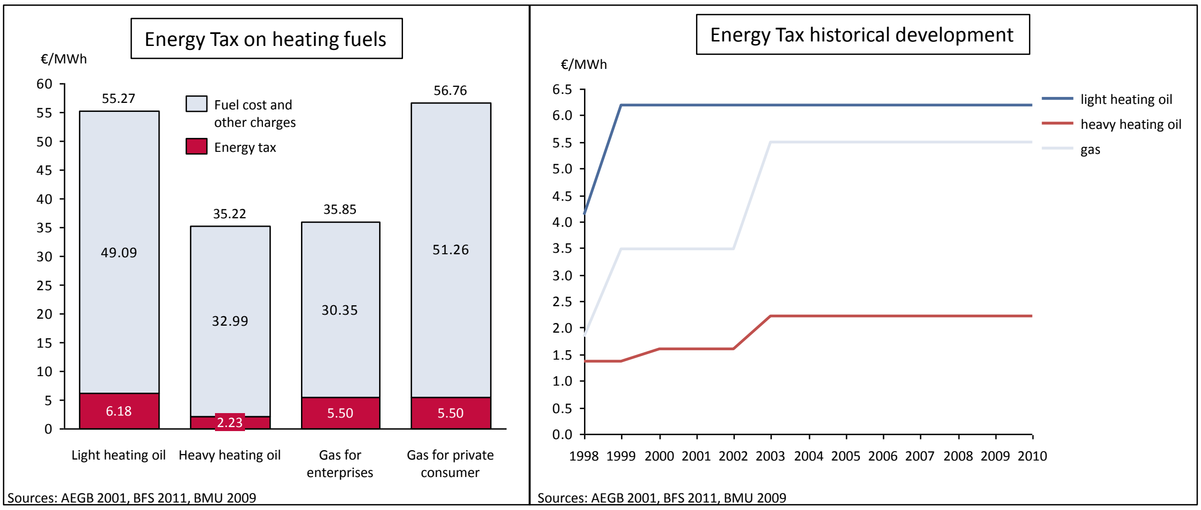
[10] Greenfield projects are such where not related infrastructure had been in place before. A major share of energy projects are replacements of old infrastructure where some of the old infrastructure can remain in place.

[11] Biomass cogeneration capacity is not promoted by the KWKG cogeneration act but by the EEG renewable energies subsidy scheme which contains more generous subsidies than the KWKG production capacity scheme (Seefeldt, Mellahn, Rits, & Wetzel, 2011, p. 30-31).

[12] Subsidies are capped at 20% of the total grid costs and the average subsidy amounts to 18.1% of total investment (§ 7a KWKG; Seefeldt et al., 2011, p. 39). For such infrastructure investments the initial equity share as of total investment usually amounts to 20-30% of total investment. A 20-30% equity share and 18% subsidy implies that little to none equity is required for building district heating infrastructure.

mainly fiscal purposes. In the 1990s energy policy in Germany changed and the "Energiewende," the transition from nuclear and fossil fuels to renewables, became political agenda. In line with the "Energiewende" the eco tax reform was initiated in 1999 (BMU, 2004, p. 3). The government decided to increase taxes with the target to set incentives to 'leverage existing energy savings potential […] as well as the expansion of renewable energies' (p.3).

Graph 3 shows changes of heating fuel energy taxes over time and in proportion to total fuel costs. For fossil heating fuels the energy tax were raised several times until 2003 and nowadays correspond to 10-16% of total fuel cost. To indirectly support renewable resources solid biomass and solar heating are exempted from these unconventional taxes (BMU, 2004, p. 4).



Graph 3

Exemption from fuel taxes constitutes an indirect subsidy for renewable energies but as the graph indicates taxes have not been raised since 2003. Since alternative policies have been introduced to promote renewable energies and there are currently no signs for changes.

2.3 Regional level regulations and policies

In Germany the regions ("Länder"=states) can set energy policies as long as there do not exist federal regulations overruling the state policy (see appendix 1.3). As shown in the previous chapter the federal government has made extensive use of its competences and established a broad set of tools to regulate the market. For this reason only little space is left for states to regulate which, nevertheless, was made use of. Most states have some sort of direct subsidy system for renewable energy projects in place. The state of Baden-

Württemberg has even adopted its own renewable energies heating act for residential buildings which supplements the federal policy. Additional regulations are rather unique. Direct subsidies that complement federal tools by considering local conditions are more usual.

With 16 "Länder" in Germany a detailed discussion of all local subsidies would go beyond the scope of this paper. These subsidies are nevertheless crucial factors for the economics of heating units. Therefore, they are analyzed exemplary by the subsidy schemes of Bavaria, Baden-Württemberg and North Rhine-Westphalia. All three regions are prominent for solid biomass. Taken together the three states represent about 40% of installed biomass cogeneration capacity in Germany (DBFZ, 2011a, p. 12).

Table 2 provides an overview on the three different subsidy programs.

	Baden Württemberg	Bavaria	North-Rhine Westphalia
Program Name	EFRE	BioKlima	PROGRES
Subsidy	50 EUR/t CO2 amendment equivalent for 15 years of plant operation	20 EUR/t CO2 amendment equivalent for 7 years of plant operation	15% of total investment
Subsidy cap	200'000 EUR or 20% of total investment	30% of total investment or 200'000 EUR	50'000 EUR for heating unit and another 40'000 if a heating grid is installed as well.
Accumulation with KfW subsidy	No	Yes	Yes
Valid for cogeneration	Yes	No	Yes
Source:	UM Baden-Wuerttemberg, 2010	TFZ, 2010a	C.A.R.M.E.N., 2009

Table 2 Comparison regional biomass subsidy systems

The North-Rhine Westphalia subsidy is issued on the investment cost and the two other on tons of amended CO2 equivalent. The subsidy is paid out at time of investment based on the calculated value of the amended emissions over that period.

Table 3 shows the subsidy as share of total investment cost of a 500 kW heating unit.

	Unit	Baden Württemberg	Bavaria	North-Rhine Westphalia
Investment cost	EUR	500'000	500'000	500'000
Unit size	MW	0.50	0.50	0.50
Full load hours	h	3'000	3'000	
Produced energy	MWh/a	1'500	1'500	
Assumtion on amendements	t CO2/MWh	0.3	0.3	
Amendment period	years	15	7	
Total amendment in t CO2 equivalent	t CO2	6'750	6'300	
Subsidy	EUR/ t CO2	50	20	
Total potential subsidy	EUR	337500	126000	75'000.00
Actual subsidy respecting cap	EUR	200'000	126000	50000
Subsidy as % of investment	**%**	**40**	**25**	**10**
Additional subsidy from KfW	EUR	-	10'000	10'000

Table 3 Regional subsidies as percent of total investment

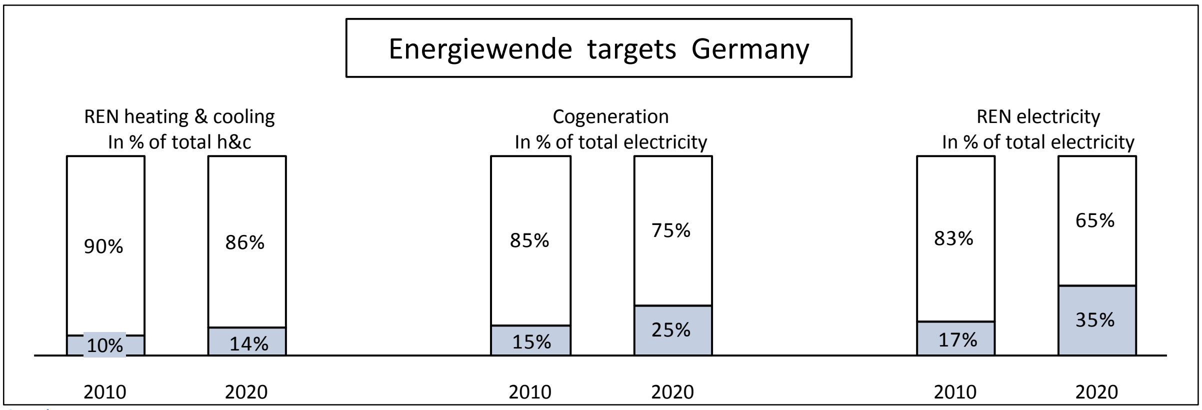
As the table indicates regional subsidies are very generous with a range between 10% and 40% of the total project cost. Given that heating systems usually just require an equity contribution of 20-30% the subsidy scheme lead to an environment where almost non private equity from project investors is required to finance new heating infrastructure.

Since the subsidies have different caps one cannot draw generalized conclusion on which scheme is the most attractive. The attractiveness of the schemes depends on the unit sizes. Nevertheless, the caps on maximal subsidy indicate that politics tend to support smaller units more than larger. Additional quantitative analyses on that topic can be found in chapter 7.7.

2.4 Conclusion biomass heating regulations and policies

In this chapter political factors with respect to the medium and large-scale biomass heating sector were discussed. Three institutional layers with regulatory power exist. The highest, the EU, is limited in how much energy policy it can set. Nevertheless it used its mandate for environmental issues and adopted some important regulations with effects on the heating market. Among others, it set the 20-20-20 targets and a regulation that all new and renovated buildings from 2020 onwards have to fulfill nearly zero emissions standards. In the realm of federal policies both EU regulations will lead to policies that foster a decline of the heating energy consumption as well as expanding renewables heating.

The federal institutions in Germany are the most powerful in terms of energy policy setting. Over the last 15 years they made extensive use of this power and highly regulated the market with the target to promote the “Energiewende,” the transition from a fossil and nuclear energy supply to a local and renewable energy provision. Graph 4 summarizes quantitative targets and the current state. These targets are written in law and thus legally



Graph 4

Sources: Bundesregierung 2011, BMU 2011, §1 KWKG, §1 EEG, §1 EEWärmeG binding for the executive and market regulating German ministries.

As the graph indicates, existing policies need to remain in place or be enforced in order to meet the ambitious targets. Thus the current subsidy system is considered to be the minimum level of support and more favorable conditions are likely.

As discussions have shown the current subsidy system consists of a complex mix of regulations and other policies. Generally for each of the political targets from Graph 4 there exists a separate act to promote and regulate the sector. Nevertheless the tools are overlapping and for instance the renewable energies act also contains rules promoting cogeneration. Thus, Table 4 summarizes them according to their influence on the biomass heating market for units >100 kW.

	Solid biomass electricity	Solid biomass heating	District heating grid	Cogeneration
Energy Taxes	• Local RES fueled electricity grids are exempted from 2.05 ct/kWh$_{el}$ tax (does not apply for RES el reimbursed with EEG subsidy and feed-in to the public grid!)	• No energy taxes on renewable fuels but 0.5-0.6 ct/kWh on fossil fuels		• Exemption from fuel taxes if efficiency higher than 60% (pure electricity production is exempted from fuel but pays electricity taxes)
Cogeneration Act			• Up to 20% of district heating grid is sponsored through direct subsidies	• Direct subsidy of 1.5-2.5 ct/kWh$_{el}$ for cogeneration units
EEG	• Complex system of guaranteed feed-in tariff for REN electricity • Higher feed-in tariff for NaWaRo material (rest wood from forests & farming etc.)	• Trend towards higher support for units <5 MW while smaller units primarily serve for heating with electricity only as by-product		• Guaranteed feed-in tariff only available for cogeneration units
Building ordinances and EEWärmeG		• EEWärmeG requires new buildings to be heated by RES (>50% for biomass) and traditional pure oil or gas heater are not allowed anymore • Heating ordinance leads to higher building efficiency and thus to smaller heating market		• Renewable heating quota can be substituted by high efficient cogeneration unit
KFW loans	• Preferential loans (2-4% for investors with good credit rating) • Loan payback starts in period 3 providing 2 years of equity payback • Easy access to debt financing	• Preferential loans (2-4% for investors with good credit rating) • 20 EUR/kW or maximal 50'000 subsidy • Loan payback starts in period 3 providing 2 years of equity payback • Easy access to debt financing	• Preferential loans (2-4% for investors with good credit rating) • 60 EUR/m or maximal 1'000'000 EUR direct subsidy • Loan payback starts in period 3 providing 2 years of equity payback • Easy access to debt financing	• Preferential loans (2-4% for investors with good credit rating) • Loan payback starts in period 3 providing 2 years of equity payback • Easy access to debt financing

Table 4 Summary federal policies with effects on the heating market

Moreover, the EEG act analyses have shown that primarily small cogeneration units with up to 5 MW_{th} will be built in the future. For these small cogeneration units, the EEG subsidy remains high and will lead to an expansion of biomass fueled cogeneration capacity. The KWKG cogeneration subsidy scheme, by contrast, is designed to promote survival of existing but not construction of greenfield fossil fueled cogeneration capacity. This means the governments promotes a more efficient use of existing fossil fuel energy infrastructure but makes sure that new built infrastructure is fueled by renewable sources.

Construction of district heating grids is promoted through the KWKG cogeneration act, and KFW preferential loans. At the same time, new buildings need to fulfill renewable heating and cooling quotas. Thus, generally more buildings will be connected to district heating grids. These need to be fueled to some extend by renewable energies. Otherwise the renewable heating requirements for new and significantly renovated buildings cannot be fulfilled anymore.

The third institutional layer with effect on the energy market is the state level. As energy policy setting is a shared competence in Germany and the federal government was very active in regulating the market, little potential for regulating is left for the state level. The Bundesländer still have own promotion tools for renewable heating. Promotion tools are generally direct subsidies. Since direct subsidies are issued as cash to investors they lower their equity requirement and thus their risk. The total contribution from subsidies usually lies somewhere between 10% and 40% of the total project cost. Together, with preferential loans from the federal KfW program, investment conditions are relatively attractive compared to usual investment opportunities. Nevertheless, local subsidies also favor smaller heating and cogeneration units up to a size of about 0.5-1 $MW_{th.}$

3 Market size and potential

Heating consumes 1’370 TWh or about 37% of total German energy consumption (Scholz & Gerhardt, 2010, p. 60). Economically and technically, solid biomass has the potential to cover only parts of this heat energy consumption. In this chapter the potential for this biomass heat demand potential for the next ten years is assessed. The potential of additional demand encompasses every heat project biomass heating constitutes an economically feasible option to other heating sources. The most crucial criteria for biomass heater to become economically feasible is its size. Only heaters larger than 100 kW are considered to contribute to the future potential.[13] Moreover, further criteria like replacement rates of heaters or time of operation of the heaters limit the potential.

The assessment shows the market is generally limited by resource supply and not by demand. If the entire potential would be developed 12-15% of the entire German wood harvest would need to be used for energy provision. Wood, however, is also used for material applications like paper or board production. Monetary value generation is usually much higher from material application than from energetic application. Thus the energy market is unlikely to be able to replace the material wood industry as consumer for as much as 10-15% of the total raw material. Thus total potential demand could only be met if major volumes of biomass would be imported.

A bottom up model is used for the analysis. The heating market is split into its subcategories: social infrastructure, office buildings, residential sector, and process heat. For each of these categories the development of demand for heating energy for the following ten years is estimated. Where available the estimation is based on literature and otherwise derived by interpreting factors like energy consumption per building type and construction market figures. Once the development of demand in the sector is assessed it will be estimated how much of it is theoretically suited for biomass heating. Among others only sites where heater with a capacity of at least 100 kW can be installed are suitable since economies of scale are very important for biomass heating (see chapter 7.1). Finally, the potential from the different sectors are accumulated to indicate total potential demand.

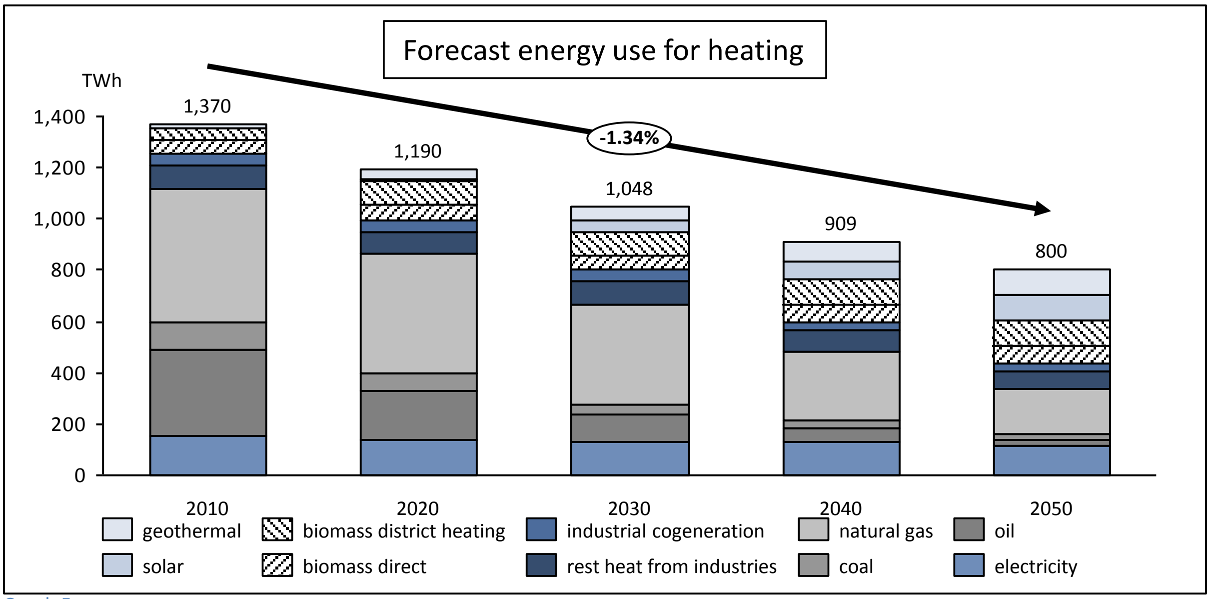
Up to date, biomass heating is concentrated in certain sectors which are public and social infrastructure heating, district heating for private houses and office buildings, agriculture (e.g. green houses or stock farming), process heat for the chemical, paper and wood industry (DBFZ, 2011a; Viehmann et al., 2011). Therefore, analyses on these sectors will be more detailed than for other sectors. Before detailed discussions on the potential of

[13] Chapter 7 shows that scale is the most crucial variable for biomass heater to be economically. Findings are that generally heaters below 100-500 kW are not economically.

different heat sectors start, the development of heat and biomass energy consumption is indicated.

3.1 Development of heat energy consumption

Subsequent data of a study from Scholz and Gerhard (2010) is discussed. The authors made a forecast of the German energy consumption serving as planning tool for the federal government's energy strategy. As Graph 5 shows out of total heat energy about 70% are covered by fossil fuels nowadays. Scholz and Gerhard (2010, p.60) estimate this share to decline to about 27% in 2050. The decline is assumed to come mostly from efficiency increases and therefore lower consumption.

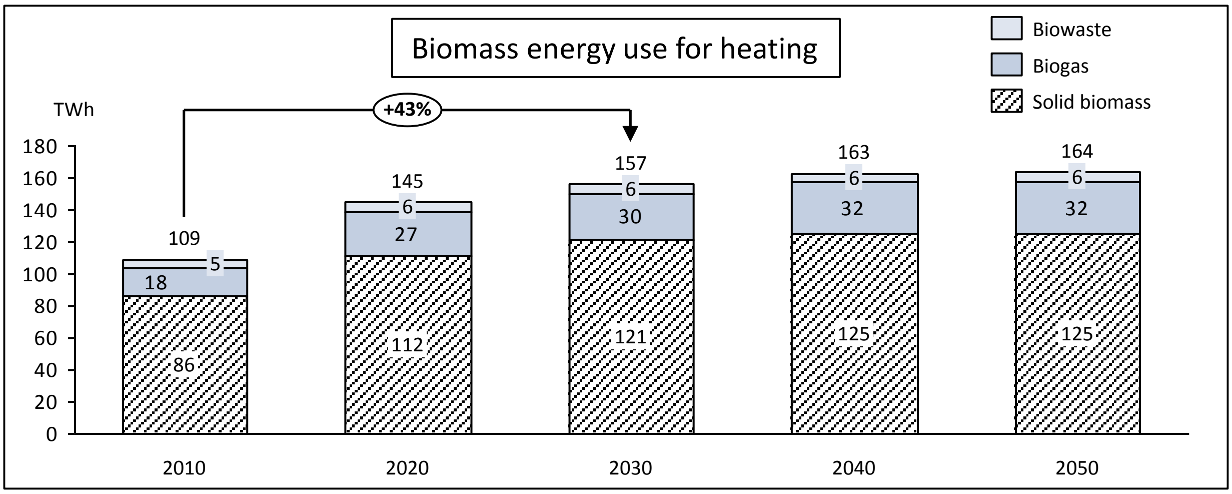


Graph 5

Source: Scholz & Gerhardt, 2010

Most efficiency increases can be achieved by better insulation and thus less demand for heating buildings (room heating). Room heating currently amounts to about 55% of all heating energy demand and is expected to decline by about 1.73% annually. Non room heat energy (most of it industrial process heat) is difficult to avoid as for instance certain industrial processes require high temperatures. Thus heat consumption not used for room heating is expected to decline by only 0.6% annually.

Efficiency increases will be complemented by replacing fossil fuels with renewable sources. Scholz and Gerhardt (2010) note that biomass is limited in Germany because total energy demand exceeds total the potential to be extracted from plants grown in the country. Therefore they estimate its share based on the resource availability. As Graph 6 indicates they expect solid biomass to increase by about 43% over the next 20 years but then to remain at that level because of resource constraints.



Graph 6

Source: Scholz & Gerhardt, 2010

However, since the study was published, the biomass market has started to internationalize and their model needs to be adapted to the new circumstances. Over the last years overseas imports of biomass have increased significantly. In 2009 first EU countries started with large-scale wood pellet imports from Canada and the US. Currently the EU already imports 2.5 mio t/a to replace coal (EUWID, 2011). These industry pellets can also be used for other purposes such as district or industrial heating. Until 2020 EU imports are expected to increase to 18 mio t/a, an equivalent of about 84 TWh/a (Schaubach & Witt, 2012). These 84 TWh of pellets is the equivalent of about half the German forest harvest (DeStatis, 2010a, p. 379). The real biomass heating potential, therefore, can be larger than expected from Scholz and Gerhard (2011). For these reasons their resource constraint model will following be complemented by a model estimating total theoretical demand.

3.2 Residential buildings

Following the additional potential for biomass heating in residential building is analyzed. First it will be indicated, that, despite declining demand and too small buildings for biomass heating, increasing penetration of district heating leads to a growing potential in the sector. Thereafter, this potential is estimated by adjusting and extrapolating the results of a study on the contracting potential in the rental apartment sector. Adjustments consider the growth of district heating and the decrease in energy consumption to the model used in the original study.

Residential heating consumption is expected to decline in the future by 1.7% annually or about 48% until 2050 (Scholz & Gerhardt, 2010, p. 62). The declining energy consumption is a result of a stagnating population combined with increasing efficiency standards. Over the coming 40 years, the German population is expected to be slowly declining and little additional housing space will be required (p. 62). In chapter 2.2.1 on heating ordinances it was mentioned that building energy efficiency regulation became much stricter over the last years and that further revisions will lead to zero energy efficiency standards by 2020. A stagnating population combined with a decreasing energy consumption per capita leads to a declining energy consumption.

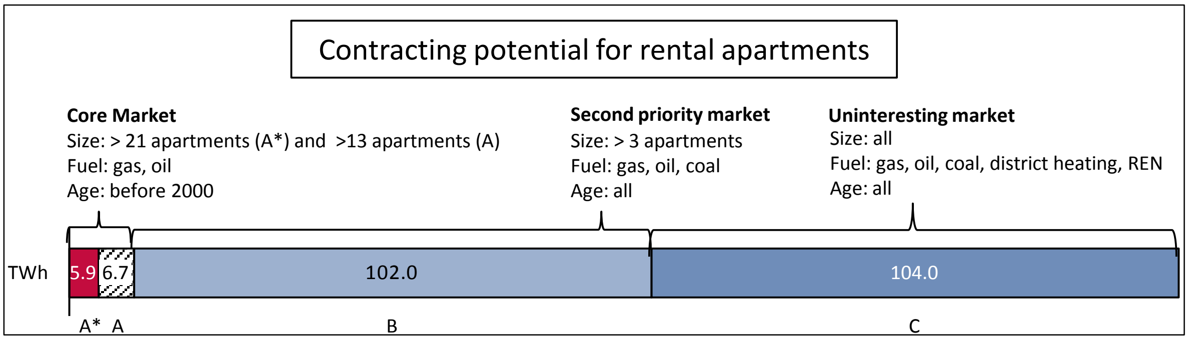
Solid biomass heaters require a minimum of 100-500 kW output to be economically viable (see part 3 & chapter 5.2 of this paper).[14] This corresponds to an area of 1’000-5’000 m^2. At a level of 5-30 kW per building, energy consumption in the residential sector is relatively low. Typically only apartment buildings or district heating grids are large enough for biomass heating.

Despite decreasing energy consumption and the low consumption per house the potential for biomass heating in the residential sector is considerable. Policies like the cogeneration act, the EEG renewables energies act as well as the renewables heating ordinance promote construction of additional district heating capacity. Scholz and Gerhardt (2010, p.60) expect about 60% of room heating to be distributed through district heating grids in 2050 compared to the 13% of today. This capacity will replace existing heating systems of standalone heater.

Total theoretical potential for solid biomass heat demand in the residential sector can be assessed extrapolating a study from Eikmeier et al. (2009). Eikmeier et al. (2009) assessed the contracting potential for rental apartments. In Germany there exist about 39.9 million residential buildings of which 21.1 million are rental apartments (Eikmeier et al, 2009, p. 77; Scholz & Gerhardt, 2010, p. 8). The authors analyzed the potential based on following criteria: heating unit age, volume of rental units per buildings as approximation of the energy demand, and fuel type of existing heating unit.

[14] The advantages of biomass over other heat sources increases with unit size as well as full load hours.

The authors split rental apartment heating market into three categories the core market A* and A with building of more than 21 and more than 13 rental units respectively, the second priority market with buildings of more than three rental units and old fossil fuel heater, and the uninteresting market. Graph 7 shows their results.



Graph 7

Sources:Eikmeier et al, 2009

As in the study the core market is also constitutes core market for solid biomass heating. The second priority market is currently considered to be of subordinated priority because of the low energy consumption from these buildings. If district heating increases as planned to a level of 60% in 2050, a major share of small houses, second priority market, will be supplied by heating system large enough to be economically interesting for biomass heating. Given the current pace of district heating grid expansion it is assumed that 20% or 20 TWh/a of the 102 TWh/a second priority market constitutes core market until 2020 (see Seefeldt et al., 2011). So the total core market amounts to 32.6 TWh/a.

The Eikmeier et al. (2009) study only looks at rental apartments which represent only half of all buildings. Private property buildings are usually small buildings with gardens which therefore neither are interesting for direct biomass heating nor for district biomass heating. A linear extrapolation of the figures would, therefore, not be correct. Because of the lower attractiveness of private buildings the potential of the 18.8 million private building is assumed to be half that of the 21.1 rental units or 16.3 TWh/a.

Furthermore, the Eikmeier et al. (2009) study assesses the current contracting potential as of today's energy demand. Differing from this approach in this paper the potential for the coming 10 years is analyzed. The major difference from the static Eikmeier et al. (2009) approach and the dynamic analyses in this paper are that dynamic analyses need to consider development of demand. When heating systems are replaced this goes often along with a renovation or rebuilding of the house which also leads to a declining energy consumption. Respecting these efficiency increases the heating energy potential for replacing old heating systems with new biomass heaters will be expected to be only 1/3 (16.6 TWh/a) of the 48.9 TWh/a derived from Eikmeier et al. (2009) data.

3.3 Public and social infrastructure buildings

Public and social infrastructure buildings are those serving a public purpose like schools, swimming pools, sport association, churches etc. In Germany there exist about 301'000 these (Clausnitzer, Jahn, & von Hebel, 2011, p.9). Even though, the 301'000 public infrastructure buildings is a small number compared to the 39.9 million residential buildings, public and social infrastructure building are attractive for solid biomass heaters. Public infrastructure buildings are usually larger and need a lot of heating energy. They are often close to each other and thus easy to connect with central heating grids. Moreover, capital costs are less relevant for public infrastructure projects than for private ones. Public institutions get low interest rates on the market and can take advantage of special KfW preferential loan programs for public institutions (Fette, Clausnitzer, & Gabriel, 2011). Furthermore, owner of the buildings stand under high scrutiny for their choice of energy source and energy efficiency standards.

Given their high relevance for biomass heating the potential of public and social infrastructure buildings heat demand is assessed as follows. It is estimated how many of these buildings of at least 1000 m^2 [15] size and under normal condition will consider replacing their heating system over the following ten years. Based on this information, the total potential is derived.

Clausnitzer, Jahn, and von Hebel (2011) conducted a study on the energetic renovation and new building requirement for social and public infrastructure. New heating systems are usually installed either in new buildings or during energetic renovation measures. Therefore, the potential demand for solid biomass heating can be derived from the study. Among others, in the study the volume of buildings, their size and age are analyzed. Based on

[15] This minimum criteria is derived as follows. Biomass heaters need a minimum capacity of 100-500 kW to become economically (see chapter 7). From HessenEnergie (2007) it follows that heating units with a net capacity of 100-250 kW are installed for an annual heat supply of 150'000-200'000 kWh/a. Fette et al. (2011, p. 4) found that public buildings need, depending on their type, around 150-200 kWh/a and m^2 after they are renovated according to the current German standard EnEV 2009. 150'000 kWh/a divided by 150 kWh/a and m^2 amounts to 1000 m^2.

further research on the different building categories and their age projections for renovation requirements are made.

Table 5 shows figures from the Clausnitzer, Jahn, and von Hebel (2011) data set. The main criteria for public infrastructure buildings to be attractive for biomass heating are: To be larger than 1'000 m^2 and to be renovated or new built over the coming ten years. Thus out of the Clausnitzer et. al. (2011) data set only buildings that fulfill these criteria are shown in the table. Moreover, derived from other sources (Energie Agentur NRW, 2008; Fette et al., 2011; Tippkötter & Wallschlag, 2009), the table also indicates average heating energy consumption per m^2 for building of these categories. Multiplying the two data with one another, the total energy consumption of to be energetically renovated and newly built buildings with over 1'000 m^2 are calculated.

	# total	Average size per building in m^2	% of all public infrastructure space	energy consumption of to be renovated in kWh/ m^2	Energy consumption of to be newly built (estimation) in kWh/ m^2	# to be new build	# to be renovated	Energy consumption of to be newly built and renovated in GWh/a
Hospital	3350	6500	6.9%	220	170	750	520	**1215**
Care center	7000	4900	10.9%	150	100	1650	2500	**2531**
Rehabilitation center	500	9800	1.6%	150	100	50	400	**630**
School	53500	2000	34.1%	148	98	3300	18000	**5813**
Sport center	33000	1100	11.6%	210	160	6750	6400	**2684**
Swimming hall	1350	3500	1.5%	234	184	250	400	**489**
Youth hostel	1600	1000	0.5%	150	100	90	630	**104**
Theatre, orchestre	160	2400	0.1%	170	120			
Event hall	310	4000	0.4%	170	120			
Total	100770		67.7%			12840	28850	**13465**

Table 5 Derivation of social and public infrastructure buildings solid biomass heating potential

As the table shows to be newly built and renovated >1000 m^2 buildings correspond to about 13,465 TWh/a of heating energy consumption after the renovation or new construction. Thus, social and public infrastructure has a core potential of 13.5 TWh heat demand for biomass heating over the next ten years. However, some of the smaller than 1000 m^2 buildings will also be renovated in the same period and then likely to be connected to the large buildings heating unit through district heating. Thus the total theoretical potential for social and public infrastructure is estimated at 14 TWh/a.[16]

[16] The <1000 m^2 building's energy consumption lies around 2.1TWh/a.: 30% (to be rebuild or renovated)*100'000 m^2 * 71 kWh/ m^{2}a = 2.1 TWh/a

3.4 Office buildings

Like public and social infrastructure buildings, office buildings are generally large and therefore well suited for heating with solid biomass. Their total potential is assessed as follows. The annual potential of heated space and their energy consumption for three different categories is analyzed, for new built offices, significantly renovated offices, and old offices with renovated heater systems. Finally the data is merged leading to the total additional potential for biomass heating over the next ten years: 4.27 TWh.

The heat potential from new office buildings amounts to 130 million kWh/a. Heinze (2011, p.33) state that new office space in Germany amounts to 2.6 mio m^2. According to the 2009 and 2012 building ordinances these must not consume more than 50-70 kWh/a and m^2 which leads to the 130 million kWh/a.

1.63 mio m^2 [17] of office space is significantly renovated every year. Assuming about half of these buildings also replace their heating system during renovation work a total of 0.815 mio m^2/a remains. These must not consume more than 50-70 kWh requirement leading to a total demand of 40.75 mio kWh/a.

Furthermore, in the office sector, heating systems are also replaced without significantly renovating the rest of the building. Heat from that category amounts to 683.9 mio kWh: The Institut der deutschen Wirtschaft Köln (2012, p.1) found that on average 1.5% of all heating systems are replaced every year. From Schlomann et al. (2011, p.93) can be derived that offices in Germany, excluding public infrastructure, have a total space of about 391 mio m^2. This means heating systems for 5.8 mio m^2 office space is annually replaced. Excluding the significantly renovated office space, there remain 4.885 mio m^2/a of office space with renovated heating systems. Old buildings of this sort consume 130-150 kWh/a m^2 (Schlomann et al., 2011, p.94). Thus heaters for 683.9 mio kWh[18] office spaces heating are replaced every year.

[17] The Heinze (2011, p. 36) data shows that on average of the last eight years volume of significantly renovated buildings amounts to 63% of the new built volume. Extrapolating this figure 1.63 mio m^2 (0.63*2.6 mio = 1.63 mio m^2) of office space is significantly renovated every year.

18 4.885 mio m^2*140 kWh/a and m^2

Table 6 Potential heat demand from office buildings summarizes calculations for office space heating potentials. Over the ten years period the 0.85464 TWh annual potential sum up to a total potential of 8.54 TWh.

	spaces in mio m^2	heating energy/m^2	mio kWh/a
New built	2.6	50	130
Substantially renovated	0.815	50	40.75
Heating system replaced	4.885	140	683.9
Total	**8.3**		**854.65**

Table 6 Potential heat demand from office buildings

However, because of their quality of insulation old buildings have to be at least 1000 m^2 and new built as well as significantly renovated ones 2000-3000 m^2 for being suited for biomass heating as single objects.[19] Not all office space is larger than 1000 $m^2$of old buildings or 2000 for new buildings. Given that office have on average an area of 1200 m^2(Heinze, 2011), it will be assumed that about 50% of all office space is large enough for being heated by solid biomass directly or through district heating. This corresponds to 4.27 TWh over ten years.

3.5 Industry and process heating

Famous for its industry and manufacturing, Germany has high energy consumption in these sectors. Industry and trade even exceed total energy consumption from room heating (Scholz & Gerhardt, 2010, p. 12). Generally the industry sector is very attractive for biomass heating. A high share of costumers requires a lot of energy and this equally distributed over the year. The high energy demand means sufficient demand for medium and large sized biomass heater. The constant consumption makes capital cost on a per kWh base less relevant relative to fuel cost. On the other hand, industrial investors generally require shorter payback periods than residential or public. They also consider primarily economic and not environmental reasons when choosing a heating technology.

Nast et al. (2010 cit in. Lauterbach, Schmitt, & Vajen, 2011, p. 12) analyzed the heating energy demand by sector and temperature level. The data is presented in Table 7.

[19] Schlomann et al. (2011, p.94) found that older office buildings consume about 130-150 kWh/a and m^2 of heat for room and warm water heating. For new buildings and significantly renovated buildings[19] modern regulation of the renewables heating and building ordinance hold which imply that they must not consume more than 50-70 kWh/a m^2 (EnEV 2009, EnEV 2012). Significant renovations are among others those where a specific kind of work like exchange of windows are conducted and where the affected area encompasses more than 10% of the building space or at least 50 m^2. The minimum heater size for biomass to become economically feasible is between 100-500 kW. Thus, with an energy consumption of 50-70 kWh and 130-150 kWh respectively and old buildings have to be at least 1000 m^2 while new built as well as significantly renovated ones 2000-3000 m^2 for being suited for biomass heating as single objects.

In TWh	Warm water + room heating	< 100°C	100-500°C	500-1000°C	>1000°C	Total
Food	7.3	9.4	11.6	0	0	28.3
Textile	2.1	2.9	0	0	0	5
Wood	0.3	1.3	0.3	0	0	1.9
Paper	2.9	3	11.1	0	0	17
Print and publishing	0.9	0.4	5.1	0	0	6.4
Chemicals	8.3	15.4	24	51.2	12.6	111.5
Rubber and plastics	1.9	1	3.8	0	0	6.7
Glass, ceramics, stone and earth processing	4.2	1.3	2	29.6	61.2	98.3
Metal (production and processing)	5.3	0.9	2.9	34	133.5	176.6
Mechanical engineering	5.6	1.7	1.3	0.6	1.7	13.1
Production of metal proudcts	6.5	2	1.6	0.9	2.1	10.9
Truck production	9.9	3	2.3	1.1	3.1	19.4
Other car industry	1.4	0.4	0.3	0.1	0.4	2.6
Other	4.8	1.9	1.5	0.4	1.4	10
Total	61.4	44.6	67.8	117.9	216	507.7

Table 7 Heat demand from industries

Out of those the following are unlikely switching to biomass heating:

- Those requiring heat >1000° C as these generally require special technology
- Metal (production and processing) as these processes usually need special features of the energy source, e.g. pure fuels with particular carbon content
- Glass, ceramics and earth processing as these processes usually need special features of the energy source
- Energy >500° C from the chemical industry as a major share from the chemical industry is processing fossil resources which leave energy rich waste. Incentives to switch the fuel are relative low if supply contracts exist with fossil resource provider and high caloric waste can be used in the process.

The remaining heat consumption sums up to 160 TWh/a. Considering efficiency improvement a potential of 129 TWh/a remains if the heating units are replaced.[20] As suggested by the guidelines of the Association of German Engineers (VDI standard 6025), it will be assumed that industrial heater are replaced every 15-20 years averaging at 18 years. Thus the potential heat demand for industrial biomass heating over the next 10 years constitutes 70 TWh[21] annual consumption.

[20] While energy demand for heating is assumed to decline significantly, efficiency for industrial process heating will decline less. In particular processes above 100°C profit only marginally from higher insulation standards and materials. Thus, in the following model, industrial heat consumption for heating and warm water is assumed to decline by 40% and other applications only by 10% if the heater is exchanged.

[21] 10/18*129 TWh= 70 TWh

Detailed analyses of each industry would exceed the scope of this paper.[22] However, so far biomass heating has not become prominent in specific industries. Viehmann et al. (2011, p.149) found in a study that insufficient data is available to assess how much biomass is used for heating in industry. They, nevertheless, note that it was extensively used in nutrition, agriculture (e.g. greenhouses or breeding), paper and wood industry. This trend can be explained by their proximity to the resource. A key issue of biomass heating is the resource supply which is easier for in these industries. Taking the same assumptions as before, the 10 year energy demand potential solid biomass heating in the sectors food, paper, wood and others amounts to 27 TWh/a.

3.6 Conclusion market size and potential

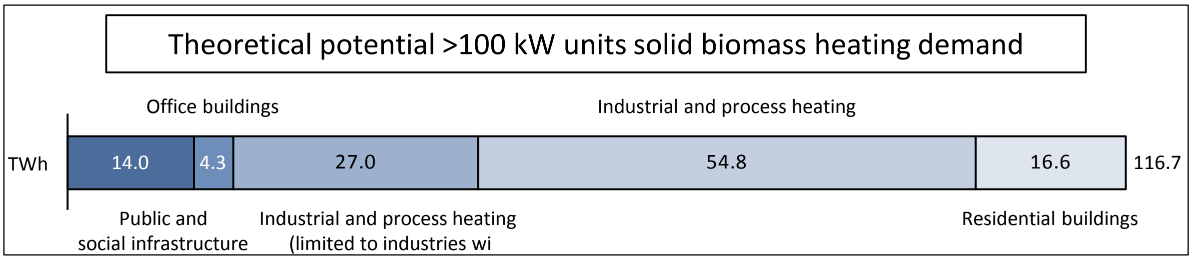
For medium and large size biomass heating plants only large customers are relevant. These are particular scarce in the residential sector where only big apartment buildings or houses connected to a district heating grid have a large enough energy consumption for installing >100 kW heating units. District heating is politically planned to increase significantly. In the public infrastructure sector and office building sector single buildings are larger and thus better suited for solid biomass heating. A significant share has the required minimum size of 1’000-2’000 m^2. Moreover, public institutions generally profit from low interest and thus capital cost, a criteria that makes many private project uneconomically. However, insulation standards have increased enormously, wherefore a sharp decline in heating consumption in all three building categories will take place. After renovation, buildings often require less than half the energy they used to.

In contrast to the private sector, industrial heat demand will stay relative stable. With demand from that sector exceeding demand for private and public building room heating already nowadays, the need of heating energy in Germany will remain high. So far only a few industries are used to use biomass as fuel. The theoretical potential for additional clients from those industries and others is very high. For this theoretical potential to be developed, economics of industrial biomass heater have to be favorable. Fuel costs are very significant for these economics. As industrial projects have a high energy demand as well as

[22] Further information on the type of processes for using heating energy can be found at Lauterbach et al., 2011; Viehmann et al., 2011; Nast et al., 2010

many full load hours, capital cost/ kWh are lower for industrial projects than for private. Therefore, they are more relevant for their profitability.

For each category the theoretical potential for demand within the coming 10 years was calculated. Replacement rates as well as heat demand and full load hours were considered. Graph 8 shows the result.



Graph 8

The energy content of the total German forest harvest including high quality stem wood has an energy content of about 100 TWh/a (DeStatis, 2010a, p. 379). This means about 12-15% of all harvested wood would need to be used for energy production to cover the potential demand. These 12-15% would generally to be covered by wood currently used for material applications as paper and board production or by imports. Since prices for wood used for material applications are a multiple of those for energetic applications total potential demand can generally not be met by German sources (see chapter 5). Even with major imports as forecasted to be an equivalent 84 TWh by 2020 for the entire EU, meeting potential demand would be very ambitious.

4 Financing costs solid biomass heaters and cogeneration units

Over the following four chapters a model to analyze the costs of solid biomass heating in dependence of the heating unit size is developed, the biomass heating economics model. The basic of the model builds the following formula which represents total cost of biomass heating for one year:

$$C_{biomass\ heating} = C_{financing} + C_{fuel} + C_{operation\ \&\ maintenance} \quad (1)$$

Where $C_{financing}$ = Financing cost; C_{fuel} = wood and fossil fuel costs; $C_{operation\ \&\ maintenance}$ = Operation and maintenance cost

In the biomass heating economics model these costs are calculated for every period and a project lifetime of 20 years. Then, the influence of variables influencing the three cost variables from formula (1) are investigated either in respect to the first period or over time. Since cost of biomass heating also depend on the size of the unit (economies of scale), four different heater categories are investigated exemplary of different heating unit size categories: a 350 kW_{th}, a 750 kW_{th}, 1500 kW_{th}, and a 1000 kW_{el} + 5000 kW_{th} cogeneration unit.

The findings from the model include that full load hours and economies of scale from the heating unit size are the cost factor with the highest influence on the cost of biomass heating. Moreover, financing cost become the more important the less full load hours the heater has. Resource prices constitute another crucial cost factor accounting for between 33% and 42% of total cost for units above 500 kW_{th}.

This and the following two subchapters discuss each one of three cost variables from formula (1). Formulas on how these variables are calculated are explained and parameters for remaining variables are investigated. When all formulas and parameters are determined, in chapter 7 the costs are modeled and the marginal effects of the most crucial parameters are investigated.

4.1 Methodology for calculating $C_{financing}$

In this chapter the first cost variable from formula (1) is determined, $C_{financing}$ - the financing cost. Following formulas explains how $C_{financing}$ is calculated and which variables and parameters therefore are investigated in this chapter.

Financing costs are computed as:

$$C_{financing} = D_{financing} + E_{financing} \qquad (2)$$

Where $D_{financing}$ is the annuity of the loan and $E_{financing}$ is the annuity of the equity.

The formula for the annuity $D_{financing}$ is:

$$D_{financing} = D * \frac{i*(1+i)^n}{(1+i)^n-1} \qquad (3)$$

Where D= total loan; i= interest rate; n = years

The annuity of equity is:

$$E_{financing} = PE * \frac{RoE*(1+RoE)^n}{(1+RoE)^n-1} \qquad (4)$$

Where PE= private equity; RoE = return on equity demanded by the equity investor

The formula for deriving D and PE is:

$$Total\_invest = \ Eq + D \qquad (5)$$

Where Eq= Equity; D= debt; total_invest= total project cost including peak load and biomass heater infrastructure

D is computed as follows:

$$D = \ d * Total\_invest \qquad (6)$$

Where d= debt ratio

d calculates as follows:

$$d = 1 - eq \qquad (7)$$

Where eq = equity ratio.

Moreover, Eq, the equity, composites of two factors private equity and subsidies:

$Eq = PE + subsidy$

Thus PE, the private equity, is calculated as follows:

$$PE = (Total\_invest * eq) - subsidy \qquad (8)$$

When inserting these formulas in one another the following variables are required for determining $D_{financing}$:

- RoE = Return on Equity
- I = interest paid on the loan
- *total_invest* = Total project cost
- n = periods or investment horizon

- eq = equity contribution
- *subsidy* = All direct subsidies

This chapter focuses on finding the input parameters for these variables. All except for total invest are determined in the first subchapter, chapter 4.2. Total invest is a key variable that is complex. Among others it depends on the project size, multiple components of heater infrastructure, and the heater category (pellets, wood chips or cogeneration). Due to the complexity of the variable most of this chapter, subchapter 5, 4.3 and 4.4, focuses on developing cost curves wood chips and cogeneration heater installation cost in dependence of their size.

4.2 Financing variables

Following all variables for financing cost except for installation cost are found. These variables should be representative for the German market for which reason input data is derived from averages of large amount of existing German heaters where possible.

Interest rates and investment horizon

Interest rates on the loan and the investment horizon are usually determined by the KfW preferential loan scheme. The KfW, the public German Credit Institute for Reconstruction, provides loans up to 20 years for fixed rates. Rates depend on the investment grade of the investor and traditionally range between ~1.5% and 6% (see chapter 2.2.2). A company with a one year default risk of 1.2% to 1.8%, which is comparable to a B range rating of S&P, pays close to 4% annually on a KfW credit. Thus, in the solid biomass heating economics model an interest rate of 4% with a time horizon of 20 years is assumed for debt capital for heaters up to 2 MW_{th}. Furthermore, payback will assumed to take place as annuity.

However, the KfW preferential loan can only be obtained up to a total size of 2 MW_{th} net capacity. Therefore, the cogeneration unit cannot apply for such credits. Units above 2 MW_{th} have to get financed on market conditions. Market interest rates can be approximated by information retrieved from the Bundesanzeiger. Private companies in Germany have to submit their annual report, which then is to be published in the Bundesanzeiger. From this data base the annual reports 2012 of the "BMK Biomassekraftwerk Lünen GmbH" and "PN Biomasseheizkraftwerk Papenburg GmbH & Co.

KG” were investigated. Their interest rates were 4.8% and 5.5%, respectively. Thus in the solid biomass heating economics model a rate of 5.5% will be assumed for the cogeneration project.

Equity and debt ratios

Data from 45 plants surveyed in Bavaria in 2010 show that on average there was a leverage ratio of 59% for biomass heaters (C.A.R.M.E.N., 2011). However, the average date of installation of these heaters was 2006 wherefore at time of observation there already had been a few payback years. Thus, the average leverage and equity ratios at time of investment are assumed to be 70% and 30% in the biomass heating economics model. (Eq= 30% and d = 70%)

Return on equity

The return on equity [RoE] investors ask for on their investments varies. For instance Roques, Nuttall, Newbery, & Neufville (2005, p. 4) compared different studies on the equity cost of nuclear power and found that different authors apply rates between 5% and 12.5%. With high capital cost and low fuel cost nuclear power investments are comparable to those of bio power investments. Thus, for the basic scenario of the biomass heating economics model a value of 8% will be assumed. 8%, however, constitutes only a rough approximation for the basis scenario and the implication of differing RoE are tested in the model.

Direct subsidies

As discussed in chapter 2.2.2 on the KfW subsidy and loan scheme, the KfW provides a direct subsidy for every loan taker. The subsidy amount to 20 EUR/kW heater capacity. The subsidy is capped at 50’000 EUR. This subsidy is, dependent on the region, to be accumulated with state subsidies. Regional subsidies were discussed in chapter 2.3. They are not included in the basic scenario of the biomass heating economics model but their influence is simulated separately. Thus the equity is computed as follows:

Basic scenario:

$$Eq = PE + KfW\ subsidy \qquad (9)$$

Other scenarios:

$$Eq = PE + KfW\ subsidy + local\ subsidy \qquad (10)$$

4.3 Installation costs wood chips heaters

In this and the next subchapter the variable *Total_invest,* total project cost, is determined for wood chips heaters and cogeneration heaters starting with wood chips. The remaining category of solid biomass heaters, wood pellets, is excluded from analyses since, as investigated in appendix 5, wood pellets heaters are economically uncompetitive in the medium size.

Four main categories of wood chips heater infrastructure costs exist: the biomass heater, the fossil fuel peak load heater, the storage bunker/silo, and other components (pipes or the feeding screw etc.). Following, the costs in dependence of the unit size of each of the four categories are found. Then they are aggregated to become the input data set for the variable *Total_cost,* a cost curve for solid biomass heating infrastructure costs in dependence of the unit size.

The Literature contains little information on the cost of medium size wood chips heating infrastructure in Germany in dependence of the size. Most models, so far, concentrate on case studies of individual projects. The limited research can be explained by the lack and quality of available data. Most comprehensive data sets exist at institutes issuing subsidies. Subsidies from these institutions are only allocated if the project owner submits bills as a proof of cost. Therefore, this chapter is based on primary data from these institutes or reports evaluating such primary data.

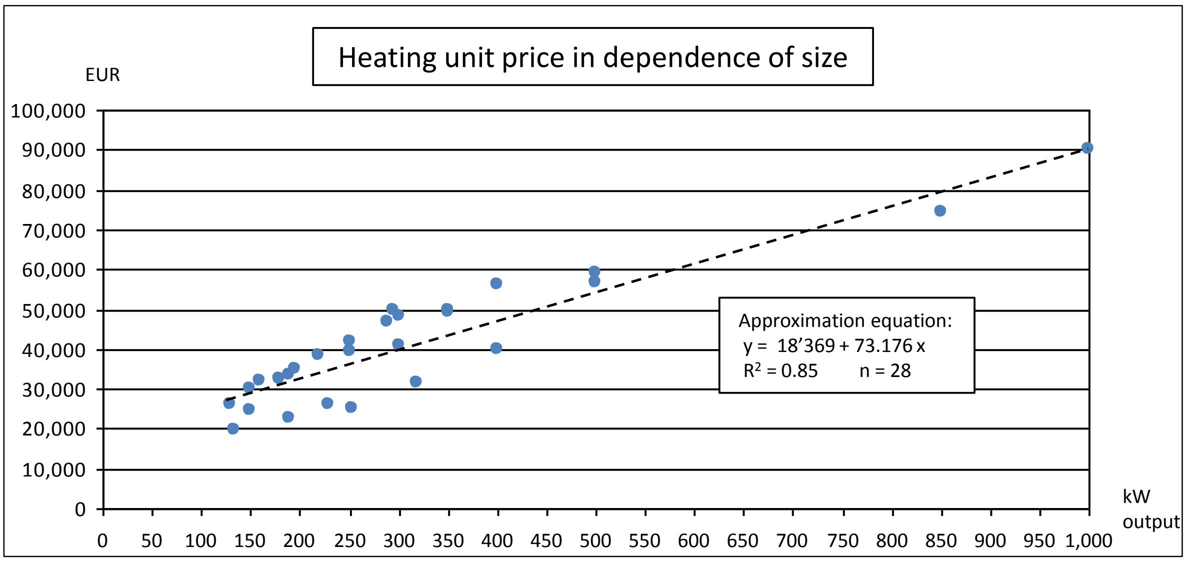
The main report evaluating primary data are the Clausnitzer (2007), Hartmann et al. (2011) and Krapf (2004) studies. The Clausnitzer (2007) study is based on data from the state of Hesse, interviews and literature research. Hartmann et al. (2011) draws on information collected from the KfW bank when issuing the KfW preferential loans. Even though this is the most recent and extensive data base, its information can only be used for restricted purposes because of the limited volumes of attributes collected in the data set. Most wide-ranging information comes from Krapf (2004). Krapf evaluates detailed data from his work as consultant at QM Holzheizwerke. Most medium and large biomass heating projects in

Austria and the German states of Baden-Würtemberg and Bavaria require a quality check from QM Holzheizwerke in order to obtain certain subsidies. Finally, information from these sources are complemented by findings derived from a primary data set collected by the office of environment from the state of Hesse and price information data mined in a brochures of the Forum for Renewable Resources (FNR).

4.3.1 Installation costs wood chips heating units

Wood chips heating units can be divided into three categories: small units up to 100 kW, standardized compact, and special solutions. Standardized heaters are available as small units up to about 100 kW and for medium units up to about 500 kW (Hartmann et al., 2011, p. 67). Small units are not covered by this paper. Standardized systems are mass produced and less sophisticated to install. Units usually larger than 350-500 kW are generally individually adjusted heaters. Specialties of the heating costumers, as e.g. higher temperatures for industrial processes, or unusual design for the fuel silo are typical problems that need to be tackled individually for such heaters >350-500 kW. Following the cost for both, standardized solutions up to 500 kW and individual solutions, are investigated.

Standardized units are usually cheaper than special solution. Based on data found in a comprehensive brochure on wood chips heaters, the FNR (2010), the following cost curve for standardized heaters was found with a linear regression: P = 18 369 + 73.176 *x. P stands for price and x the size of the heaters in kW. The data do not include transport, planning and installation but only the unit itself. Graph 9 shows the curve and data points.



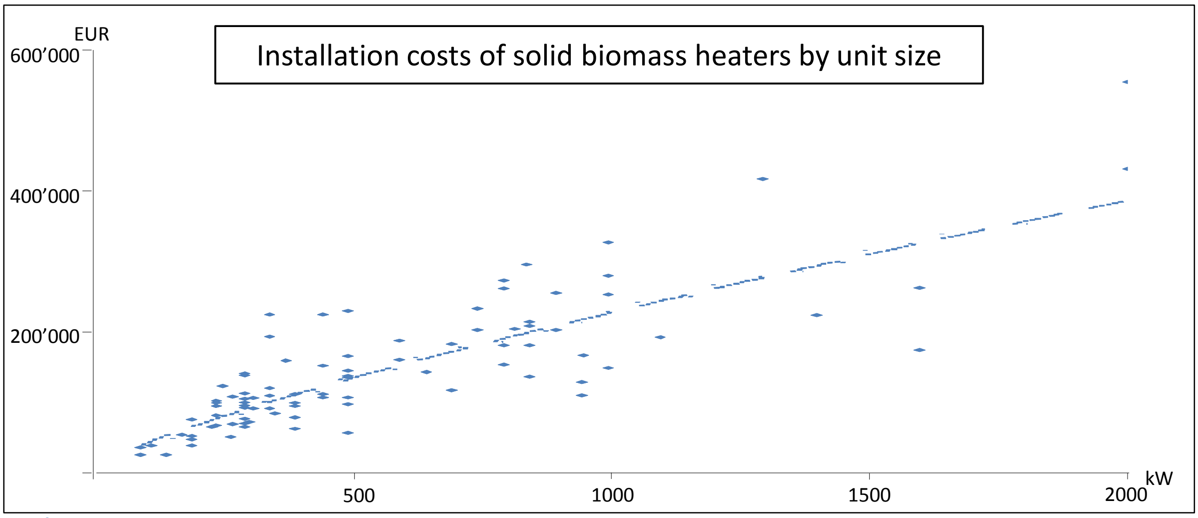
Graph 9

Source: FNR, 2010

The findings, as shown in the graph, build the basis to approximate the heating unit cost in chapter 4.3.5 as part of the total infrastructure cost, *total_invest*.

The cost of >350-500 kW units, the individual solutions, is best approximated by Krapf (2004) findings. He includes a few <500 kW and mostly >500 kW heater in his data set on cost of biomass heaters. Moreover, his data also encompass installation and planning instead of simply the unit and therefore cannot directly be compared to the FNR (2010) data.

For the purpose of this paper Krapf (2004) numbers were adjusted for inflation.[23] Graph 10 shows Krapf (2004) findings as shown in his paper. On 2012 prices the cost curve is P=1'243.17*x^0.774.



Graph 10

Source: Krapf, 2004

As the previous findings on heating unit cost also these findings from Graph 10 constitute an interim result. As discussed in chapter 4.3.4. they constitute the basis for the final cost curve, *total_invest*.

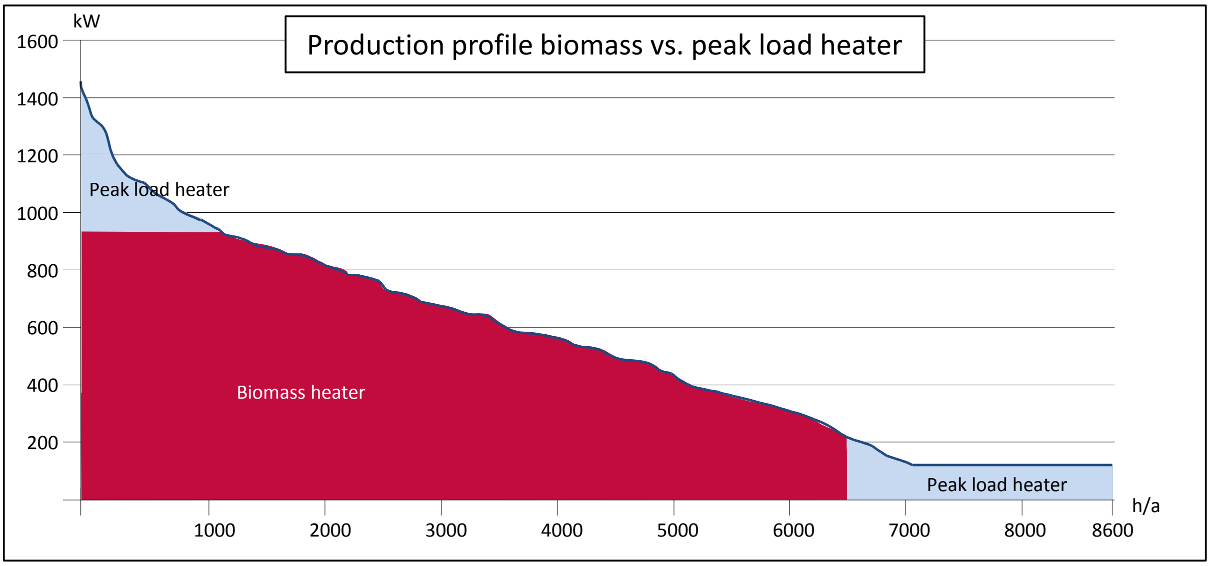
4.3.2 Installation costs peak load heating units

A major share of individually designed heater systems (heating units usually larger than 350 and 500 kW capacity) also has a fossil fuel peak load systems. At these sites biomass heaters serve to provide base load. Following, it is explained how these systems work and how

[23] Inflation corrections are based on data from the the German Office of Statistics' inflation index (DeStatis, 2012c). The Krapf (2004) data were collected from 2000 to 2004 a period long enough for external factors to shift prices. However, Hartmann et. al. (2011) panel data from 2005 to 2009 show that except for inflation the age has little influence on the validity of installations costs and thus the Krapf (2004) model. Biomass heating is a mature technology with only incremental technology progresses and therefore price differences.

much energy is usually contributed by the biomass and how much by the peak load heater. Thereafter, a cost curve for the peak load system is estimated.

Biomass infrastructure is much more expensive than fossil fuel infrastructure. Moreover, biomass heaters generally achieve higher efficiency if they run at almost full capacity. Thus, one installs a biomass base load heater that runs most of the time and another small fossil fuel heater that only runs at very cold days as well as during revisions and reparations. Graph 11 indicates that relationship.



Graph 11

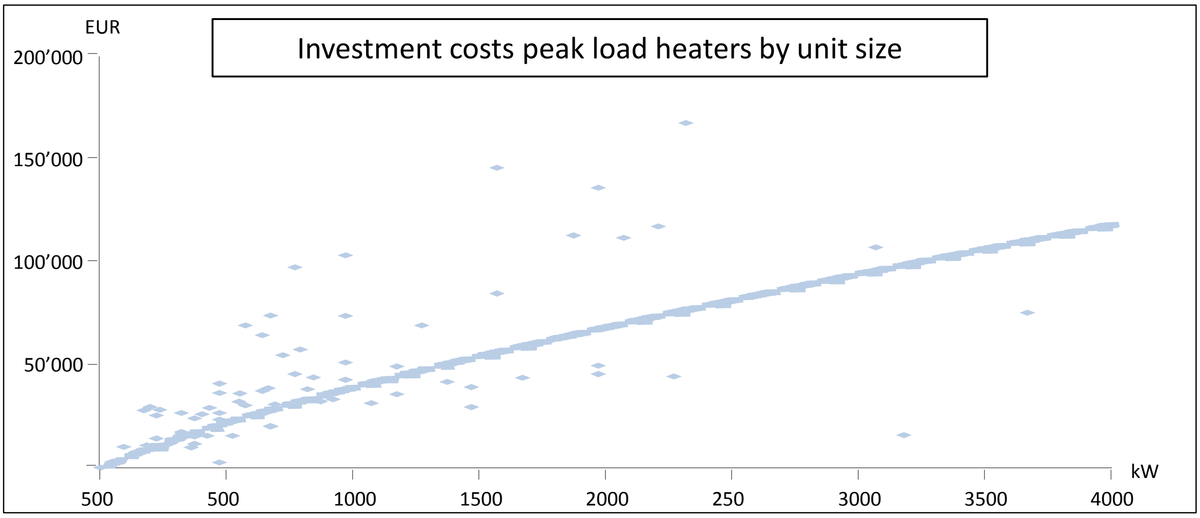
The peak load capacity only serves as backup for the biomass infrastructure and for short periods of peak or very low demand.[24] On average the peak load heater has about two times the capacity of the biomass base load heater since it must be able to serve as backup and peak load system at the same time (see HessenEnergie, 2007). Data from C.A.R.M.E.N. (2011, p. 2) indicate that, despite the peak load heater's capacity exceeds the biomass heater's capacity by far, the peak load heater provides only between 11.5% and 20% of total heat energy. As shown in Table 8, the share provided by fossil fuels decreases with the heater size. The decreasing share can be explained by lower consumption volatility. Generally, the larger the unit the more consumers are connected to the district heating grid. A higher volume of consumer leads to a better balanced demand. As better balanced the demand as better it is suited for base load heat and thus for biomass heaters.

[24] The efficiency of biomass heater decreases significantly when the heater runs below full capacity. If demand falls below a certain level somewhere between 50 and 80% of the base load capacity, the system usually turn off the biomass heater and uses the peak load heaters.

Size biomass heater	0.1-0.5 MW	0.5-1 MW	>1 MW
Energy provision from natural gas	19.9%	15.2%	11.6%

Table 8 Share of natural gas energy provision in base load/peak load biomass heating systems

The cost of peak load system's infrastructure was analyzed by Krapf in his (2004) research. Graph 12 shows his analyses. On 2012 prices the corresponding cost curve is P=223.71*x^0.7744.



Graph 12

Source: Krapf, 2004

The curve constitutes a component of the final finding from this chapter as shown in chapter 4.3.5, *total_invest*.

4.3.3 Installation costs storage systems

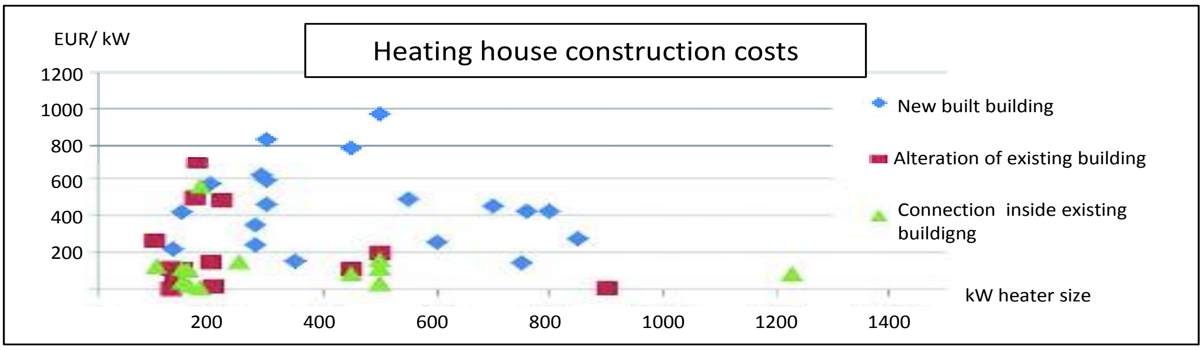
Many types of wood chips storage system exist in a broad variety of solutions, which lead to a high volatility in building cost. In his study Clausnitzer (2007, p. 106) assessed the cost of different solutions for standardized heater from 60 kW to 220 kW. He found for standardized solutions (in this paper ~100-500 kW) almost no differences in total cost for the fuel storage system depending on the size of the heating unit. Differences in building cost depend on the storage solutions only. This relationship is due to standardization in the logistics and storage systems. For instance, wood chips for a 120 kW heater are delivered by the same size of truck as for 220 kW heaters. They only vary in frequency of delivery. The major cost factor for wood chips comes from logistics and delivering half loads would be more expansive than building a larger storage. Thus, the Clausnitzer (2007, p. 106) findings on storage solutions are generally valid for standardized units between 60 and about 350-500 kW. Table 9 shows his findings.

Type	Cost in EUR
50 m^3 wood chip bunker in the ground outside a building	10’500
Small house for heater and storage of 50 m^3 built of massive material (total size 100-110 m^3)	24’000-26’400
Small house for heater and attached storage container. Built of light material.	15’000

Table 9 Cost of biomass storage systems by category

For individual solutions, those usually larger than 350-500 kW, volatility of fuel storage construction costs are higher than for standardizes solution. Costs for individual solution depend on the logistics concepts of the project. For instance, in Vierrat, Finnland, a 13 MW heating unit’s wood storage is only about 200% of the size of a 0.5 MW unit in the neighboring village. The 13 MW unit is supplied just in time and the 0.5 stores several weeks’ demand. In the solid biomass heating economics model, the costs for the building are approximated with Clausnitzer (2007) data.

At individual solutions heater, the silo and heater are in the same building wherefore one cannot separate cost of one from the other. Hiendlmeier (2012) collected information on the construction cost of individual solutions. She includes connecting roads, building and earth moving work. She finds that independent of the size these constructions cost amount to between 50 and 600 EUR/kWh (Hiendlmeier, 2012). Graph 13 shows the data set.



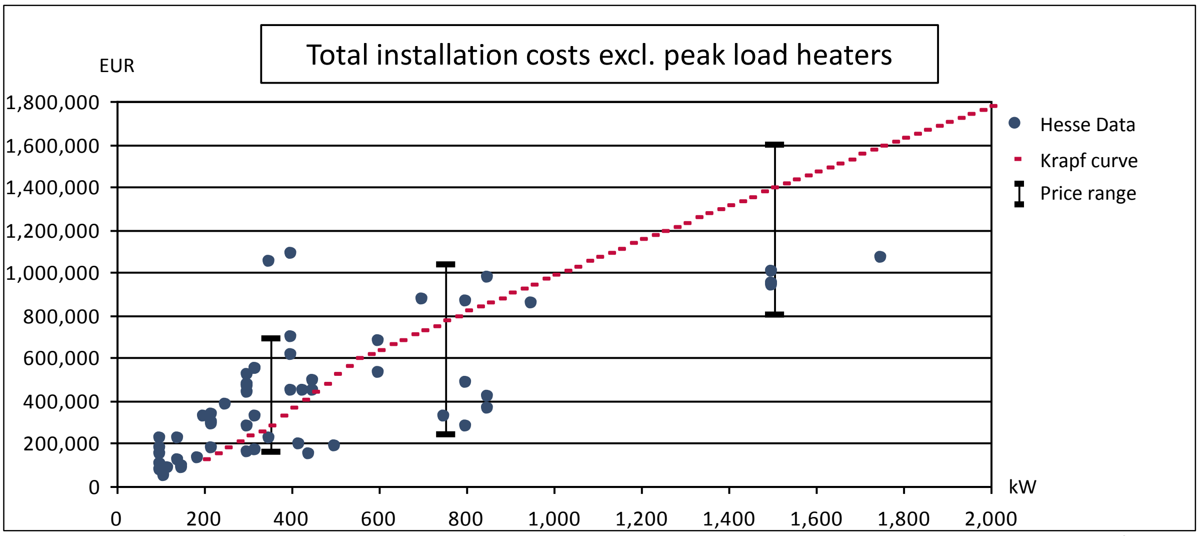
Graph 13

Hiendlmeier (2012) differentiates new buildings and modification of existing buildings. As the graph indicates this differentiation is crucial for assessing total cost. For the biomass heating economics model 400 EUR/kW biomass capacity will be assumed. The high standard deviation from the 400 EUR/kW will be given credit by investigating the effects of varying installation costs in additional analyses.

4.3.4 Total infrastructure installation costs

The heating unit and building corresponds to about 60-80% of the total infrastructure cost (Krapf, 2004). The rest accounts to planning, pipes, filter and other infrastructure. With increasing size this additional infrastructure also becomes more expansive. For instance, starting from a size of about one MW different filter technology, electronic filter, and exhaust gas recovery systems are usually installed (Clausnitzer, 2007, p. 60). On the other hand these additional installations allow for more flexibility in the fuel choice. In the following other cost will not be assessed individually but they are directly included in a cost curve for the entire unit including biomass heater, building and other cost.

Krapf (2004) investigated such a cost curve for average total installation. On 2012 price level the cost curve is P=1195.7*x^0.8539. In the solid biomass heating economics model cost estimations for units larger than 500 kW are based on the Krapf (2004) curve. Krapf (2004) investigated a broad range of heater from medium to large whereas Clausnitzer (2007) concentrated on medium to small heater 60-350 kW. Thus, for heater smaller than 500 kW installation costs are approximated with Clausnitzer (2007) data. This affects in particular cost for the building. The final curve is shown in Graph 14.

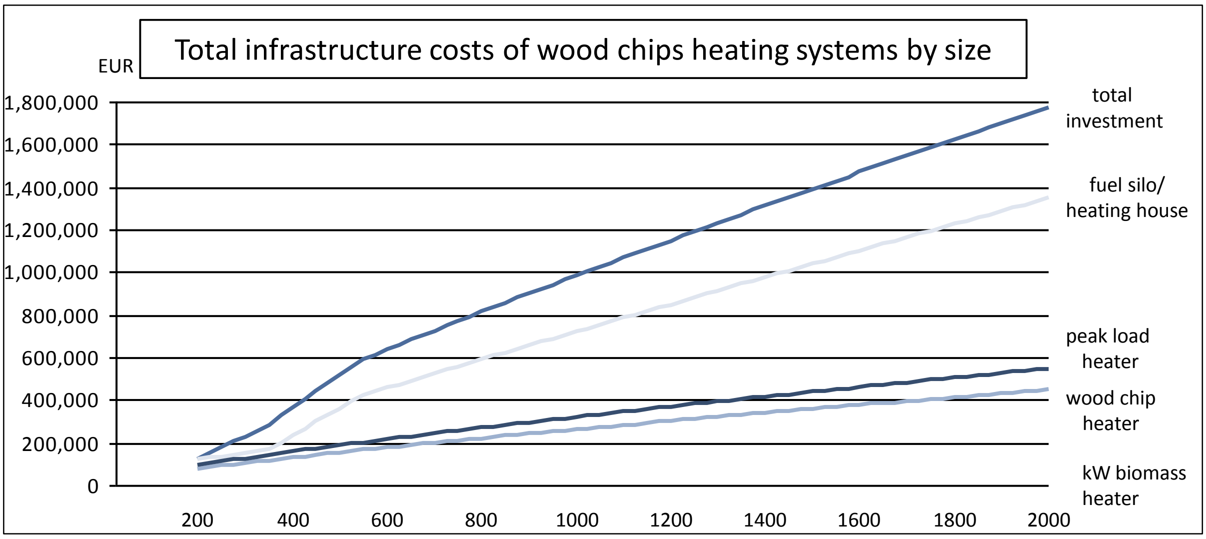


Graph 14 Sources: hessenEnergie 2007; Krapf, 2004

The graph shows not only the curve used in the solid biomass heating economics model but also a data set as well as a price range of installation costs. The data set shows price points from subsidized biomass heater in the German state of Hess. As the price points show, installation costs, including buildings costs, vary significantly between different projects (HessenEnergie, 2007). Therefore, the price range was derived from the data points. When the economic impact of different parameters is modeled in chapter 7, the price range derived from the data set indicates the spectrum for investigations on installation costs.

4.3.5 Conclusion installation costs wood chips heaters

Biomass infrastructure costs split into heating units cost, building cost, peak load heater cost, and other costs. Relative precise cost curves for biomass and peak load heater were found. For the building cost approximations of standardized solutions <350 kW are based on Clausnitzer (2007) data. Above that level costs are approximated based on Krapf (2004) and Hiendlmeier (2012) with 400 EUR/kWh. Since cost factors vary considerably no individual curve for other costs was found but other costs correspond to the spread between total installation cost and the accumulated cost for the three other categories. The spread correspond to the average other cost. Graph 15 summarizes the findings. Cost curves shown in the graph constitute the model for approximating the installation cost for wood chips heater systems in the solid biomass heating economics model, variable *total_invest*. The high variances of building cost are given credit for by investigating variations in this factor in chapter 7.



Graph 15

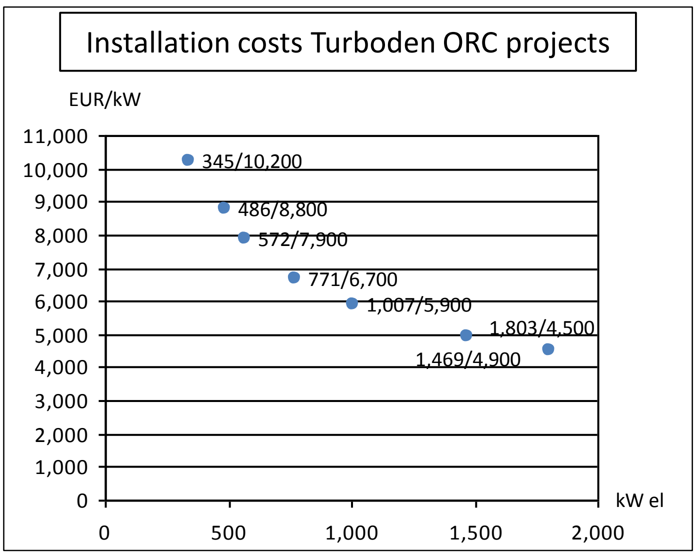
4.4 Installation costs biomass cogeneration units

Following the installation cost of ORC cogeneration systems are determined. Predominant technologies for cogeneration (0.1-2 MW_{el} with 0.15-5 MW_{th}) in Germany are the steam engine and the organic ranking cycle (ORC) (Kralemann, 2011, p. 13). As explained in appendix 6, the installation costs of different steam engines are not comparable to one another but these of ORC cogeneration units are. For this reason, the analyses in this paper are limited to ORC cogeneration units.

From a conceptual point of view ORC cogeneration plants consists of two parts, the heater and the ORC unit. Both are designed to be delivered in more or less standardized forms. This means, ORC systems constitute a direct alternative for pure heating. For instance, if a new district heating grid is to be built with a heat demand for 4 MW_{th}, the project developer has two alternatives a 4 MW_{th} boiler for producing purely heat and a 5 MW_{th} boiler together with an ORC unit which produces 1 MW_{el} and 4 MW_{th}. The rest heat (the 4 MW_{th}) from ORC units is usually below 100° C and thus within the typical range for district heating grids for heating buildings.

Cost analyses for solid biomass ORC cogeneration units in this paper are based on cost for units from the Italian producer Turboden. In total 93 ORC units for solid biomass heating existed in the end of 2011 in Germany. Thereof, 73 were from Turboden, a 78% market share (DBFZ, 2011a ,p. 21; Turboden, 2012a).

Duvia, Guercio, & Rossi di Schio (2009) have investigated installation costs of Tuboden ORC plants. They found total installation cost for ORC units and heater for district heating to be as shown on Graph 16. These cost include all installation cost including the ORC unit, biomass furnace, thermal oil boiler, fuel handling, civil works, connection to the grid and engineering (Duvia et al., 2009). Since Turboden has a representative market share and only a few products, cost points from Graph 16 instead of a cost curve serves as variable *total_invest* for cogeneration in the solid biomass heating economics model.



Graph 16 Source: Duvia et al., 2009

5 Fuel costs solid biomass

As mentioned before the annual cost of biomass heating is computed as:

$$C_{biomass\ heating} = C_{financing} + C_{fuel} + C_{operation\ \&\ maintenance} \qquad (1)$$

This chapter discusses variable C_{fuel} which is calculated with the following formula:

$$C_{fuel} = E_{biomass} * P_{biomass} + E_{gas} * P_{gas} \qquad (11)$$

Where $E_{biomass}$ = total biomass energy inputs; $P_{biomass}$ = price biomass; E_{gas} = total natural gas input for the peak load heater; P_{gas} = natural gas price

The main focus of this chapter lies on determining $P_{biomass.}$ Over three subchapters, chapters 5.1 -5.3, an extensive model is developed for determining 20 years price paths for $P_{biomass}$. In addition to determining $P_{biomass}$, in chapter 5.4 values for P_{gas} are found and in chapter 5.5 $E_{biomass}$ and E_{gas} are discussed.

5.1 Part I $P_{biomass}$ model: Wood fuel mix

Modeling $P_{biomass}$ is complex and thus building the model is divided in three parts: first fuel mix categories are defined, second fuel price paths are developed, and third the both are merged to a single model.

Wood is a very heterogeneous fuel that exists in different categories (recycling wood, forest wood etc.). Not all wood categories can be fueled by all heaters but usually they are supplied by a mix of different categories. The weight of different wood categories in this mix depends on technical attributes of the heaters. Generally the larger the unit the better the technical attributes and thus the lower quality it can burn. Thus, in the first part of the $P_{biomass}$ model fuel mixes in dependence of the heater size are developed for four different heaters sizes.

Each wood category has its individual demand and supply curve and prices deviate significantly from one another. In the second part of the $P_{biomass}$ model, a scenario of the future fuel prices for each of these categories is developed. Finally in Part III, both Part I and II of the $P_{biomass}$ model are merged to become the $P_{biomass}$ model which shows price paths for different heater categories.

With the approach to develop an extra model for resource prices of the heating unit size, the $P_{biomass}$ model, this paper distinguishes from comparable studies (see Clausnitzer, 2007; Duvia et al., 2009; Hartmann et al., 2011). The multi category approach of this paper makes analyses significantly more complex than in other literature where analyses are mostly based on the C.A.R.M.E.N (2012) forest wood chips index or simple assumption of one static fuel prices for all heater categories. However, the C.A.R.M.E.N (2012) index is only representative for units up to 500 - 1000 kW_{th} . In the market one finds significant price spreads between different fuel categories. For instance, the biomass for a 100 kW unit can cost as much as 400% more than that for a 1500 kW unit. Therefore, single index based models are not representative to indicate the operation costs of biomass heating units of different sizes. For these reasons, the multiple fuel categories approach developed subsequently closes a gap in research by laying the foundation for analyzing economics of non-standardized heaters (those >500 kW).

5.1.1 Biomass fuel mixes for heater categories

As explained in detail in appendix 7 solid biomass is a diverse fuel which exists in the following categories:

- Saw mill by-product wood chips (the cuttings of saw mills)
- Forrest wood chips (branches, stem wood, roots etc. chipped in the forests)
- Recycling wood (chipped boards from construction, old furniture etc.)
- Landscape care wood (bushes, tress etc. from road sides, parks etc.)

Not all heaters can use all of these biomass fuels. Burning the wrong material can lead to problems as poor burning efficiencies, sedimentation of slag in the boiler, too high emissions in the fumes etc. In particular technical attributes like filter technology or heating chamber quality lead to constraints in the use of particular fuels. The level of technical sophistication generally increases with the size of the heater. Therefore, following the fuel mixes are discussed in relation to the heater size. Moreover, for every category a typical fuel mix is found. The fuel mixes and attributes of heater types that lead to these fuel mixes are summarized in a table at the end.

<500 kW_{th}

Smaller units below 500 kW_{th} have a high demand on the fuel quality (size of wood chips, amount of bark in the fuel etc.). Generally they can only burn clean forest wood chips and sawmill by-products. Forrest wood chips usually contain so called fine particles as bark, dirt or needles. In the burning process these fine particles leave a higher share of ash than clean wood (FNR, 2007, p. 163). However, <500 kW heater can only burn material where a maximum of about 1.5% of the input material remains as ash (Viessmann, 2012). Therefore, forest wood chips needs to be sewed that only clean material remains. Sawmill by-product wood chips are mostly clean enough.

These heaters of <500 kW are also constrained by the share of humidity in the wood, while the humidity values of forest wood chips are often too high wherefore they need to be mixed with saw mill by-product wood chips.[25] For these reason and by respecting data from C.A.R.M.E.N. (2011), in the solid biomass heating economics model a fuel mix consisting of 70% forest wood chips and 30% sawmill by-product wood chips will be assumed for <500 kW.

500 kW_{th} to 1 MW_{th}

Heaters above 500 kW are usually less critical regarding humidity and ash than small ones. Units from 0.5 to 1 MW_{th} can burn material with up to about 3% ash and 50% humidity (Viessmann, 2012). This means one can use unscreened forest wood chips and sawmill by-products. Furthermore, it is possible to add up to about 20% landscape care wood (Viessmann, 2012). Landscape care wood has a higher share of foreign particles and fine material than screened forest wood chips or sawmill by-products. Moreover, it often contains traces of unwanted elements that lead to poor emission values. Thus, it can only be added mixed with other fuels but not purely (Viessmann, 2012). For the solid biomass heating economics model a maximum of 20% of landscape care material will be assumed for

[25] Fresh wood has a humidity share of about 45-60% if it is unprocessed (FNR, 2007, p. 86). This means 45-60% of the material is water that needs to be gasified in the heating process. As gasifying water requires energy, the lower the share of water the better it is. Mechanically dried wood can have as little as 8% while wood tried only in the sun has about 30% humidity (Vogt & Fehrenbach, 2010, p. 19). Sawmill by-products usually have 40-50% humidity (Austrian Energy Agency, 2009). Smaller heater generally require wood with less than 30-35% humidity (Viessmann, 2012). This means sawmill by-product and forest wood chips need to be at least sun dried before the can be used in <500 kW units. However, the drying process can also be done by leaving branches piled in the forest for a few months before chopping.

0.5 – 1 MW_{th} units. The remaining 80% will be assumed to be 50% forest wood chips and 30% sawmill by-product wood chips.

1 MW_{th} to 3 MW_{el}

Above 1 MW_{th} heater are much less critical regarding input fuels than smaller ones. Smaller units generally require more or less constant humidity values, either dry wood with about 15% or wet wood with ~30-45%. Above 1 MW_{th} units do not need constant humidity values and can fuel whatever humidity value is on offer. Moreover, the burning chamber still works with much more foreign particles with ash values up to about 6% (Viessmann, 2012). Therefore, Forest wood chips can be fueled without major limitation regarding its quality (Viessmann, 2012).

Moreover, at this size high quality filter technology becomes economically attractive. Professional filter are very expansive and electronic filter for 1 > MW_{th} units, for example, costs already about 140’000 EUR. They are still economically as they allow for the use of lower quality wood regarding emissions (BlmSchG; BlmSchV 2010; FNR, 2007, p.198). With such filters in place it is possible to use up to about 40% landscape care material, including some landscape care wood (Viessmann, 2012). Furthermore, these units can be fueled with some shredded recycling wood of the cleaner categories AI and AII-AIII (~20%). In the solid biomass heating economics model either 20% recycling wood or 40% landscape care wood are contained in the fuel mix of 1-3 MW units. The remaining 60-80% are assumed to be forest wood chips since for >1MW units forest wood chips are cheaper than sawmill by-product wood chips (see chapter 5.2.3).

> 3 MW_{th} and Cogeneration

Units larger than three MW_{th} usually have very advanced technology that allows for a high variation in humidity, major share of ash and high contamination values in the material (up to AIII). Thus more landscape care material and recycling wood can be used. Generally it is better to mix landscape care material with recycling wood as both contain different chemical elements. While landscape care material has higher chlorine values due to its proximity to streets, recycling wood usually contains more metal (Viessmann, 2012). If only one category would be used it is likely that the filter technology is not sufficient and either of the two values exceeds the maximum allowed values. Moreover, landscape care material is limited available. Thus, a mix is sometimes required by resource limitations. Even though, there exist plants fueled with only one wood category, in the biomass heating economics model a mixture of 30% recycling wood of the AI and AII-AIII category together with 40% landscape care and 30% forest wood chips will be assumed for biomass heater.

Cogeneration units have similar boiler as the >3 MW heater. They only differ from these by the restriction not to use recycling wood. For receiving the EEG subsidy they must fuel with either of the other categories. Therefore, the biomass heating economics model assumes 60% forest wood chips and 40% landscape care wood for cogeneration units with more than 3 MW_{th}.

Table 10 summarizes fuel mixes:

Category	Max ash	Humidity	Filter	Fuels	Fuel assumptions solid biomass economics model
0.1-0.5 MW_{th}	1.5%	<30%	Basic filter	• Screened and dried forest wood chips • Screened and dried sawmill by-products	• 100% forest wood chips
0.5-1 MW_{th}	3%	~30-50%	Better filter required to fulfill regulatory requirements (BImSchmG)	• Better quality (fresh) forest wood chips • Sawmill by-products • Limited amounts landscape care wood (generally no road side greenery)	• 50% forest wood chips , 20% landscape care wood, and 30% sawmill by-product wood chips
1-~3MW_{th}	6%	variable	High quality filter become economically attractive	• All kind of forest wood chips incl. foreign particles and needles • Sawmill by-product • Limited amounts of landscape care wood • Limited amounts of recycling wood	• 20% recycling wood & 80% forest wood chips • 40 landscape care wood & 60 forest wood chips
>3 MW_{th} and Cogeneration	higher	variable	Very advanced technology	• All kind of forest wood chips incl. foreign particles and needles • Sawmill by-product • Limited amounts of landscape care wood (higher share than for 1-3 MW heater) • Limited amounts of recycling wood (higher share than for 1-3 MW heater) • No recycling wood for cogeneration	• 30% recycling wood, 30% landscape care wood & 40 % forest wood chips • 60% forest wood chips and 40% landscape care wood for cogeneration

Table 10 Summary constraints from biomass fuels and fuel mix assumptions solid biomass heating economics model

5.2 Part II $P_{biomass}$ model: Wood fuel prices

Wood is a much more heterogeneous fuel than gas or oil. Given the heterogeneity of the resource the pricing for a generalized model is a sophisticated task. In this section first the heterogeneity and its implications are discussed. Based on the findings existing indices are compared to determine the index with the best data base for the fuel prices parameters in the solid biomass heating economics model. As will be shown, the Euwid index serves this purpose the best. However, data points from the Euwid index need to be adjusted in a separate subsection to meet the purpose of this paper. These adjusted historical fuel prices build the basic for the last part of the section, a simple forecast on the future fuel prices development.

5.2.1 Constraints for wood fuel pricing

Generally, the metric of interest for energy consumer is price per energy content expressed in units which corresponds to EUR ct/per kWh. Because of its multiple uses as resource for material and energetic applications wood is not traded in MWh but wood specific units like solid cubic meter, loose cubic meter, and tons. Moreover, wood is a heterogeneous material. Following, the magnitude and implication of this heterogeneity and differing units are discussed in respect to fuel pricing.

Wood is traded in different categories of recycling wood, forest wood chips, sawmill by-products, and landscape care wood. These categories have sub-categories like recycling wood AI to AIV or saw dust and sawmill by-product wood chips. Categorization of sub categories derives from their application in practice. For instance, sawmill by-products can be used for paper, board particles and wood pellets production as well as direct energetic fueling. AI recycling wood, however, can be used for particle boards and the energy industry but not for paper production. The different applications lead to different demand functions for each sub category.

Moreover, sub categories are either recycled waste, waste from landscape care or by-products for sawmills or stem timber growing. For this reasons supply of these categories is limited and depends on the primary product supply. In particular sawmill by-product, recycling wood and landscape care wood supply are constrained. Forest wood chip supply is more flexible. These dynamics of supply and demand functions lead to individual price curves for all sub categories.

Furthermore, in practice division of sub categories goes even further. There also exist different types of timber. In respect to energetic applications the type matters in particular because of differing energy content. The four major wood types in Germany, pine, oak, breech, and spruce, vary between 5 and 5.2 kWh/kg dry mass (AG Energiebilanzen E.V., 2012).

For energetic applications, however, wood types are less relevant than variations from humidity in the wood. Wood contains water that is expressed in humidity values. A 50% value means that 50% of the wood consists of water. In the burning process this water is an undesirable ingredient as it contains no energy but consumes energy for evaporation. The energy used for heating the water until evaporation level is the energy contained in the wood mass. Thus, the major share of this energy required for evaporating vanishes as water fumes and gets lost for the energetic processes. This means the energy value of wood falls with increasing humidity content. Humidity for wood varies in practice between 15% and 50%. For instance a pine with 15% humidity contains 4.32 kWh/kg useful energy and only 2.26 kWh/kg with 50% humidity (AG Energiebilanzen E.V., 2012).

Furthermore, because of their different applications wood categories are traded and thus priced in different units. For instance, recycling wood is traded in tons; sawmill by-products in loose cubic meter and some energy wood even in MWh. The mentioned attributes of material heterogeneity and humidity variances exacerbate transforming price information expressed in one unit into another. For instance, a ton of recycling wood with 15% humidity has a higher energy value than a ton with 20% and one loose cubic meter of sawmill by-product might have a different bulk density than another. Given this complexity indexing and generalizing wood fuel prices is a sophisticated task. Nevertheless, there exist three different indexes of wood for energy use in Germany. Following, these three will be discussed with respect to the constraint of wood fuel pricing and the solid biomass heating economics model.

5.2.2 Wood fuel indices

In Germany three institutions publish regular indices on wood fuels: the Federal Statistical Office of Germany (DeStatis), a public Bavarian institution for the promotion of renewable resource called C.A.R.M.E.N. EV. (Carmen), and the German wood industry specific newspaper Euwid. Following their indices are discussed and the Euwid indices are found to be the best for further research in the solid biomass heating economics model.

DeStatis

The Federal Statistical Office of Germany, DeStatis, tracks pricing of various raw and processed wood products to publish those indexed. Traditionally these indices have served the wood products industry. With increasing importance of wood as fuel a new index was required. Because of the federal act on long distance heating (AVBFernwärmeV §24 Abs. 4), heat provider can only include variable pricing terms in their contracts if these represent the real variance of their cost. In other words supplier of district heat can only include variable pricing terms if these are based on indices (Vorholt, 2010, p. 292). Thus, existing indices for wood pellets, raw wood etc. used to serve as wood price indices. However, their match of real cost was rather poor and the DeStatis created in 2010 a new index which is a weighted average of existing indices (p. 292).

The index of wood for energetic applications is based on price information for so called industrial wood, on sawmill by-product, wood pellets and some other wood products (DeStatis, 2012a). Prices for wood products as wood pellets or briquettes are based on representative surveys in the industry (DeStatis, 2012c, p. 6). Prices for raw products as different sorts of industrial wood are stated from state owned forestry companies (Vorholt, 2010, p. 291).

Given the multiple sources and valid statistical methods, the DeStatis index is a good source to track general energy wood price developments. However, it states only one price development path for all different categories of wood. As explained before, in practice there exist multiple categories and sub categories of wood and each has its own supply and demand curve with significant price variances between these. Furthermore, different categories of heater use different categories of wood. A single index does not account for these differences but would only be sufficient for heater which uses a mixture of different wood fuels. Thus, the DeStatis index is a good tool to track the general wood price development but an insufficient tool for detailed analyses of heater size depending fuel cost.

CARMEN

The Central Agricultural Resource Marketing and Development Network, a public Bavarian institution for the promotion of renewable resources also called CARMEN, publishes an index for forest wood chips. The index is based on price information from 50 to 60 forest wood chip producer from all over Germany (C.A.R.M.E.N, 2012). This information is quarterly surveyed by phone and email.

Advantages of the (C.A.R.M.E.N, 2012) survey encompass division into load size and regions. Prices for forest wood chips also deviate with load sizes. The major price component of forest wood chips constitute logistics and chipping but not the raw material (FNR, 2007, p. 210). Moreover, the forest wood chip market is a regional market and thus pricing is regional. In locations with a higher share of forests supply exceeds that of other sites.

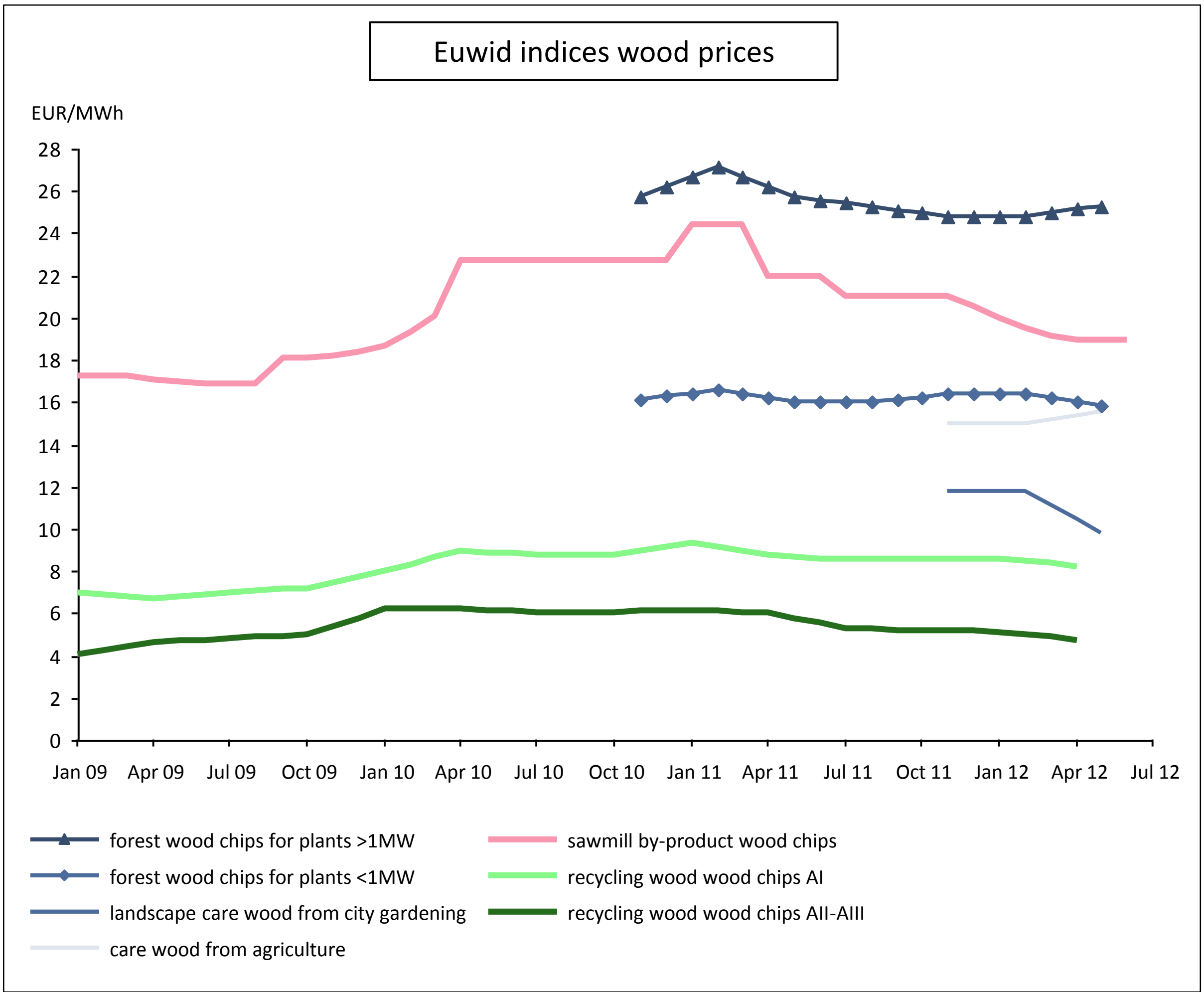
Nevertheless, the CARMEN index only represents one wood category while in practice supply for above 500 kW units are often based on a fuel mix of different categories. Moreover, the index is targeted at very small costumers with units below 100 kW. Thus, the index is a representative source for units up to about 500 kW or maximum 1000 kW.

EUWID

The Euwid is an industry newspaper publisher. Among others they publish weekly an issue on renewable energies, recycling markets and the wood processing and raw wood markets. Given this broad spectrum of industry newspapers their information services encompasses all wood categories available for fueling. Moreover, because of their journalistic work in a market of limited size, they are connected to most of the major market participants. In addition to general market news, the journalists conduct telephone interviews and publish pricing information for different sub categories of wood. Over the years these pricing surveys have developed to indices. These indices are published on regular bases while periods between different updates follow the nature of the market. For instance, prices of sawmill by-products change more often than forest wood chips and thus one is published every two month and the other quarterly. These indices respect regional differences where necessary. Given that the Euwid has comprehensive information on all major sub categories following analyses are based on their indices

5.2.3 Euwid Wood indices

There exist Euwid indices for all major sub categories of wood, e.g. for sawmill by-product wood chips, forest wood chips for small and large plants, for saw dust, for recycling wood of different categories and recycling stages. Moreover, the indices are published as price per unit while these units are different for different categories. Furthermore, the data only represents regional prices and not country wide prices. For sawmill by-products and recycling wood no weighted average but the upper and lower end of the pricing range is stated. Thus the data is very comprehensive and corresponds to the requirements of the wood markets. However, information need to be modified to serve the purpose of this paper, to become indices that show fuel prices of different categories as Euro per MWh on average for the German market. Assumptions and adjustments of the indices are shown in appendix 8. Graph 17 indicates the results.



Graph 17 Sources: Euwid multiple indices and issue of Euwid recycling, Euwid wood and wood products, Euwid renewable energies

As the graph shows the actual fuel price is strongly dependent on the type of wood used for fueling. As discussed in chapter 5.2.1 on technological constraints for wood fuel pricing, the fuel type depends on the technology. The larger the unit the better it can use cheaper fuels because of better filter and burning technology.

Furthermore, indices for forest wood chips and landscape care material were established only recently and no observations on their historical development are available based on the Euwid data set. Nevertheless, the Euwid indices only represent a historical development and for analyzing life cycle cost of biomass heaters futures price paths are required.

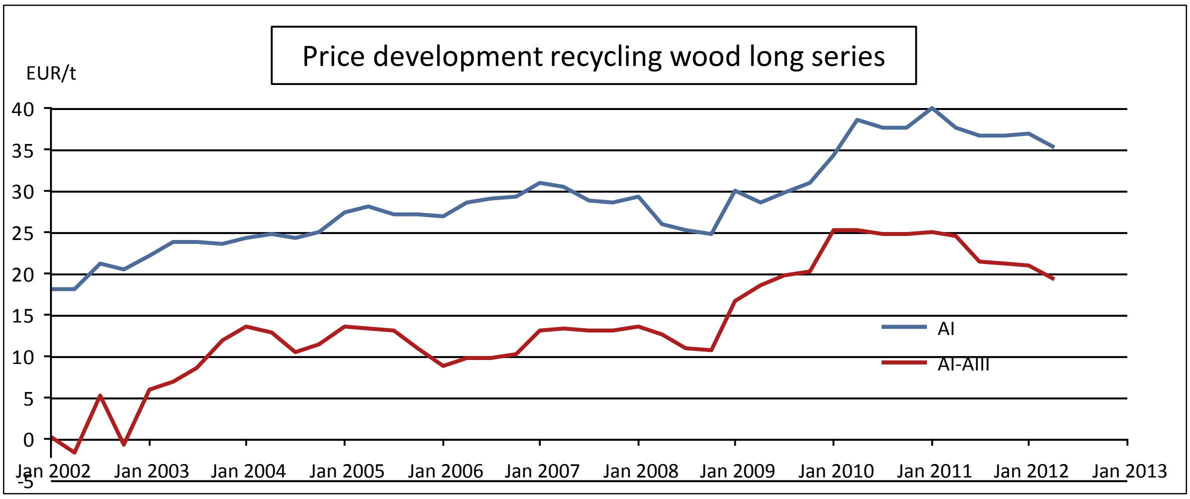
Therefore, in the next section futures price development scenarios are discussed while Euwid data serves as base for the analyses.

5.2.4 Wood price development scenarios

Following analyses on the potential wood price development are based on qualitative factors. Depending on the fuel, crucial factors for supply or demand structure in the markets are indicated. Based on these, assumptions on the potential price range for the coming ten years are made as foundation for scenarios in the solid biomass heating economics model.

Recycling wood

In April 2012 AI and AII-AIII recycling wood cost about 8.25 EUR/MWh and 4.25 EUR/MWh, respectively. Traditionally the material was used in the wood material industry, in particular for particle board production. Since 2001 increasing demand came from the energy industry (DBFZ, 2011a, p.9). The following graph shows the price development over time.



Graph 18 Sources: Euwid recycling

As the graph indicates prices increased significantly over the last decade. Particle board demand was stagnating since the crash of the housing boom in 2007 but demand from the energy industry increased continuously (DeStatis, 2010b; DBFZ, 2011a, p.9). Thus price increases were driven by the upcoming demand from bioenergy power plants that started in 2001 to receive subsidies for recycling wood fueling (DBFZ, 2011a). Recycling wood remains the cheapest wooden fuel for plants with advanced filter technology (plants > 1-3 MW) (See Graph 17).

However, in the latest revision of the act on the promotion for renewable energies, the EEG 2012 regulation, subsidies for fueling recycling wood for electricity production were cancelled for future plants (see chapter 2.2.3). Despite that recycling wood is the cheapest fuel, lower input prices often do not compensate for the lack of subsidies. Thus, it is unlikely that price increases continue as they did before. Hence, in the scenarios of the solid biomass heating economics model a maximum increase of 50% over the coming ten years will be assumed.

Moreover, existing power plants fueled with recycling wood have been planned based on a fixed feed-in tariff for twenty years. Thus, demand for recycling wood from the energy industry continues for at least 20 years of operation. Given the first EEG subsidies started in 2001, the remaining time of operation covers at least another ten to twenty years. It is to be expected that operation and recycling wood demand continues thereafter. Once high capital costs are depreciated after the 20 years subsidy period, biomass power plants generally remain economically even at normal market feed-in tariffs. Thus, demand and prices of recycling wood are not assumed to fall significantly over the next 20 years. Nevertheless, increasing recycling wood supply or reduced demand because of a declining particle board industry could lead to some price decreases. Hence, a maximum price decrease of 50%[26] over the next ten years will be assumed.

Landscape care wood and forest wood chips

Forest wood chips currently costs between 16 and 24 EUR/MWh, landscape care material between 10 and 14 EUR/MWh according to the Euwid wood price model. The Euwid data only dates back two years wherefore it cannot be analyzed for historical developments. Nevertheless, the C.A.R.M.E.N (2012) index can be used as a proxy for historical prices of these categories. The C.A.R.M.E.N (2012) index covers forest wood chips for below 1 MW units back to 2001. Major differences of forest wood chips supply for below 1MW and above 1MW units constituted economies of scale and the amount of material that needs to be sifted out for below 1 MW units. As all other cost factors remain the same for both

[26] Recycling wood used to be waste and negative prices are possible (see Euwid). Thus, a 50% price fall is more likely for recycling wood than for instance for forest wood chips. The recycling wood market survives even at a lower price range than forest wood chips. Forest wood chips only receive income from resource sales, for recycling wood, however, negative prices for disposal are usual. Thus, for recycling wood a 50% fall is considered as to be in range and for forest wood chips only 30%.

categories, prices developments are highly correlated. Prices for forest wood chips are also correlated with those of landscape care material. Both have the energy sector as the only source of demand and processing cost from raw material to wood chips in the bioenergy fuel bunker are the same. They only vary in raw material cost, which make a minor share of the final price. The C.A.R.M.E.N (2012) index shows that there was little price volatility in wood chip prices and a drift towards rising prices. In the eleven years the price increased continuously in small steps to today's level, double the price of 2001.

Unlike fossil fuel prices landscape care wood and forest wood chip prices have little volatility. For fossil fuels, the initial resource (as it is sold as exploration license) or speculation on it corresponds to a major share of the cost (Yergin, 2011). For forest wood chips and landscape care wood the original resource price of the material is extremely low corresponding to only one or two euros per loose cubic meter (~5% of total price) (FNR, 2007, p. 209). Thus, even doubling of the resource material in the forest would correspond to only 5% to 10% cost increase for forest wood chips. Moreover, transportation cost for forest wood chips are too high for long distance trading (>100 km street distance) and the pricing takes place in a regional market. Regional markets imply less supplier and costumers as well as limited possibility for speculation and therefore less volatility of the resource material in the forests.

The highest share of the forest and landscape care wood chips cost/price derives from processing in the forests and logistics to the costumer (FNR, 2007,p.210). Thus, the major price drivers are wages as well as capital and fuel cost for chipper and truck. Wages and capital cost are relative stable factors. Only fuel prices vary significantly. Thus, out of all four cost drivers, the three later and material costs, only diesel faces significant volatilities. With three stable factors and only one volatile, volatility in the final product price is relative small. For these reasons in the solid biomass heating economics model, a price range of maximum 30%[27] lower and 50% higher prices will be assumed in the scenarios for the coming 10 years.

Sawmill by-products

Sawmill by-product wood chips prices are very difficult to forecast for a long period. The main costumers for sawmill by-product wood chips are the wood processing (thereof mostly

[27] Given total inflation of 20% since 2001 a fall back to the initial price level is unlikely (DeStatis, 2012c).

particle boards), pulp, paper and energy industries (Weimar, 2011, p. 20). Graph 19 shows demand of the two major wood processing industries and the pulp and paper industry over time. The energy industry is not included in the statistics but consumes about as much as the pulp and paper industry (Weimar, 2011, p. 20).

Graph 19 Sawmill byproducts consumption of wood material industry

Sources: DeStatis, 2010b

As the graph shows, the consumption changed over time. Given the high demand volatility one cannot forecast the price for these wood chips. Moreover, for these wood chips commodity prices account for about half the cost and logistics for the other half. Given the relative higher significance of commodity prices, trading takes place in a trans-regional realm (~300 street kilometers). As stated above, the larger the area of trading the higher the volatility becomes. Moreover, the graph shows two other trends, the decline of the particle board industry since the burst of the housing boom in 2007 (see various articles Euwid wood) and a stagnating German paper industry (Data Monitor, 2011, p. 11). Given a trend towards electronic instead of paper media consumption as well as overcapacities in the housing market of several European countries, no significant increases in demand are to be expected for sawmill byproducts in the midterm future. For these reasons, in the solid biomass heating economics model, cost increases of about 70% upwards and 50% downwards will be considered for the following 10 years.

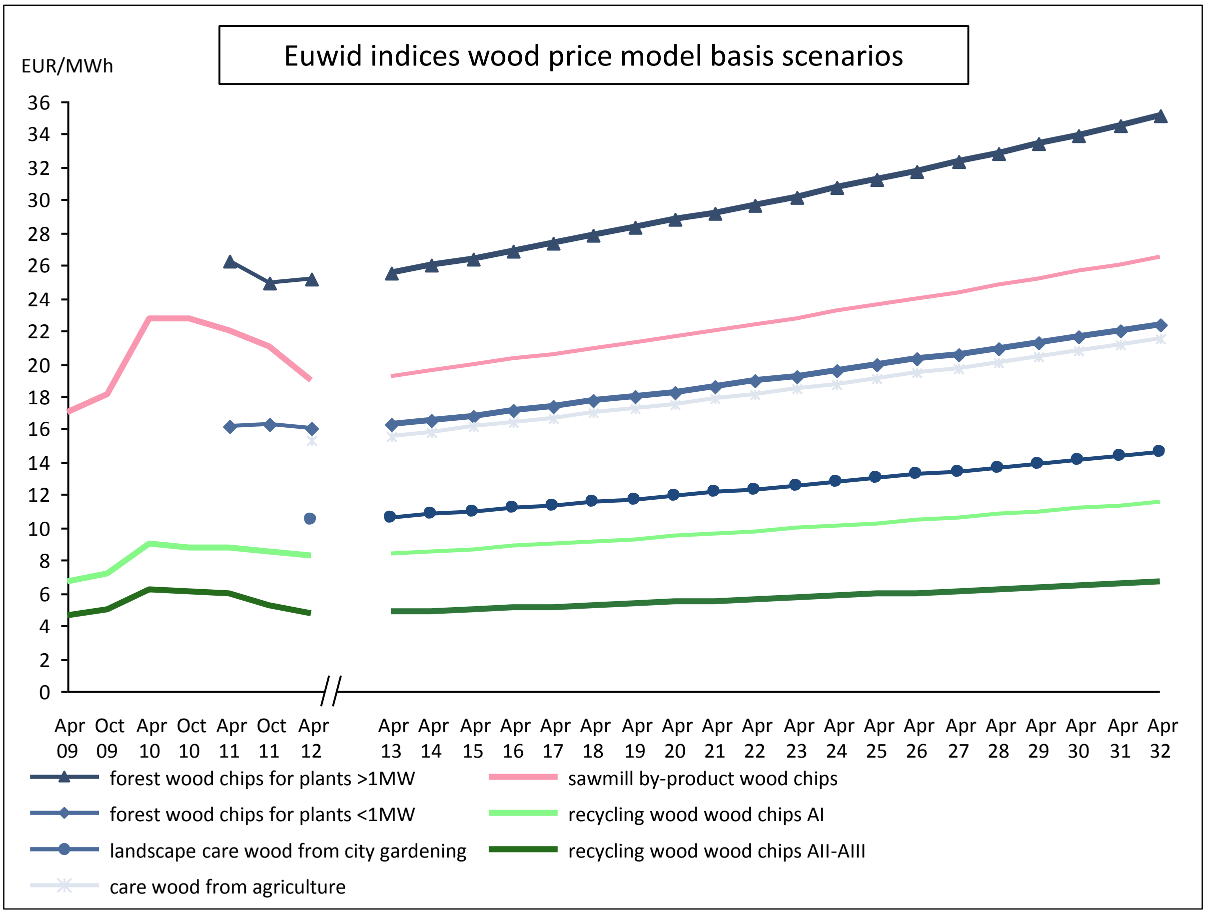
5.3 Part III $P_{biomass}$ model: Conclusion

It was shown that wood is a very heterogeneous fuel that therefore is divided into different categories. Each category has its individual demand and supply curve wherefore prices deviate significantly from one another. Use of fuel categories is determined by technological attributes as filter and burning chamber complexity. Generally the larger the unit the cheaper fuel it can burn. Heaters were divided into four different groups. For each group a realistic fuel mix was developed as foundation for the solid biomass heating economics model. Table 11 summarizes fuel mixes for different categories.

Category	Fuel assumptions solid biomass economics model
0.1-0.5 MW_{th}	• 100% forest wood chips
0.5-1 MW_{th}	• 50% forest wood chips, 30% sawmill by-product wood chips & 20 landscape care wood
1-~3MW_{th}	• 20% recycling wood & 80% forest wood chips • 40% landscape care wood & 60% forest wood chips
>3 MW_{th} and Cogeneration	• 30% recycling wood, 30% landscape care wood & 40 % forest wood chips • 60% forest wood chips and 40% landscape care wood for cogeneration

Table 11 Fuel mixes by category for the biomass heating economics model

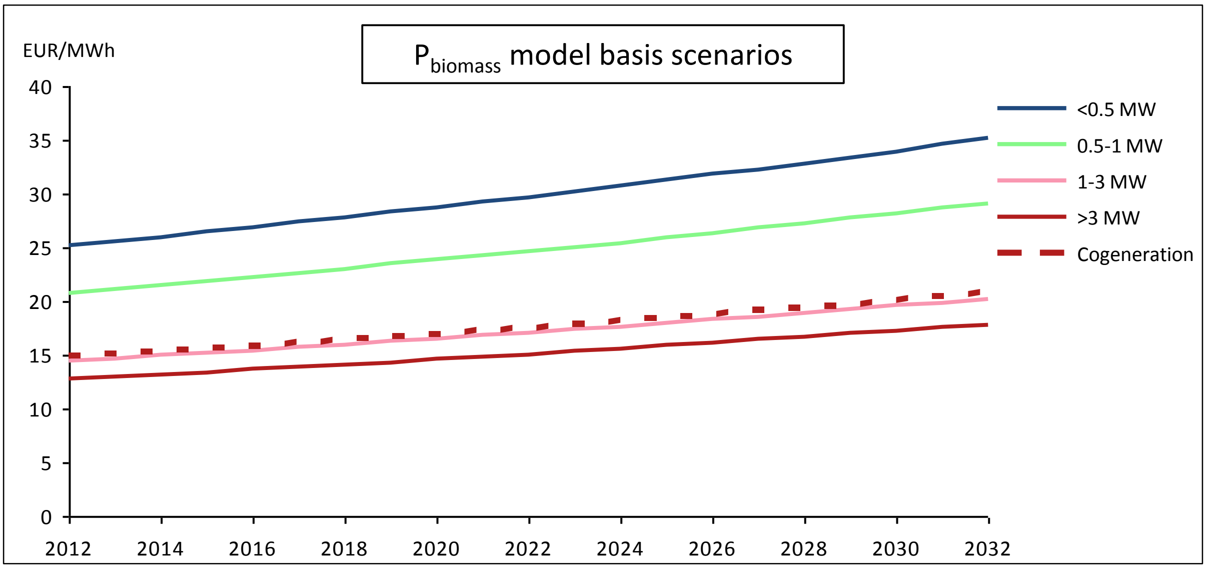
Next out of the C.A.R.M.E.N (2012), the DeStatis (2012a) and Euwid indices, Euwid indices were found to have the best fit as data base for a fuel price model because it is the only that differentiates multiple fuel categories. The indices were adjusted to indicate prices for wood categories in EUR/MWh and on average for the German market. Through, qualitative analyses of market factors the price range for potential price developments of the different fuel categories were developed. Graph 20 shows the basis scenarios for different wood fuels.



Graph 20

The base scenario assumes constant prices growth at the 1.7% inflation rate. All other scenarios can be found in appendix 8.1. The minimum and maximum scenarios in the appendix correspond to the maximum and minimum price developments found before. Given high uncertainty of price developments, after increase at the average inflation level of years all prices are assumed to increase only by the inflation of 1.7% (DeStatis, 2012c).

Given the wood price model and the fuel mix model one can merge the two to obtain the $P_{biomass}$ model. The $P_{biomass}$ model leads to fuel prices in dependence of the heating unit categories as they are used in the biomass heating economics model. Graph 21 shows the outcome for the basis scenario. The scenarios high and low fuel prices are discussed in chapter 7.3 on the effects of fuel prices on the solid biomass heating costs.



Graph 21

5.4 Natural gas prices

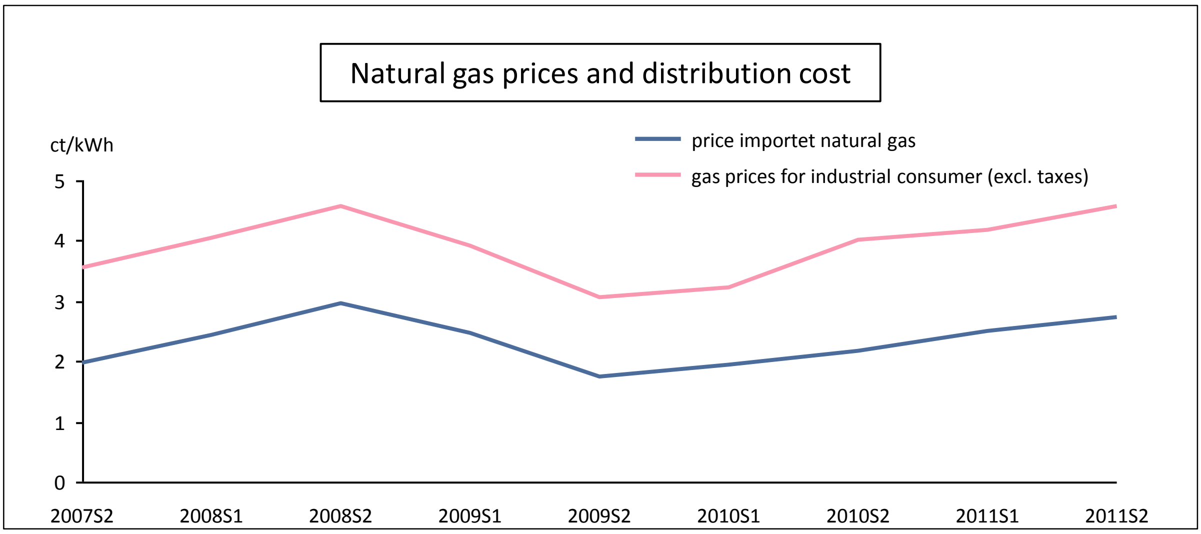
As mentioned at the beginning of the chapter C_{fuel} is computed as:

$$C_{fuel} = E_{biomass} * P_{biomass} + E_{gas} * P_{gas} \qquad (11)$$

Following, a model for determining futures gas prices, the P_{gas} in the fuel formula, is developed. First the three cost drivers for natural gas prices are determined and then a forecast for each of these is developed. Finally the forecasts are aggregated to a gas price forecast.

Natural gas prices are determined based on three factors, the price of natural gas itself, distribution cost, and taxes. Historical natural gas prices can be retrieved from statistics and futures can be modeled based on price information for natural gas price derivatives for the NCG market which are traded at the European Energy Exchange (EEX) in Leipzig. The NCG market covers all major German natural gas grids. Taxes can be found in the law books.

Germany imports 86% of its natural gas (DeStatis, 2012a). Thus, prices paid for natural gas in the NCG market are almost equal to the prices paid for imported natural gas. Prices paid for imported natural gas are surveyed by the German Federal Office of Statistics (DeStatis, 2012a). Distribution cost can be calculated as the spread between the price for final consumer (excluding taxes) and the price of the imported natural gas. The European Office of Statistics, Eurostat, surveys gas prices paid by industrial consumers. Graph 22 shows development of prices paid for imported natural gas and prices paid by industrial consumers.



Graph 22 Sources: Eurostat 2012 ;DeStatis, 2012d

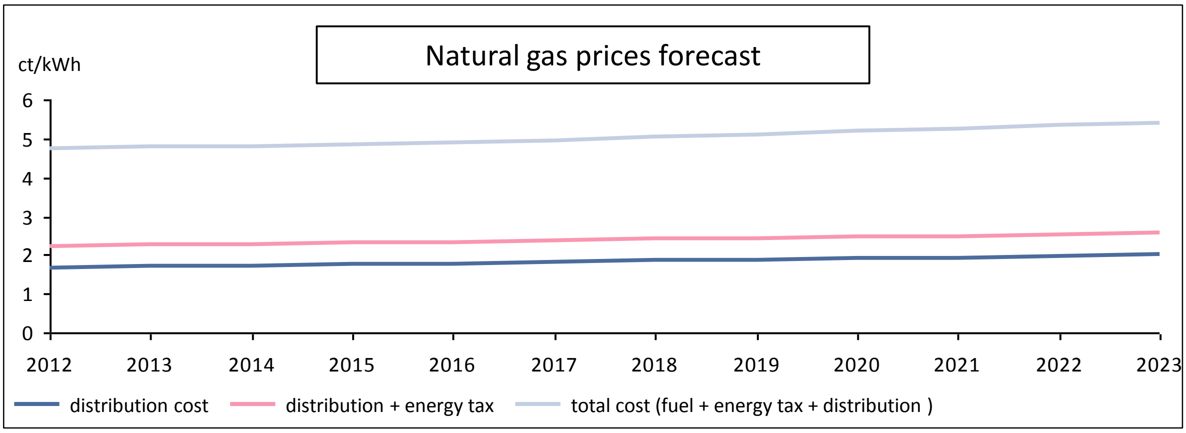
As the graph indicates the spread between distributed and imported gas remains relative constant at about 1.6 ct/kWh. A model in which the distribution cost grows at inflation cost according to DeStatis (2012d) inflation index leads to an even better fit than constant price assumptions of 1.6 ct/kWh. Thus in the following model distribution cost will be assumed to start at 2011 Season 2 cost of 1.66 ct/kWh and thereafter to grow at the last ten years average German inflation of 1.7%.

The futures price for imported natural gas is difficult to determine. Major volumes of imported natural gas in Germany follow the oil price indices and therefore are highly volatile. However, the best forecast currently available is price expectations stated in form of natural gas price futures. Current price of natural gas price futures for the NCG as traded at the EEX are shown in Table 12.

Year	Cal 13	Cal 14	Cal 15	Cal 16
Price in ct/kWh	2.533	2.548	2.545	2.545

Table 12 Future prices natural gas

As the table indicates price expectations are relative constant at 2.54 ct/kWh. Thus, in the following model prices will assumed to remain constant at 2.54 ct/kWh until 2016 and thereafter to grow at 1.7% inflation rate. Graph 23 summarizes estimations under discussed assumptions on gas infrastructure cost, distribution cost and taxes. Energy taxes on fossil fuels were discussed in chapter 2.2.5 on energy taxes and correspond to 0.055 ct/kWh for heating fuels.



Graph 23

5.5 Heater specifications

As mentioned the formula for C_{fuel} is:

$$C_{fuel} = E_{biomass} * P_{biomass} + E_{gas} * P_{gas} \qquad (11)$$

Following $E_{biomass}$ and E_{gas}, the natural gas and biomass input energy are determined. $E_{biomass}$ is calculated as:

$$E_{biomass} = \frac{E_{biomass\_out}}{\eta_{biomass}} \qquad (12)$$

Where $\eta_{biomass}$ = efficiency of the biomass heater; $E_{biomass\_out}$ = biomass heater output

When the heater burns the biomass not all of the input energy can be converted into heat but some of it is lost. $\eta_{biomass}$ indicates how much of the input energy can be converted into useful energy.

Moreover, $E_{biomass\_out}$ is measured in full load hours. It is calculated with the following formula

$$E_{biomass\_out} = unit\_size * full\_load \qquad (12)$$

Where unit_size = the size of the unit; full_load = the volume of full load hours

In other words full load hours is the total output energy divided by gross capacity of the heater. For instance, a heater running one day at full capacity produces 24 full loads hours as does another that operates two day at 50% of its capacity. This unit makes it easier to compare heaters of different sizes.

E_{gas} would usually be calculated the same way as $E_{biomass.}$ Nevertheless, in the biomass heating economics model it is calculated as in percent of $E_{biomass.}$

This means the formula for E_{gas} is:

$$E_{gas} = \frac{E_{biomass\_out} * gas\_ratio}{\eta_{gas}} \qquad (13)$$

Where η_{gas} = efficiency of the natural gas peak load heater; gas_ratio = the energy output of natural gas in percent of the biomass energy output.

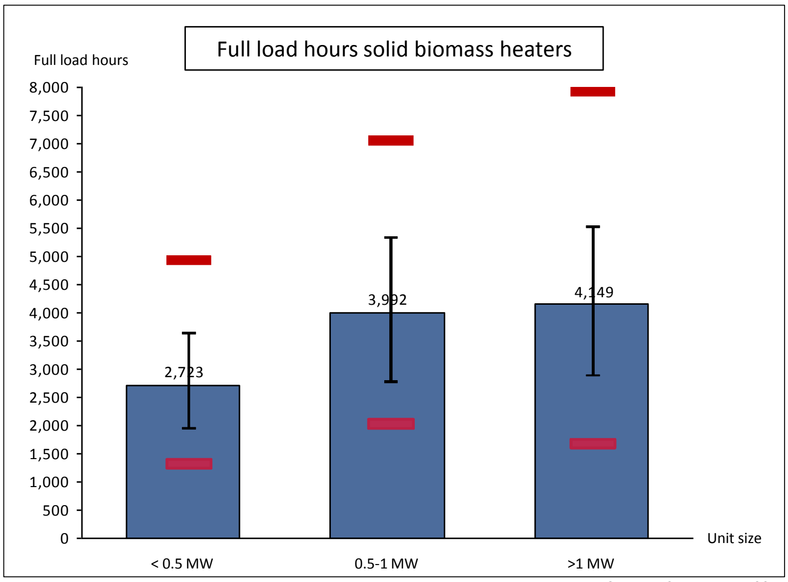
Thus summarized the following variables are required for determining $E_{biomass}$ and E_{gas} of the biomass heater systems:

- full_load = full load hours
- η_{gas} = efficiency of the natural gas peak load heater
- $\eta_{biomass}$ = efficiency of the biomass heater
- gas_ratio = the energy output of natural gas in percent of the biomass energy output

These variables should be representative for the German market wherefore input data is derived from averages of a critical mass of existing heaters, from the CARMEN (2011) survey on 132 biomass heater in Bavaria. Moreover, variables deviate by the size of the heating unit wherefore variables are determined individually for the heater categories of the solid biomass heating economics model, 0-0.5 MW, 0.5-1 MW, 1-3 MW, > 3 MW and cogeneration.

Full load hours

The theoretical maximum value for full load hours is a full year at full operation or 8760 full load hours. Because of maintenance work or production at below full capacity, values are much lower in practice. They are between 2700 and 4200 hours and with a maximum of about 8500 hours.



Graph 24

Sources: C.A.R.M.E.N., 2011

Full load hours were surveyed by C.A.R.M.E.N. (2011) on a sample size of 112 units. Graph 24 shows average values, standard deviations and maximal values. Assumptions in the solid biomass heating economics model correspond to the average values of each category for the basic scenarios. Volatilities are accounted for through a sensitivity analysis. Moreover, for cogeneration and >3 MW no individual data is available. Thus, in the basic scenario full load hours are approximated with the 4349 full load hours of large biomass heaters.

Heater and ORC unit efficiencies

Efficiencies indicate how much of the input energy can be transformed into useful energy by the heaters. Findings of CARMEN are shown in Table 13. As can be seen efficiencies of biomass heater are about 80% for all categories and those of peak load heater increase with the size of the unit.

Biomass heater size	< 0.5MW	0.5-1 MW	1 MW-3MW	>3 MW
Biomass heater efficency	79%	80%	80%	80% (estimate)
Peak load heater efficency	81%	82%	86%	86% (estimate)

Table 13 Natural gas and biomass heaters efficencies

Since the ORC cogeneration unit converts heat energy into heat and electricity, efficiency values for the unit are different than those for standalone heaters. Generally the ORC system consists of two pieces from different producer which both have their own efficiency values, a heater and an ORC energy conversion unit. The ORC heating unit is similar to the standalone heater and often even stems from the same manufacturer. Thus, its efficiency is assumed to be the same as efficiencies for large heaters, 80%. Once transformed from biomass into heat energy in the biomass heater, the heat is converted further in into heat and electricity in the ORC unit. Conversion in the ORC unit is relative efficient with 78.4% thermic and 19.6% electrical efficiencies and thus combined 98% efficiency (Stoppato, 2012; Turboden, 2012b).[28]

The formula for total ORC thermic and electric output is as follows:

$$E_{el\_output}=(E_{biomass} * \eta_{biomass}) * \eta_{el\_output} \qquad (14)$$

$$E_{th\_output} = (E_{biomass} * \eta_{biomass}) * \eta_{th\_output} \qquad (15)$$

Where E_{el_output} = electricity output; $E_{biomass}$ = biomass input; $\eta_{biomass}$ = efficiency of the biomass heater; η_{el_output} = electric efficiency ORC unit; η_{th_output} = thermic efficiency ORC unit

Transforming given formulas leads to the following formula for $E_{biomass}$ for ORC sytems:

$$E_{biomass} = \frac{unit\_size * full\_load}{\eta_{biomass} * \eta_{th\_output}} \qquad (16)$$

Share of natural gas energy provision

gas_ratio, the energy output of natural gas in percent of the biomass energy output is shown in Table 14. As can be observed energy provision from the peak load heater decreases with size of the project. Usually, demand is better distributed over time in a larger heating grid. Hence, the peak load heater is needed less often and the biomass driven base load heater runs more steadily. Given this relationship for the cogeneration unit a value of only 5% will be assumed for the solid biomass heating economics model.

Biomass heater size	< 0.5MW	0.5-1 MW	1-3 MW	>3 MW
Peak load energy as % of biomass heat production	20%	15%	12%	5% (estimate)

Table 14 Share of fossil fuel energy provision in biomass/fossil fuel base load/peak load systems

[28] Efficiencies decrease if the heater runs at partial load (Stoppato, 2012). The biomass heating economics model assumes the heater to run either at full load or not at all.

6 Operational costs solid biomass heating

Formula (1), the cost of biomass heating formula, is:

$$C_{biomass\ heating} = C_{financing} + C_{fuel} + C_{operation\ \&\ maintenance} \qquad (1)$$

In this chapter the third variable $C_{operation\ \&\ maintenance}$ which encompasses all non-financing and fuel related cost factors is determined. The formula for $C_{operation\ \&\ maintenance}$ in the biomass heating economics model is:

$$C_{operation\ \&\ maintenance} = ash\_disp. + labour + main\&rep + electricity \qquad (17)$$

Where ash_disp = ash disposal cost; labour = labour cost; main&rep = maintenance and reperation; electricity = electricity cost or revenue

Following the formula and input parameters for each of these parameters are discussed. As values for these parameters vary significantly with the size of the heating units, they are investigated separately for the four heater categories introduced in chapter 5 on fuel and heater categories (<0.5 MW, 0.5-1MW, 1-3MW and >3 MW).

Ash disposal

Roughly 1% to 8% of the wood is not burned in the heater but remains left over as ash. This ash needs to be disposed. C.A.R.M.E.N. (2011) collected information from 32 heating units. Their average disposal cost amounts to 148 EUR/t.

Since the volume of ash depends on the volume of input material, in the biomass heating economics model ash disposal cost are calculated in dependence of $E_{biomass}$ = total input biomass energy. Thus the costs are calculated with the following formula:

$$ash\ disp = \mathrm{x\%} * 148\ \mathrm{EUR} / 5.158/\mathrm{MWh} * E_{biomass} \qquad (18)$$

Where x= the weighted average ash content of the fuel mix[29]; $E_{biomass}$= total input biomass energy (total wood energy vs. total biomass heat output); 5.158 is the energy content of one ton of dry material as found in appendix 8.

[29] For instance, for a fuel that contains 80% forest wood chips and 20% recycling wood AI x= 2.5%*80%+6%*20%=2.8%

Moreover, the following table shows assumptions on the ash content of different wood categories as used in the solid biomass heating economics model. The assumptions are based on FNR (2007, p. 163).

Category	Forest wood chips plants >1MW	Forest wood chips plants <1MW	Landscape cleaning material	Sawmill by-product wood chips	Recycling wood AI	Recycling wood AII-AIII
Ash content	2.5%	1.5%	2.5%	1%	6%	8%

Table 15 Ash contents biomasses

Labor costs

Wood chip heaters are not stand alone systems but require manual work. For instance, when the fuel is refilled someone supervises the process. Furthermore, wood chips have an inconsistent size and consistency. This leads to congestions in the feeding system or fuel silo which needs to be solved manually. Krapf (2004) approximates total labor cost in man hours/kW installation per year. His assumptions are shown in Table 16. Moreover, FNR (2007, p. 205) indicate that with increasing unit size employees need to be more skilled. Thus, labor costs for the heater are calculated as shown in Table 16.

Size in kW	Man hours per year and kW installation (as in Krapf 2004)	Cost of full employee /year (as in FNR, 2007)	Cost per man power/h	Cost of manpower per year and kW installation
350-500	0.6	30’000 EUR	15	9
500-1000	0.5	40’000 EUR	20	10
>1000	0.4	50’000 EUR	25	10

Table 16 Labor costs biomass heaters

Moreover, Duvia et al. (2009) say ORC plants require one full employee for operation. The work load varies only marginally with the size of the plant because usual tasks imply supervision and steering of the processes, cleaning and alike. An employee that fulfills these qualifications costs about 40’000 EUR (FNR, 2007, p. 204).

In the biomass heating economics model labor costs are calculated with the following formula:

For standalone heater: $$labour = x * unit\ size \qquad (19)$$

For the cogeneration unit: $$labour = 40'000 \qquad (20)$$

Where x = cost of manpower as shown in Table 16; unit size= the size of the heating unit in kW

Maintenance and reparation

For maintenance and reparation cost of the building there exist a guideline from the Association of German Engineers (VDI). The VDI (VDI standard 2067, p.1) says 1% of investment of the buildings investment cost are annually required for each maintenance and repairmen. The same is true for other equipment which according to VDI standard 6025 has about 2% of maintenance and reparation cost. According to VDI standard 2067 maintenance and reparation for ORC units amount to between 1 and 2% of investment cost and 2% will be assumed in the solid biomass heating economics model.

Thus maintenance and reparation are calculated with the following formula

$$maint\&rep = 2\% * total\_invest \qquad (21)$$

Insurances

According to Krapf (2004) insurances correspond to about 0.2 to 0.4% of total investment cost. The FNR (2007, p.234) states about 0.5 to 1% of total project cost. The FNR value is based on consulting experience of the author and Krapf (2004) on a research and a large data set. Thus a value of about 0.4% of total investment cost is used in the solid biomass heating economics model. The corresponding formula is:

$$Insur = 4\% * total\_invest \qquad (22)$$

Electricity for biomass heater

The system requires support electricity to run the feeding system, filter and other components. In their 2011 survey, C.A.R.M.E.N. (2011) indicate electricity consumption to be dependent on the produced energy and the unit size. Their data is shown in Table 17.

Heating unit size	< 0.5 MW	0.5-1 MW	1-3 MW	>3 MW
Electricity consumption in % of heat output	2.2%	1.4%	1.3%	1.3%

Table 17 Electricity consumption biomass heating systems

Thus electricity are as follows in the biomass heating economics model:

$$electricity = x\% * E_{biomass} * \eta_{biomass} * P_{electricity} \qquad (23)$$

Where $E_{biomass}$ = input energy biomass; $\eta_{biomass}$ = biomass heater efficency[30]; x= electricity consumption of the heater as shown in Table 17; $P_{electricity}$= electricity price for industrial consumer

Electricity production for cogeneration

Besides own consumption, cogeneration units also produce electricity. In the biomass heating economics model, electricity sales categorizes as parameter of $C_{operation\&maintenance}$, however with a positive value. In other words all cost that can not be covered by electricity sales remain cost that need to be covered by heat costumers and thus constitute biomass heating cost.

Return from electricity sales is fixed by the EEG at ct/kWh (see chapter 2.2.3). The tariff differs by multiple criteria like the fuel mix, volume of energy sold etc. Calculations for the 1 MW ORC unit investigated in the biomass heating economics model are shown in appendix 9. Assuming the fuel mix scenario developed in chapter 5.2 on fuel mixes and the production level assumed in the biomass heating economics model scenarios, the feed-in tariff amounts to 19.8 ct/kWh.

Moreover, cogeneration units require a significant amount of electricity for operation. In the model, the energy consumption is deducted from the produced energy. The furnace and the ORC unit each require together 10.2% of the electricity produced by the ORC unit (Turboden, 2012b).

Therefore, electricty sales calculates as follows:

$$electricity = (E_{biomass} * \eta_{biomass} * \eta_{el\_output}) + (1 - el\_cons) * el\_feed\_in \qquad (24)$$

Where η_{el_output}= electric efficency of the ORC unit (see chapter 5.5 on heater specification); el_cons= electricity consumption of ORC system = 10.2%; el feed _in = EEG feed-in tariff = 19.2 ct for the 1 MW unit in the biomasse heating economics model

[30] Biomass heater is discussed in chapter 5.5 on heater specifications

7 Solid biomass heating economics model

Along the last three chapters all input variables and formulas for the biomass heating economics model have been determined based on the following formula:

$$C_{biomass} = C_{financing} + C_{fuel} + C_{operation\,\&\,maintenance} \qquad (1)$$

In this chapter the costs of biomass heating are simulated with the model for 20 years of plant operation. Then the effects from varying certain parameters are tested. Depending on the tested variables, effects over time or on the first period are discussed.

The main findings from the analyses are that full load hours and economies of scale from the heating unit size are cost factor with the highest influence on the cost of biomass heating. Moreover, financing cost become the more important the less full load hours the heater has. In the basic scenario they amount to 19-22% of total operational cost for heater and 47% for cogeneration units. Resource prices constitute another crucial cost factor: they account for between 45% and 50% of total costs. Last, total heating cost from solid biomass are 30% higher if fuel prices rise to the possible maximum than if they fall to the possible minimum price level found in chapter 5.3.

As shown before for various variables the input value depends on the unit size (different fuel cost, full load hours etc.). For this reason economics for biomass heating are investigated for each size category. Exemplary for the four different categories, heating cost calculations for the following unit sizes are modeled: 350 kW_{th} heater, a 750 kW_{th} heater, a 1500 kW_{th} heater and a 1000 kW_{el}/5000 kW_{th} cogeneration unit.

Moreover, the cost formula for $C_{biomass,}$ formula (1) shows total annual cost. For comparing effects of different parameters these cost are divided by heat energy output and then compared to one another in EUR/MWh.

$$C_{compare} = \frac{C_{biomass}}{E_{biomas\_output} + E_{gas\_output}} \qquad (25)$$

In the simulation the effects of the following parameters are investigated: unit size, resource cost, installation cost, full load hours, and return on equity [RoE]. Most variables are only investigated for the first period since effects for the following are analogous. Resource prices, however, are simulated over 20 years of plant operation. For simulations over time different assumptions apply. Resource price and thus fuel cost development scenarios were discussed in chapter 5. Financing remains stable since it is modeled to consist of two annuities with 20 periods (see chapter 4). Operation and maintenance cost are simulated to increase by 1.7% annually, an approximation for the German inflation rate.

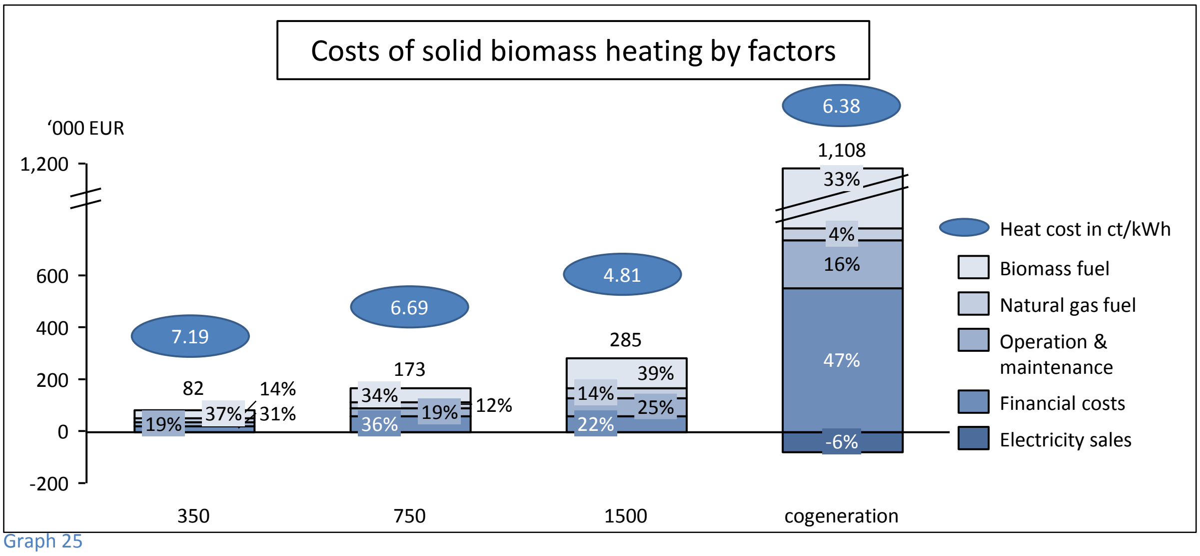
Table 18 shows all input factors of the biomass heating economics model as found in the previous chapters.

	Size in kw	**unit**	**350**	**750**	**1500**	**1007el Cogeneration**
Installation cost	ORC unit, furnace and installation	EUR				5,941,300.0
	Building		26,400	300,000	600,000	
	Heater	EUR	115,791	208,864	357,159	
	Peak load heater	EUR	26,036	46,978	80,355	240,000.0
	Other	EUR	150,000	212,709	351,166	
	Total	EUR	318,227	768,551	1,388,680	6,181,300.0
Finance structure	Equity	%	30%	30%	30%	30%
	Total equity	EUR	95,468	230,565	416,604	1,854,390
	Thereof private equity	EUR	88,468	215,565	386,603	1,854,603
	Thereof equity from subsidies	EUR	7,000	15,000	30,000	
	Debt	%	70%	70%	70%	70%
	Debt	EUR	222,759	537,986	972,076	4,326,910
	Interest rate	%	4%	4%	4%	4%
	Return on equity	%	8%	8%	8%	8%
	Depreciation in a	EUR	20	20	20	20
	Annuity Debt	EUR	16,391	39,586	71,527	362,037
	Annuity Equity	EUR	9,001	21,956	39,376	188,874
	Total Capital contribution/a	EUR	25,011	61,542	110,903	550,947
Fuel cost	Full load hours biomass heater	h	2,723	2,992	4,149	4,149
	Biomass input/a	MWh	1,206	2,805	7,779	26,631
	Price biomass period 1	EUR/MWh	25.13	20.82	14.44	14.75
	Efficency biomass heater	%	79%	80%	80%	80%
	Thermal bioenergy output	MWh	953	2,244	6,224	16,700
	Natural gas heat input/a	MWh	234	416	839	971
	Natural gas price period 1	EUR/MWh	47.58	47.58	47.58	47.58
	Efficency peak load heater	%	81%	82%	86%	86%
	Natural gas heat output/a	MWh	190	341	722	835
	Electricity efficiency ORC unit	%				19.6%
	Thermal efficiency ORC unit	%				78.4%
	Gross electricity output	MWh				4,173.89
	Electricity consumption ORC unit	%				5%
	Net electricity output ORC unit	MWh				3,965.20
Operational and maintenance	Ash disposal cost	EUR/MWh	0.43	0.44	0.72	0.72
	Ash dispoal cost total	EUR	519	1,248	5,580	19,104
	Maintenance and reparation	EUR	6,365	15,371	27,774	61,813
	Insurance	EUR	1,273	3,074	5,555	24,725
	Labour cost	EUR	3,150	7,500	15,000	50,000
	Heater electricity consumption as % output energy	%	2.2%	1.4%	1.3%	1.3%
	Electricity consumption	MWh	21	31	81	217
	Electricity consumption	EUR	3,983.75	5,969.04	15,372.05	
	Net electricity production	MWh	-21	-31	-81	3,748
	Return electricity sales	ct/kWh				19.8
	Return electricity sales	EUR				74,082

Table 18 Input factors biomass heating economics model

7.1 Cost of biomass heating

Graph 25 shows the output of the basic scenario, all parameters as stated in the output table, Table 18. The graphs indicates total cost and the share of total cost by category for the first period. It also states the heat production cost as total.



Graph 25

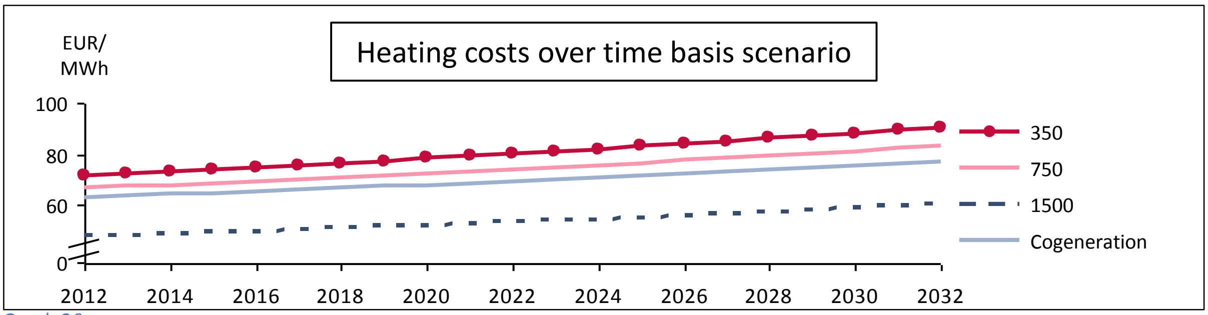
It can be observerd that biomass heating units profit severly from scale. The kWh heat energy from 350 kW units is 2.38 ct/kWh or 66% more expansive than those from 1500 kW units. However, heat from the cogeneration unit is more expensive than from standalone heater. This can be explained by the high capital cost for the unit and relative little return from electricity sales. For standalon heater the annuty amounts to 19-36% of total cost whereas for cogeneration 47%, at least 11% more than for pure heating. Electricity sales compensates only for 6% of total cost and therefore cannot cover additional capital costs.

District heating is compensated with 6.8-8.4 ct/kWh in Germany (Kraft & Schmitz, 2011, p. 6). Thus direct heating from all heater categories is competitive. Since district heating requires additional capital costs of 0.5-2 ct/kWh[31] it starts becoming competitive above 500 kW.

[31] 0.5 ct/kWh corresponds to about 800m and 2 ct/kWh to 3.2 km of district heating grid. Assumptions i=4% ; n=20; cost: 277 EUR/m; subsidy 60 EUR/m see footnote 32

7.2 Economic impact of heating unit sizes

Graph 26 compares the four basic scenarios over time. In the basic scenarios operational cost increase by the assumed inflation rate of 1.7% annually and other factors as discussed before.



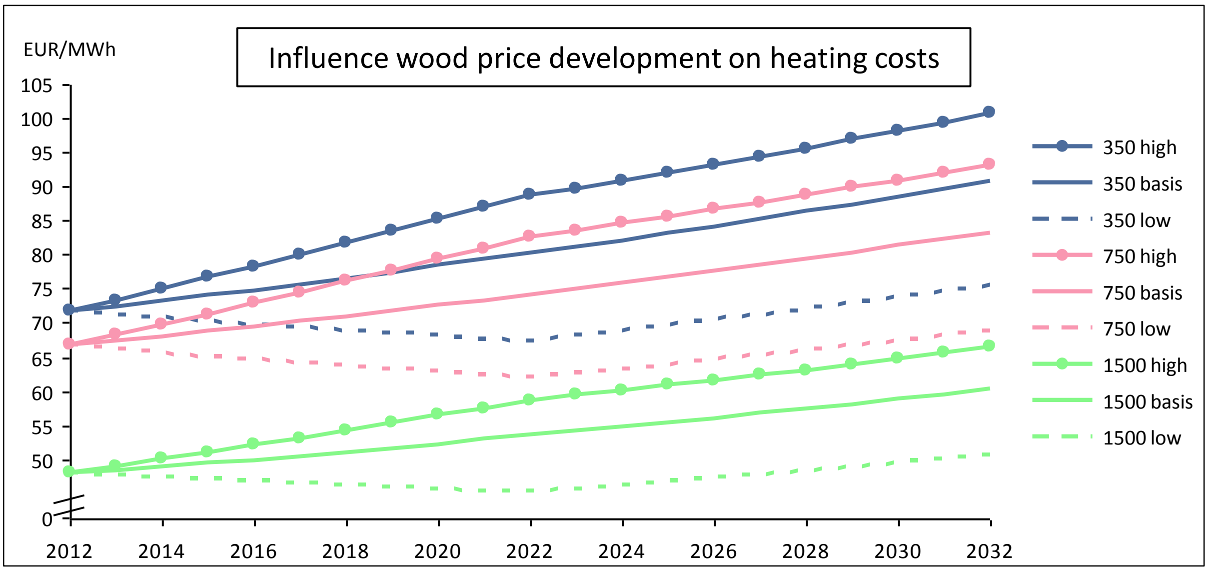
Graph 26

The graph signifies that cost spreads of different heater sizers are significant and do not vanish over time. The huge cost spread between small and large units leads to the conclusion that as long as there are potential costumers nearby, investors should extend district heating grids as far as possible and to connect more costumers to profit from the economies of scale. Lower costs of larger projects allow for major investments in district heating grids before financial cost of the grid surpass the economic profit from lower heating grids. For instance, with economic advantages of 22 EUR/MWh for heat from a 1500 kW unit compared to those from a 750 kW unit, additional grid of up to 2.6 kilometers would be economically.[32]

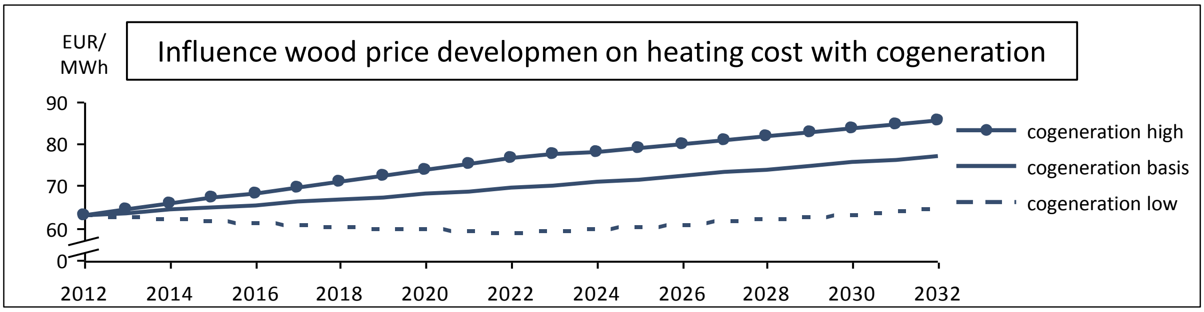
7.3 Economic impact of resource prices

Graph 27 and Graph 28 show the basic scenarios and a low and high fuel price scenario for each of the four heater categories. The low and high scenarios assume that the maximum values found in chapter 5.2.4, the chapter on resource prices, would be reached in continous steps over the next ten years. Thereafter prices increase by the inflation rate of 1.7%.

[32] Hartmann et al. (2011, p.68) found that the heating grid costs 277 EUR/m length. The KfW subsidizes heating grids with 60 EUR/m which leads to total installation cost of 217 EUR/m. Moreover, assuming the 750 kW heaters energy output of 2244 MWh/a times 18.79 EUR/MWh cost spread leads to saving of 42’158 EUR/a with the larger unit. With a 4% interest rate and 20 years investment horizon an annuity of 42’158 EUR is reached with an investment of about 572,941 EUR which corresponds to 2640 m. This calculation does not include cost for connections between costumers and the grid. However, connections are almost totally paid for through KfW subsidies of 1800 EUR/connection.



Graph 27

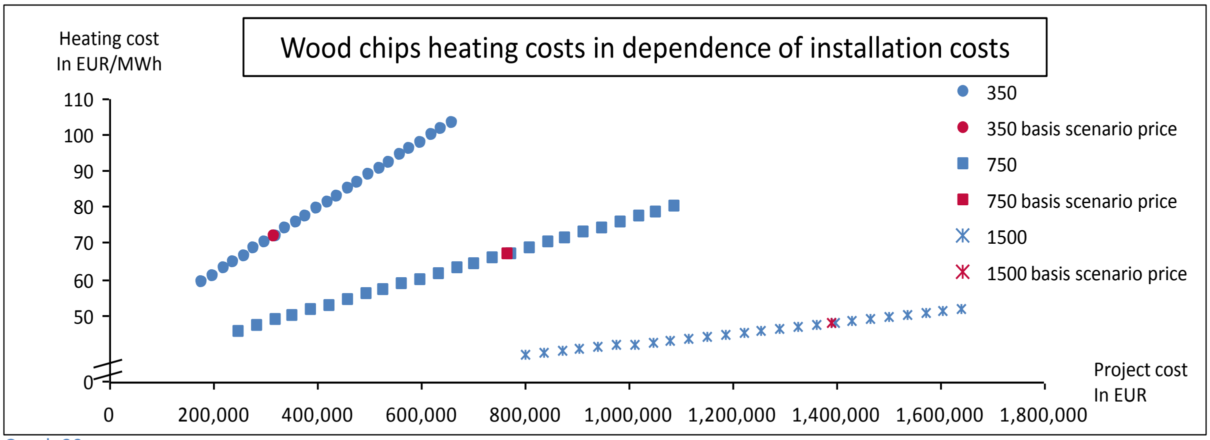


Graph 28

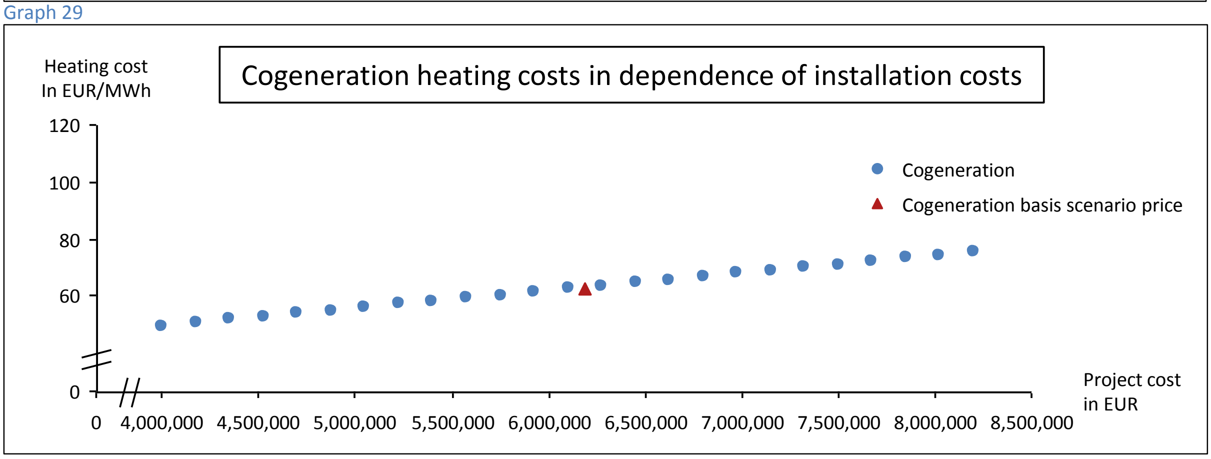
The graphs indicate that the smaller the unit the more resource price volatilities affect the heat price. In general, the spreads between the lowest and the highest resource price scenario account to 29-31% in heating cost differences for all heater categories or 9-11% between the basic and highest scenario. In absolute terms this implies enormous advantages for larger units. For instance, the 350 kW unit has a heat price of 8.0 ct/kWh in the basic scenario and 5.4 ct/kWh for the 1500 kW unit. If the high cost scenario takes happens the 8-10% higher heating cost for both heater sizes imply 0.86 ct/kWh higher cost for the 350 unit and only 0.52 ct/kWh for the 1500 kW unit.

7.4 Economic impact of installation costs

Graph 29 and Graph 30 show the impact of installation cost on the heating price, the heating price to unit cost elasticity. The price curves correspond to what was found to be the range of installation cost in the HessenEnergie (2007) data set as discussed in chapter 4.3.4.



Graph 29



Graph 30

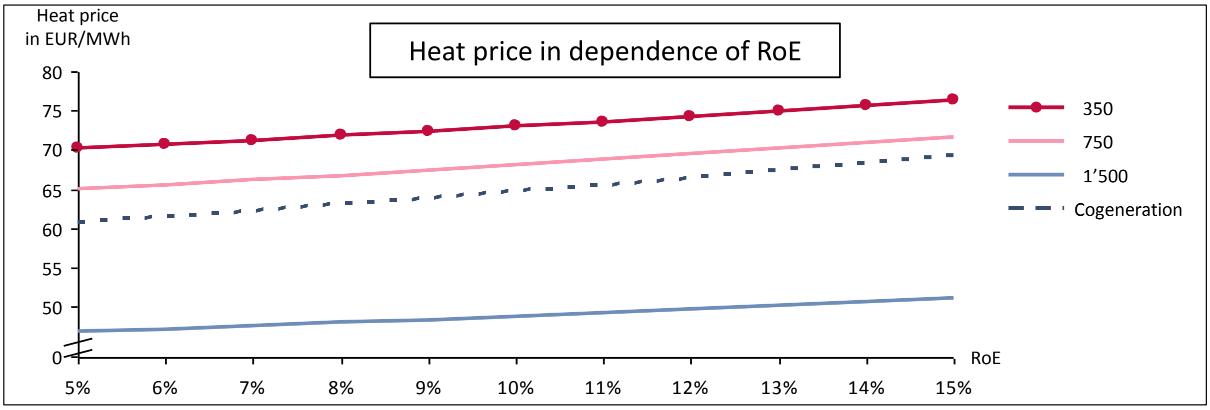
The curves signify that the elasticity decreases with the size of the heater. In other words the larger the unit the lower the spread between heating prices for projects of the same category and with different installation costs. As the graph indicates, installation price variations are crucial for units smaller than 1 MW but less relevant for the larger units. For instance, if installation cost increase from 400’000 EUR to 500’000 EUR the heat price increases by 0.41 ct/kWh for the 750 kW unit and by 0.93 ct/kWh for the 350 kW unit. For units above 1 MW and the cogeneration unit the heat price over installation price elasticity is not that severe. For instance, for the cogeneration unit even an increase of 500’000 EUR leads to only about 0.31 ct/kWh increase in heating price. For small units, however, the cost spreads mean that the most expansive heater with 350 kW leads to 44% higher heating costs than the chap heater of that size.

The heat price to installation costs elasticity is strongly influenced by the plant’s operation time. As Hiendlmeier (2012) has shown >1 MW have on average about 50% more full load hours than for instance 350 kW heater. Thus when calculating the heating price as total annual cost (incl. annuity for installation cost) divided by total energy output, the denominator is much larger and fixed cost are rolled over to more energy units sold.

A high amount of full load hours is not the only factor that leads to relative constant heating prices for larger heaters independent of their installation cost. The total installation cost range constitutes the other crucial factor. While for 350 kW and 750 kW units the most expansive units cost about 300% the price of the cheapest, the spread amounts to only 200% for 1500 kW and cogeneration units.

7.5 Economic impact of return on equity

Graph 31 shows the impact of the return on (private) equity an investor has for biomass heating projects.

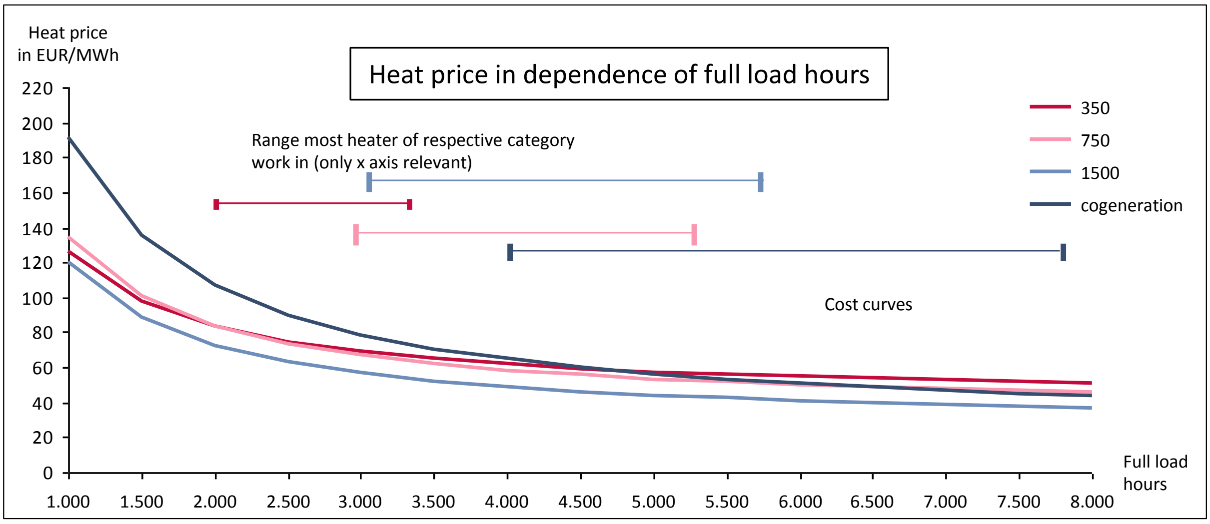


Graph 31

The graph indicates that the influence of equity cost is only modest. Even for capital intensive cogeneration units the spread between a 5% and a 15% return on equity corresponds only to a heating price increase of about 14%. For pure heater the spread amounts to 9-10%. This implies, among others, that biomass investments can be designed to be very lucrative from an investor's point and at the same time remain attractive for customers alike. For instance, an investor who expands the district heating network and replaces an old 750 kW unit by a cogeneration unit can have a return on equity of 15% and still slash heating cost for old customers

7.6 Economic impact of full load hours

Graph 32 shows the heat price in dependence of full load hours as well as the range of full load hours the different heater categories usually work in.[33]



Graph 32

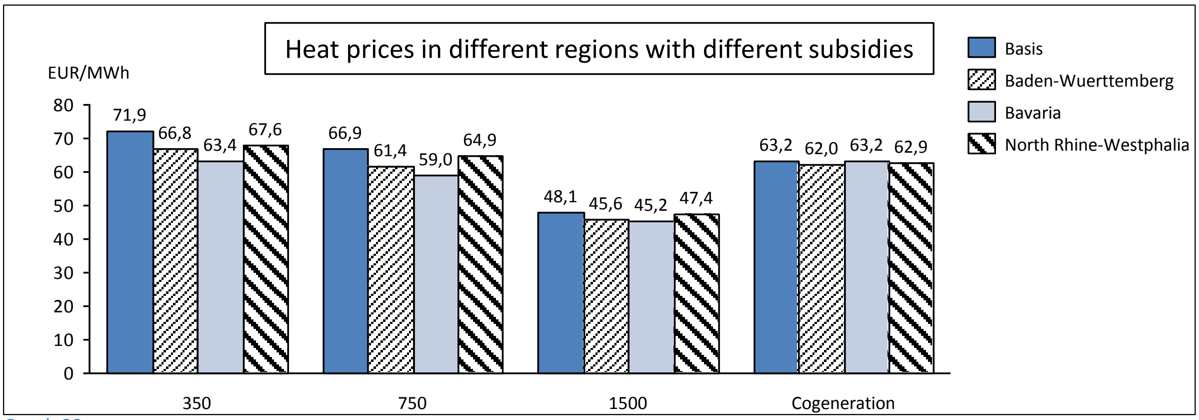
The graph shows why biomass heaters are to be used as base load systems. As the graph signifies, out of all parameters full load hours have the strongest impact on the heating price. For cogeneration units the heat price at 1500h is 72% higher than that of 3000h which is 55% higher than at 6000h. Also for standalone heater these effects are severe with the heat price of 350 kW units at 1500h 42% higher than that at 3000h which is 26% higher than at 6000h.

Moreover, on the graph it can be observed that economic performance improves with the unit size. In particular for the cogeneration unit economic effects are severe. Cogeneration leads to the highest heating prices for projects with less than 2500 full load hours and approximates the lowest heating prices above 7000 full load hours.

7.7 Economic impact of regional subsidies

Graph 33 shows the heat prices by region and unit size for different regions and assuming application of regional subsidy systems. As discussed in chapter 2.3 on regional subsidies, for all three regions the subsidy constitutes a direct payment issued at time of investment that therefore lowers a private investors annuity costs. However, subsidies are only available for standalone heater and not for cogeneration.

[33] For the cogeneration unit the increasing feed-in tariffs for decreasing full-load hours/resource consumption was respected.



Graph 33

The graph shows, that generally subsidies have the highest impact on the heating prices of smaller units, in particular the 350 kW unit. Nevertheless, compared to other influence factors, the subsidy scheme has relative small impacts on the total cost. Since the subsidy is issued at time of investment, its major influence constitutes the increase of RoE and reduction of capital at risk for the investor. The usual equity ratio had been found to be 30%. The subsidies corresponds to 8-32% (average 15%) of total investment cost for units <1 MW. With only 23-30% of all capital covered by equity at date of investment this reduces private equity requirements significantly. For small projects, subsidies pay for between 28% and 107% (average 50%) of total equity and even for 1500 kW units they still pay for up to 19% or 55% of all required equity. Thus, investors reduce their personal risk significantly through these subsidies. Moreover, even a small return on the project can lead to very attractive returns on the private equity if the investor only has to contribute about 10-15% of total investment as private equity.

7.8 Conclusion biomass heating economics model

In this chapter a major part of the economics of solid biomass heating were investigated. First an input data table for modeling financials of biomass heating was developed. The first output, the first years cost structure of the basic model, has shown that the heating unit size has an enormous impact on the heating cost. Economies of scale lead to 34% lower heating prices for the 1500 kW unit compared to the 350 kW unit. Despite cogeneration units have significantly larger energy consumption than their pure heating unit counterparts, their heat production costs are higher than those for large heating units. This is due to their investment cost and thus annuities. Their annuity amounts to 47% of total annual cost compared to only 22-31% for standalone heaters. This economic disadvantage cannot be compensated by electricity sales which only pays back 6% of the annual cost under the basic model assumptions (47% - 6% > 31%). The basic model, however, is based on the assumption of 4130 full load hours' annual production. For instance, at locations with more full load hours of heat demand the contribution from electricity sales increases significantly and above 7000 full load hours, cogeneration units are competitive against large standalone heaters. Sites with that high amount of full load hours heat demand are in particular those with industrial or large district heating grids as costumers.

In general, full load hours have a significant, often even the most significant, impact on the heating cost. Up to about 4000 full load hours the economic performance of heater increases extremely with every additional full load hour of demand. Thereafter, other factors like resource prices become more relevant. Because of this economic importance full load hour constitutes a crucial factor for the economic advantages of large over small heating units. The data shows the average demand profile of <500 kW units (2703h/a) is about 35% below that of a >1000 kW units (4149 h/a). Differences in demand can be explained by the costumer structure. Large units usually have more costumers and thus a more stable demand. Heat costs for projects with less than 2000-3000 h/a (<500 kW units) are that high, that alternative fuel types or extending the grid and installing larger units becomes likely more economically than biomass heating with small units.

The second most important cost factors constitute the resource prices. The differences between the lowest and the highest resource price scenario account to about 30% in heating cost differences for all heater categories or 9-11% between the basic and highest scenario. This is particular important for small units with a high base price, where the high resource price scenario leads to economically uncompetitive heating prices of 9-10 ct/kWh.

Installation cost were found to be varying from the cheapest to the most expensive by 300% for small and by 200% for large heaters. In particular for small units this spread is a crucial factor. The smaller the unit the larger the heat price installation cost elasticity. For units above 1 MW, however, the effects have found to be only modest. For instance, a 0.5 mio EUR installation cost increase for a 6 mio EUR plant leads to only 0.31 ct/kWh increase in heating price.

Return on equity and direct subsidies, a substitute for private equity, were found to have a small impact on the heating price. Direct subsidies are the higher in percent of total investment the smaller the unit. They correspond to about 8-32% (on average 15%) of total investment for standalone heaters. Considering that a usual project has an equity share of about 30% this means investor need to contribute only between 91% and 0% (on average 50%) of total project cost to finance the heater. Already with 30% private equity contribution the RoE has a small impact on the heating price wherefore investors can ask for very attractive returns on such projects.

8 Conclusion economics of solid biomass heating

Summary

This paper has covered all major aspects of the economics of solid biomass heating in three sections on policies, market size, and economic factors of biomass heating. In the first part policies from three institutional layers in politics were investigated. It was shown that the EU generally only sets the framework in which member states can develop their policies. A regulation that forces member states to adopt policies for fulfilling nearly zero energy standards in the building sector and the 20-20-20 targets including the 20% renewables target are the most crucial policies from the EU level. All other policies are formed on the federal German and state level whereby the states mostly focus on providing subsidy schemes. Significant federal policies were found to be: the fuel taxes which exempt solid biomass from charges, the cogeneration act that fosters expansion of district heating grids, the EEG renewables energies act which guarantees fixed feed-in tariffs for electricity form biomass cogeneration, and the renewables heating as well as the building ordinances which guarantee Germany’s compliance to the EU’s nearly zero energy regulation. Moreover, the parliament adopted binding targets on the share of cogeneration, renewable energies and renewable electricity in the national German energy mix. In order to meet these targets the government has to either continue or enforce these renewable energies promoting policies.

In the second part the theoretical market potential was investigated. The analyses show the market is generally limited by resource supply and not demand potential. If at all, total potential could only be met by major imports of biomass. In the residential and office building sector, demand for heat energy is declining but increasing penetration of district heating still leads to an increasing market for solid biomass heating. Because of building size and owner structure, demand from public infrastructure buildings for solid biomass heating will also grow. Responsible for more than 50% of potential demand, industrial and process heating sector will be increasingly penetrated by solid biomass heating.

In the last part economics of solid biomass heating were modeled and the marginal effects different parameters were investigated. It was shown that full load hours and economies of scale from the heating unit size constitute the most crucial parameters for the economics of such power units. Given the findings it can be concluded that solid biomass heater should be larger than 500 kW and deliver energy for more than 2500-3500 full load hours to be economically attractive. Under the current promotion terms, it is very likely that increasing investments in additional district heating grids for increasing the heating unit size pays off. In addition to full load hours and the unit size, resource price paths have found to have a significant impact on the heat price. If resource prices increase to the maximum, heat prices will be 30% above the price resulting from the lowest level and 9-11% above the basic scenario level.

Subsidies lower total biomass heating cost only by an insignificant amount but make it very attractive to build additional biomass energy infrastructure. Direct subsidies for biomass heater lower total heating cost by a maximum of 0.75 ct/kWh but at the same time reduce private equity contribution to 91-0% (on average by 50%). Given the little equity contribution required for financing biomass energy infrastructure the rates investors ask for return on their equity are of subordinated priority for the heating cost. With low private equity requirements and with little impact of return on equity, the biomass heating market allows combining interests of investors and costumers while generating attractive returns without significantly affecting heat prices adversely.

Research recommendation

Energy policies and their effects are prominent in literature. As a complement this paper summarizes current policies with impact on the solid biomass heating market. Given information from this paper little additional research is required in that field. On the contrary the second part, analyses on potential demand and supply in the biomass heating market, leaves much room for further research. Existing literature is mainly focused on residential and social infrastructure as well as public infrastructure heating markets. Little was published on the market with the highest potential demand, industrial heating. Viehmann (2011) provided first work, however, similar to studies on industrial solar heating (Lauterbach et al., 2011) or industrial geothermal heating (Arens, 2010) research should deepen the topic and investigate total potential for each industry individually.

The solid biomass heating economics model complements literature such as Clausnitzer (2007), Duvia et al. (2009), Hartmann et al. (2011), or Krapf (2004) with more detailed and precise parameters than given in these studies. Additional insides from this paper encompass notably the resource price mixes and fuel categories which traditionally have been simulated to be constant across all heater categories. However, analyses in this paper are limited on providing upper and lower limits for the future resource prices. Further, research is required to model these more detailed. Research should focus on investigating supply and demand functions in these sectors as well as their future development.

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Appendices

1 Mandates for energy policy setting

Following the power sharing concept between regions, the federal Government and the EU for energy policy setting in Germany is discussed. As higher ranking institutions can overrule policies of subordinated, the chapter starts with the highest level, the EU. This is followed with by dispute on the competence split between the federal level and regional governments.

1.1 EU mandates for energy policies

As a supranational organization based on multilateral treaties of the member states, the EU can only adopt policies and regulations on topics where member states explicitly create EU competences. If such competences are established, member states give up parts of their sovereignty in favor of a European solution on these topics. Thereafter, EU institutions can force member states to adjust federal law in affected sectors until they comply with EU regulations. If these competences have not been transferred, related topics, as for instance social security systems, remain in the realm of federal and state level governments. Energy policy does not belong to these EU competences (Sauter, 2010). This means EU institutions generally have no competence to adopt regulations with effects on the energy market.

In their recent political actions Member States acknowledged that they are not willing to change the situation and to extend EU energy competences (Sauter, 2010, p.15). Among others the Lisbon treaty of 2008 shows the lack of interest to extend energy policy making competencens. In the Lisbon treaty, unofficially a set of policies that originally was meant to be enacted as the European Constitution, energy policy competence is treated with caution. In the document it says that the EU may be responsible for specific energy policy like security of supply, or to promote energy efficiency and saving.[34] Nevertheless, this responsibility is of low influence as in article 122(1) (TFEU) it states these competences may only "be executed in a spirit of solidarity" which is a fuzzy expression given the lack of legal

[34] In particular the article refers to the following four fields: [1] to ensure the functioning of the energy market; [2] to ensure the security of supply in the Union; [3]to promote energy efficiency and energy saving, and develop new and renewable forms of energy; [4] to promote the interconnection of energy networks.

obligation (Braun, 2011, p.2). Moreover, Art. 194(2) and (3) TFEU stipulate that measures in the field of energy taxation and member states' rights in deciding on the conditions for exploiting their energy resources, choices amongst different energy sources and the general structure of their energy supply are subject to unanimity (Braun, 2011, p.2). Unanimity happens, if at all, very seldom in a politcoal forum of 26 individual interest groups. Therefore, the article generally implies that measures in the field of energy taxation, exploiten of energy sources, choices among different energy sources and the structure of energy supply remain Member States competence and the EU remains without the competence for energy policies.

1.2 EU's energy policy setting methods

Despite of that the EU has no general competence for energy policy setting; it is equipped with assorted mandates in the field and extended others over the last 15 years. First of all, energy policy was one of the first EU tasks from an historical point of view (Sauter, 2010, p.11). Two of the first post-war pan European treaties were the 1951 European Coal and Steel Community (ECSC) and the 1957 European Atomic Energy Community (EAEC). Both aimed at the creation of the free and integrated market (McGowan, 1993 cit. in Sauter, 2010, p.11). The creation of the free market and market integration are two of the current core responsibilities of the EU. Accordingly, major parts of these treaties and succeeding policies are still EU mandates. Notably, since the 1990s, the EU has been responsible for the European electricity market integration and liberalization. Thus, despite of its lack of energy policy setting competence the EU influences the energy markets by its liberalization and integration function.

Moreover, a major expansion of energy related activity took place in the late 1990. Following the Kyoto conference of 1997 and sharp increases of energy prices since 2000 additional central regulation in the realm has taken place. As a first result, the EU was responsible for establishing an emissions certificate trading scheme. Before member states transferred the competence for environmental regulation to the EU. Hence, even though the emissions trading scheme also affects energy markets, it categorizes mainly an environmental tool and therefore as part of the EU mandate.

Since the right for environmental regulation has developed to a loophole for further extension of EU regulative power on the energy markets (Schumann, Bandelow, & Widmaier, 2005).[35] The EU argues for instance, that renewable energies quotas for the heating sector or the electricity production would be environmental regulation. Thus it adopted the 20-20-20 goals, which among others require member states to provide 20% of their energy from renewable sources by 2020. Environmental regulation, nonetheless, limits EU influence mainly on the promotion of renewable energies and the ban of emissions. For instance, the EU cannot demand the use of less oil but only less carbon emissions or more renewables. Even setting rules on which renewables sources to develop for achieving quotas would exceed the EU's legal competences.

Concluding the EU generally is not entitled to set energy policies but draws on alternative competences as environmental regulation or market integration to bypass it legal constraints. The loophole environmental regulation mandates is a weak competence that mainly allows for limited activity for pro renewable energy policy setting or extensive activity on abaidment of emissions. Major energy policies are still to be set on lower political layers as the federal and state level. For instance, energy taxes, the design of energy subsidies, or prescriptions on the energy mix beyond renewable quotas remain on lower level competences. Thus, following, it will be discussed how regions and the federal governments split and share these competences.

1.3 Federal and state mandates for energy policy

As its name indicates The Federal Republic of Germany is federally organized. Federalism implies a general sharing of law-making competence between the states and the federal level. However, crucial energy laws are generally in domain of the federal level since it has the strongest influence on the energy sector. Among others, the federal level has the exclusive competence for collecting income taxes (Art. 106 GG). In respect to energy policies, income taxes encompass powerful tools as taxes on fossil fuels for heating and electricity generation.

[35] Note that the EU's generally adopts energy related initiatives based indirectly on its competences for approximation of law, its environmental competences, its harmonization competence and competences for competition and economic policy making.

Furthermore, federal institutions share some policy-making competences with the state level. Important for energy policy-making are the shared competences for topics affecting air pollution (Art. 74 Abs. 1 Nr. 24 GG), protection of the environment (Abs.1. Nr. 20), and the economy (explicitly including the energy economy) (Abs.1 Nr.24). In strong contrast to the EU's environmental competence, the competence for air pollution policies is a very strong one and serves as the legal base for most policies with regulatory effects on the energy market. Among others renewable energy subsidies for electricity production, minimum standards in the heating sector, cogeneration subsidies are all legally based on the competence for policy making against air pollution.

However, a shared competence means the states may set policies in these political resorts as long as the federal level has not (Art.72 GG). For instance, the state of Baden-Württemberg adopted a law on heating and cooling. This law, however, was overruled by a country-wide policy adopted a few years later. With the right for overruling the state level and with increasing density of federal regulations, the federal level was the most powerful institution in respect to political influence on the German heating market.

1.4 Conclusion mandates for energy policy setting

The federal government is the institutional layer with most competences in the field of energy policies setting. Regional governments can only adopt policies if there do not exist any from the federal in that sector. These regional policies can always be overruled by the federal government at a later point of time. With an increasing density of energy policies the regional governments therefore loose in regulative power.

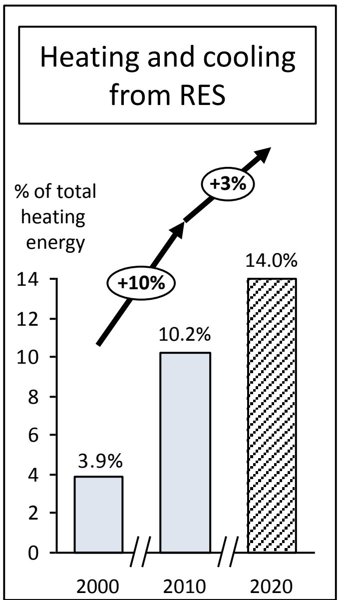
Federal policies, nevertheless, generally could be overruled by EU regulations. The EU, however, only possess competences for environmental issues and for market integration and generally not for energy policies. Because of these limited competences the EU was constrained on comparable weak policies as setting quotas for renewable energies. In the following chapters the outcome of this power sharing will be discussed.

2 Renewables energies heating and energy efficiency regulations

Following additional information on the energy efficiency and renewable energies heating regulation act are provided.

Regulation on energy efficiency of buildings has a long tradition in Germany with first rules adopted in 1977. In 2001 the EU entered this field of regulation and adopted first building energy efficiencies regulations. At that time existing German regulations exceeded EU requirements and nothing had to be changed. In 2009, however, the EU enforced regulations. The new set target is for all new buildings erected in 2020 or later to fulfill nearly zero energy efficiency standards (EG/2010/31). This means they do not consume more energy than can be produced locally from renewable sources. To achieve that target federal regulations had to be made stricter. The standard for maximum allowed primary energy consumption of new and renovated buildings were decreased by 30% and the insulation standard[36] increased by 15% (EnEv-online, 2009). The current standard still allows for about 50 kW/a and m^2 of energy consumption in new buildings wherefore federal regulations will have to be enforced further to comply to the EU's zero kW/a standards by 2020 (EnEV 2009, EnEV 2012).

Along the 2009 revision of the Energy Saving Ordinance a new regulative tool, the Renewable Energies Heating Act, was installed [EEWärmeG]. The quantitative target of the EEWärmeG act is to increase the energy share of renewable energy for heating and cooling to 14% by 2020 (EEWärmeG §1). As Graph 34 indicates the 14% target is moderate and very likely to be achieved. From 2000 to 2010 the share has risen by 10% annually on average and would have to continue doing so by only about 3% annually to achieve the targeted 14%.



Graph 34 Source: BMU, 2011b

More important than the targets are the new requirements. Expressed in EEWärmeG §5 all new and renovated buildings have to fulfill minimum quotas of heat provision from renewable energies. Simplified the act requires that at new and significantly renovated buildings heating energy must be to a certain share from solar or geothermal sources or 50% from solid biomass.

[36] the minimum amount of energy stored in the building

3 EEG development

Following it is shown how the EEG renewables energies promotion act changed over time. These developments are analyzed and a future development path for it is derived.

3.1 EEG Act revisions

EEG 2000: With the target to double the amount of electricity from RES from 6.4% to 12.5% in 2000 the government adopted the first version of the EEG act (EEG2000 §1; 2001/77/EG; (BMU, 2011, p. 16). The EEG act guaranteed investors fixed electricity feed-in tariffs for 20 years depending on the size of the power unit (EEG2000 § 5). Table 19 shows the different tariffs for biomass projects.

Size	Feed-in
<0.500 MW	10.23 ct/kWh
0.5-5 MW	9.21 ct/kWh
5-20 MW	8.7 ct7kWh
>20 MW	No subsidy

Table 19 EEG act feed in tariffs

EEG 2004: In 2004 the EEG was reformed for the first time. Key elements of the reform were an optimization of feed-in tariffs and bonuses for burning renewable sources, using new technology and cogeneration.

- The feed-in tariff optimization includes category dependent reduction of fixed feed-in tariffs and the introduction of bonuses
- The renewable sources bonus, the NaWaRo bonus, was issued for project that fueled with certain categories of biomass. Among others these were biomass from farming, gardening and forest industry. Project with fueled by e.g. recycling wood as boards from construction, old furniture etc. did not receive the bonus (EEG 2004 §8).
- The technology bonus was issued for small power plants (<5 MW) using innovative technology like the Organic-Ranking-Cycle.
- The cogeneration bonus was issued to cogeneration units (EEG 2004 §8)

The renewable sources bonus was moderately successful. The share of "renewable sources" for bioelectricity production increased from 6% in 2004 to 9% in 2006 (BMU, 2007, p. 83). The technology bonus was more successful. Considering the time lag of planning and construction for new plants, there have been more modern than conventional biomass power units installed since introduction of the bonus (DBFZ, 2011b, p.21.). No exact assessment of the cogeneration bonuses is possible as the choice between pure electricity and cogeneration power unit also depends on the resource availability. Though, in 2008 almost all newly installed solid biomass fueled power plants were cogeneration units (not all were eligible to the full bonus) (DBFZ, 2008, p. 11).

EEG 2009: In 2009 the second revision of the EEG was enacted. Among others the government increased its EEG 2004 target of 20% electricity from RES by 2020 to 30% (Lobo, 2011; EEG 2004 §1; EEG2008 §1). To achieve these targets feed-in tariffs were adjusted again. In particular the subsidy for very small units (<150 kW) was increased. Moreover, the bonuses were changed as follows (TFZ, 2010), EEG 2004, EEG 2008):

- The NaWaRo bonus was cancelled except for very small power units (<150 kw)
- The technology bonus remained unchanged
- The cogeneration bonus was increased from 2 to 3 ct/kWh

As a new tool, direct marketing was introduced. The electricity produced could be sold to surrounding costumers which were exempted from several charges (e.g. ~3.5 ct/kWh EEG charges, 2.05 ct/kWh electricity tax). The distributor in return does not receive the guaranteed feed-in tariff anymore (EEG2008 §27). This rule targets at promoting integrated decentralized concepts. Where electricity is consumed near to the site and thus does not require a distribution grid anymore. However, this tool was rather unsuccessful so far (Bundestag, 2011, p12).

EEG 2012: In 2012 the EEG was revised again. Key elements of the new system were

- an additional incentive for direct marketing
- stronger support for small units (<500 kW)
- a large decrease in subsidies for large power plants (>5 mw)
- cancellation of subsidies for strongly contaminated recycled wood
- additional subsidies for NaWaRo wood from landscape conservancy (instead of composting or burning at landfills and in the landscape, the government wants to promote collection and energetic use)
- cancellation of the cogeneration bonus and replacement by a cogeneration requirement

Because of the short period since introduction evaluations of the current system are not yet available. However, in general the cancellation of the bonuses corresponds to a decrease in the total subsidy. Other changes indicate political will to switch from larger power units to smaller and to promote the use of landscape and forest wood instead of only waste wood.

3.2 Conclusion EEG Act

As shown in the first version of the EEG act pure electricity without cogeneration was also subsidized. Conditions for pure electricity production worsened with every of the four EEG act revisions. Since the last revision in 2012 pure electricity production is only subsidized for existing plants but not for new built power plants. All new built biomass power plants need to be cogeneration units with the primary focus to produce heat in order to obtain subsidies (EEG2012 § 27 Abs.4).

The second crucial policy change in the EEG subsidy scheme was the cancelation of recycled wood subsidies (EEG 2012). Power plants within the 2000 EEG subsidy scheme mostly fuel with recycled wood since this is the cheapest wood available (DBFZ, 2011a, p. 23). Nowadays almost all recycled wood in Germany is used for material or energy production and the government decided to cancel the subsidy. New projects must fuel with other wood categories like forest wood chips or sawmill by-product wood chips. This is particularly important since prices of recycled wood only marginally correlate with prices of forest wood chips and therefore economics of new plants differ from those for existing.

Third, the government favors direct that renewable power station sell their electricity individually on market conditions instead of feeding it in to the public grid for EEG and obtaining the fixed EEG tariff. If incentives for this intention are to be reinforced this will lead to integrated and decentralized energy concepts.

All three policies, the one forcing cogeneration to target at primarily producing heat instead of centricity, the one cancelling subsidies on recycled wood burning, and the direct marketing of electricity favor small (< 5 megawatt electric [MW_{el}]) instead of large (> 5 MW_{el}) biomass power plants. Only few heat costumers have a heat energy requirement large enough to consume all the total heat production from a large centralized power plant. For instance, cogeneration power plants that supply district heating grids for entire city quarters are often not larger than 1-2 MW_{el}. Moreover, recycling wood is collected centrally in large amounts. Other wood categories, in particular forest wood chips, are available in smaller loads. At many locations not enough of these alternative resources are available to supply large biomass power plants.

4 KWK cogeneration act subsidy as promoter for solid biomass cogeneration

KWK cogeneration subsidies apply on all categories of district heating grids: on expansion of existing grids, construction of grids at existing power plants and at completely new projects where grid and power plant are built at the same time. Since the cogeneration subsidy also promotes construction of solid biomass district heating grids, it constitutes a crucial tool for the promotion of solid biomass heating. At greenfield heating grid projects, those with existing power plants and with to be built power plants, solid biomass already has a market share of 18%. At expansion of existing heating grids, it only has a market share of 4% (Seefeldt et al., 2011, p. 42). Expansion of existing district heating grids still makes more than double the greenfield capacity with 1944 MW/a and 795 MW/a respectively. The potential for expanding existing grids is limited and the ratio will turn in favor of greenfield projects in the future (Seefeldt et al., 2011, p. 42). Given solid biomass has an 18% market share at greenfield projects the share of biomass as fuel for district heating grids will be growing in the future.

5 Installation costs wood pellets heaters

Following analyses show that wood pellets heaters are uncompetitive against wood chips heater in the medium size category >100 kW.

As covered in depth in, chapter 5, different sorts of wood based fuels exist. These have high variance of attributes like humidity, size, purity and therefore also prices. To overcome technological challenges in the burning process caused by these differences a standardized product, wood pellets, was developed. Wood pellets consist of wood that is dried to a certain level of humidity and then pressed in a standardized form. This processing makes it much more homogenous then wood chips, a crucial factor for less advanced and small heating units. Moreover, pellets are more compact with a higher energy density than wood chips and wood chips are used where space is limited or expansive. However, as pellets are processed wood chips, they are generally more expansive for medium size heaters on a per MWh than wood chips (C.A.R.M.E.N, 2012).

Clausnitzer (2007) conducted a study that since was the most extensive literature on wood chips and pellets heating cost in Germany for units up to 220 kW. Based on various interviews, data sets and literature he shows that pellets retain their competitive advantage only up to about 120 kW. His findings are summarized following.

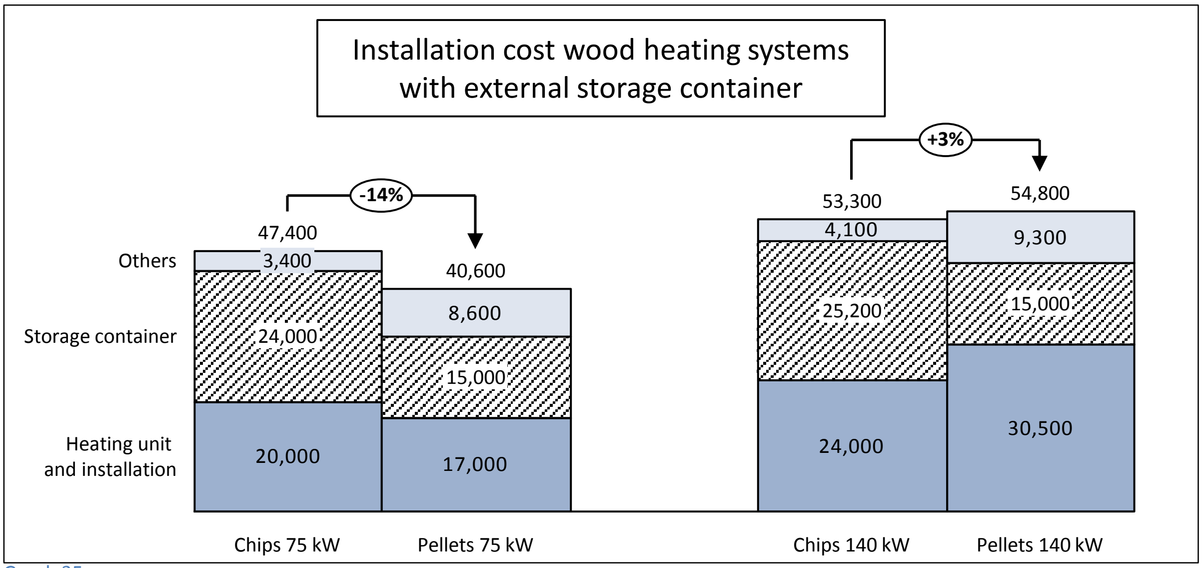
Solid biomass heating infrastructure consists of the heater, the building/heating house, and other components like pipes, the feeding screw[37], security systems etc. Medium and larger units, starting at 100-500 kW also have fossil fuel peak load heater. The biomass heating unit and building are jointly responsible for at least 2/3 of the cost (Clausnitzer, 2007).

Up to a size of 500 kW_{el} the heater is a standardized machine that is manufactured in chain. The same counts for most of the support components. Therefore, up to 500 kW_{el}, the heating unit and its installation cost do not vary significantly between different projects with the same conditions of heating unit size and quality. Cost for heating house and storage, however, vary considerable from one to another project. For instance, heaters can be placed in expansive basement rooms built in massive concrete or on earth in cheap container like buildings. At farms empty barn space leads to almost zero investment cost. Clausnitzer (2007, p. 106) shows that the heating house and storage cost for pellets of 75 kW units vary between a few percent and more than 50% of the project costs.

In order to compare the cost of different heating technologies the storage infrastructure cost needs to be standardized. For this reason the following wood chips and pellets infrastructure cost model is based on the assumption of a popular solution, a pre-manufactured container as fuel silo. Graph 35 shows the results of the comparison according to Clausnitzer (2007) data.

The graph indicates for the 75 kW unit the infrastructure costs for pellets are below that of wood chips. For the 140 kW units it is the other way around.

[37] The feeding screw is the system that transports pellets from the storage to the heater.



Graph 35

Source: Clausnitzer, 2007

At the 75 kW units lower infrastructure cost compensate for the additional cost of using the more expansive fuel. At 140 kW systems the infrastructure cost are almost equal and wood chips heating leads to lower total cost.[38] This indicates the break-even point of wood chips versus pellets is somewhere in the area between 75 kW and 140 kW. Since economic advantages of solid biomass heating systems start in the range of 100-500 kW, wood pellets biomass heating is discussed in this paper anymore.

6 Differences steam engine and ORC cogeneration units

This section this section explains that cost of steam engine cogeneration units are not comparable to on another but those for ORC cogeneration units are. This difference constitutes the reason for limiting research of this paper to the ORC technology.

From a technical point of view the crucial difference between the steam engine and the ORC unit lies in the process fluid. In the steam engine water is heated until it vaporizes and then drives a turbine. In the ORC units a different fluid with lower boiling point is heated to drive the turbine. Since at ORC units the fluid evaporates earlier it can work with lower temperatures in the entire process, an advantage for small-scale biomass cogeneration (below 5 MW_{el}). Among others because of this advantage, ORC, which has still been in

[38] This comparison is only exemplary. Factors as an insecure wood chip supply in a certain region or lower running cost because of a less error-prone technology lets keep pellets its economic advantage sometimes up to level of about 500 kW.

prototype status from 2000 to 2005, has become the most popular technology in Germany for new installed small scale biomass cogeneration units (<3 MW_{el}) (Hennig, 2009).

ORC units as used for biomass cogeneration in Germany work as follows. A large heater, similar or even the same as for standalone heating produces the heat. The heat boils the fluid in the ORC unit, which then converts some of the heat energy into electricity and leaves the rest over as usual heat energy. The heat which comes out of the ORC unit after extracting the electricity has below 100°C and is therefore only suited for basic heating applications like residential district heating. Below 100°C is not suited for most industrial process heating (see Table 7, chapter 3.5).

From a conceptual point of view ORC cogeneration plants consists of two parts, the heater and the ORC unit. Both are designed to be delivered in more or less standardized forms. They are pre-manufactured and then delivered as full units by truck. This means, ORC systems constitute a direct alternative for pure heating. For instance, if a new district heating grid is to be built with a heat demand for 4 MW_{th}, the investor has two alternatives a 4 MW_{th} boiler for producing purely heat and a 5 MW_{th} boiler together with an ORC unit which produces 1 MW_{el} and 4 MW_{th}.

Steam engines are less standardized than ORC units. They are often individual engineered for the demands of a particular client. After extracting the electricity, the left over heat can be above 100°C and therefore be used in many industrial applications (Kralemann, 2011, p. 8). For this reason, they are generally not a direct substitute for usual standalone heater but a substitute for standalone heater engineered for special applications. Thus, because of the different technical specifications comparing economics of different steam engines makes no sense and in the "solid biomass heating economics model" only economics of ORC cogeneration units are investigated.

7 Wood fuel categories

The fuel mix of chapter 5.1 consists of different wood categories. These wood categories are introduced following.

Sawmill by-products

When sawmills process wood less than 50% of the round log ends up as primary product. The about 50 to 60% remaining wood, that is carved of in sewing process, is called sawmill by-product. Two categories of sawmill by-products exist, wood chips and saw dust. Wood chips are the larger particles in form of chips and saw dust is a very fine material. These sawmill by-products are used for material application as chipboard or paper production as well as energetic use for wood pellets or directly as wood chips. Wood chips are used without major limitation in biomass heating whereas saw dust is too fine. Because of its dusty consistency it has a natural gas like burning process, which leads to explosions in the boiler. Therefore, saw dust is processed to pellets before burning and in medium size heaters fueling is generally limited to wood chips.

Forrest wood chips

In the forest industry wood chips are produced at multiple steps of the wood farming life cycle. After a full harvest new trees are planted. In regular intervals of seven to twelve years the new forests are cleaned. In the cleaning process poor quality trees are harvested to generate space to grow for higher quality trees. A major share of the cleaned poor quality trees are not big enough during the first or second cleaning process to be used for industrial applications. Therefore, it is chopped to wood chips. Furthermore, in the final harvest, where high quality trees are harvested, only a certain share of the trunk is big enough to be processed to primary wood products. Secondary quality material as tree crowns, branches or roots are chipped and become wood chips. Forrest wood chips are usually used exclusively for energetic purposes. They contain too much poor quality particles like needles, bark or soil for industrial applications.

Landscape care wood

The rise of the bioenergy industry resulted in a new category of biomass products, the landscape care wood. Landscape care wood is generally divided into two subcategories, roadside greenery and other landscape care wood including city gardening wood. Roadside greenery comes from cleaning the side of roads. Other landscape care wood comes from multiple sources. For instance, these are city gardening as cleaning river coasts, parks and alike, material from farming as apple tree, and some forest wood categorize as landscape care wood. Especially in the forest industry differentiating forest wood chips and landscape care is fuzzy. Differentiation, however, is crucial for the energy industry as subsidies for landscape care wood are higher than those for forest wood chips (EEG 2012).

Differentiation between usual landscape care wood and road side landscape care wood is also important. Proximity to car fumes leads to a different wood consistency of roadside material than other landscape care wood. Concentration of certain elements, as for example chlorine, can lead to problems in the heating process or in fulfilling maximum emission values. Thus, in particular in small heating units' one can usually only use a certain share of road side greenery and needs to mix it with forest wood chips or sawmill by-products before burning.

Recycling wood

Recycling wood is wood that already had been used for other purposes, for instance old furniture, wooden pallets or railroad sleeper. The material is collected at landfills and recycled for further use. Recycling wood is differentiated into four categories of contamination. In Germany categorization from the waste management act is used in practice. These are AI to AIV. AI wood is totally clean material, as for instance wood pallets or transportation boxes. AII and AIII are different categories in the waste management act but considered as AII-AIII in this paper. AII-AIII wood is slightly contaminated recycling wood as for instance, coated pallets or old furniture. AIV wood is highly contaminated wood as for example railroad sleeper, window frames or wood used in industrial applications.

Once collected at landfills the material is sorted into these categories and then chopped for further processing. In particular the cleaner wood categories AI to AIII are also used for industrial applications as particle board production. AIV usually needs to be disposed and therefore is used for energy production in special power plants with very advanced fumes filter technology. Generally recycling wood constitutes the cheapest wood category and therefore is highly demanded in the energy industry. Depending on the degree of contamination one even needs to pay for disposal of recycling wood. However, energetic use of recycling wood is regulated and one requires special licenses to use it (see BlmSchG). In particular small heaters often do not fulfill requirements (as e.g. appropriate filter technology) to use recycling wood. Moreover, energetic use of recycling wood is not subsidized anymore since 2012 (see EEG 2012).

Short rotation plantation

With a growing use of wood for the bioenergy industry, a new method of wood supply has evolved, short rotation plantation. In short rotation plantation wood is grown for a few years and harvested after three to seven years only to produce wood chips. However, this sector is still in the infant stage in Germany. Since wood farming competes with traditional farming for space it is also critically discussed. Nowadays, wood from short rotation plantation is still too expansive compared to alternative sources and thus will not be discussed any further (Müller, 2012).

8 Wood fuel price indices

The Euwid publishes on regular base price indices for different wood products. These price indices, however, do not serve the purpose of this paper in the form they are published. Thus, they were adjusted as follows:

- Most wood energy markets are regional markets. Logistics cost would often exceed potential gains for long distance transports. Thus, most Euwid indices state prices for different categories for regions either south, northwest and northeast Germany or for north and south Germany. For the purpose of this paper the average of regional prices was built to represent a German price.
- For Sawmill by-products (wood chips and saw dust) and recycling woods AI to AIII no single market price exists but pricing depends on contract specific conditions. Thus, the Euwid states only the range of prices for these products. For the purpose of this paper the average of the upper and lower end of the pricing range builds the data point (e.g. upper end 34 EUR and lower end 28 EUR => 31 EUR)
- For landscape care and forest wood chips not only upper and lower end prices are stated but also the weighted average. Thus, for these two categories the weighted average was taken.
- None of the indices states prices in EUR/MWh wherefore they needed to be converted. However, there exists no general conversion ratio because parameters as humidity values, wood types and alike lead to high variations within the same wood category. Hence, conversion values were built as follows:

First, given that different sorts of wood have different energy densities, approximation on the wood type mix were made. The wood mixture is approximated by the ten year average of the German wood harvest. Table 20 shows the German harvest by wood type according to DeStatis (2010b) data. As can be seen over this ten years period Oak corresponds to 3.62%, beech to 17.3%, spruce to 59.36% and pine to 19.73% of the German wood harvest. Therefore, it was assumed that forest wood chips, sawmill by-products, and recycling wood contain approximately these percentages of each wood type.

Year	Oak	Beech	Spruce	Pine	Total
2000	1,677	8,747	34,265	9,021	53,710
2001	1,819	8,957	19,810	8,896	39,482
2002	1,562	7,640	23,977	9,200	42,379
2003	2,068	8,786	30,557	9,771	51,182
2004	2,017	8,668	33,475	10,345	54,505
2005	2,202	8,802	34,590	11,352	56,946
2006	2,484	10,320	37,207	12,279	62,290
2007	2,135	10,981	50,377	13,235	76,728
2008	2,089	10,525	31,576	11,177	55,367
2009	1,688	9,336	26,940	10,109	48,073
2010	1,802	10,176	30,445	11,995	54,418
Sum	21,543	102,938	353,219	117,380	595,080
Sum %	3.62%	17.30%	59.36%	19.73%	100%

Table 20 The German wood harvest by tree types

Furthermore, information on the energy content of the wood types is based on the numbers from Arbeitsgemeinschaft Energiebilanzen EV. This institution surveys the German energy market its publications on energy figures serve as base for several German statistics, including those of the Federal German Office of Statistics. Hence, conversion units are calculated as follows:

Forrest wood chips and landscape care wood

Prices for these two categories are stated in the Euwid in Euros per ton. As humidity values of forest wood chips vary significantly the indices are based on atro prices, prices for absolute dry wood (0% humidity). Table 21 shows how the energy conversion unit of 5.158 for changing Euro/ (atro) tons forest wood chips into Euros/MWh was derived.

Wood type	Oak	Beech	Spruce	Pine	
Weigthing	3.62%	17.30%	59.36%	19.73%	100%
Energy content/t at 0% humidity (atro)	5	5	5.2	5.2	
Weighted energy contribution	0.1810093	0.8649089	3.086541	1.0257041	**5.158**

Table 21 Derivation energy content German wood in tons

Sawmill by-products

Prices for sawmill by-product wood chips and saw dust are stated in Euros per loose cubic meter (lcm). Moreover, because of varying humidity values prices are stated for 0% humidity. Table 22 shows how the energy conversion unit of 0.879 was derived.

Wood type	Oak	Beech	Spruce	Pine	
Sum %	3.62%	17.30%	59.36%	19.73%	100.00%
Energy content in MWh/lose cubic meter	1.142	1.116	0.788	0.896	
Weighted energy contribution	0.041	0.193	0.468	0.177	**0.879**

Table 22 Derivation energy content German sawmill by-products

Recycling wood

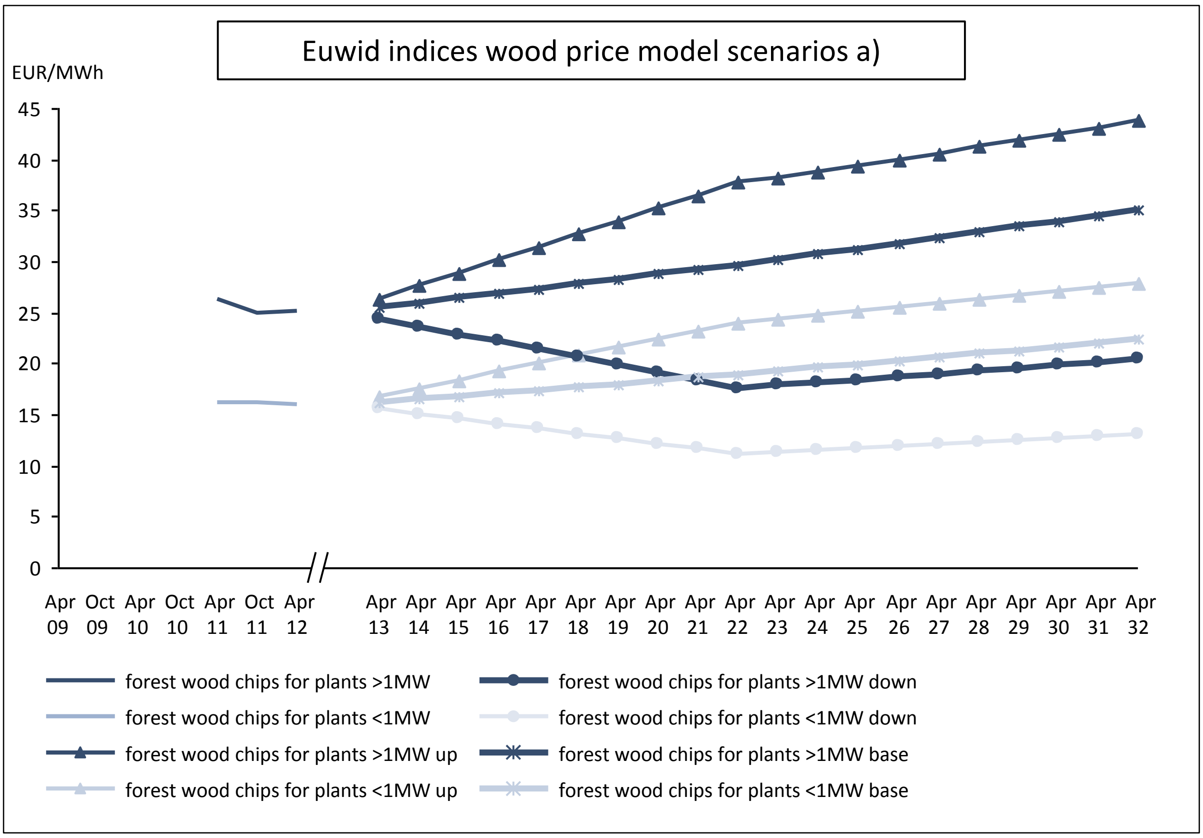
Recycling wood is traded in Euros per tons. Since recycling wood has already been processed it is usually dry. Thus, the Euwid states prices for recycling wood in Euros/per dry lutro ton. Lutro means dry as the air and corresponds to about 15% (FNR, 2007). **Table 23** shows how the energy conversion unit of 4.284 for AI recycling wood was derived.

Wood type	Oak	Beech	Spruce	Pine	
Weighted energy contribution	3.62%	17.30%	59.36%	19.73%	
Energy content/t at 15% humidity	4	4	4.32	4.32	
	0.1502377	0.7178744	2.5642033	0.8521234	**4.284**

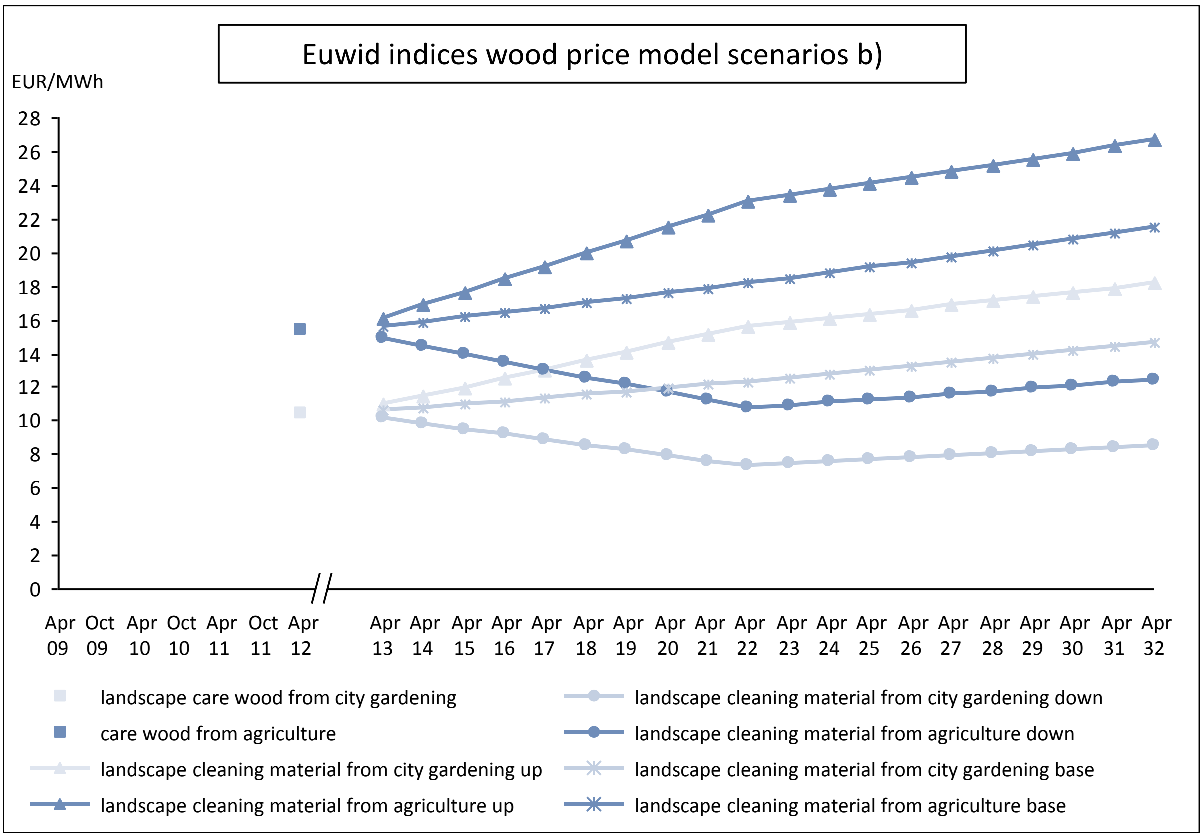
Table 23 Derivation energy content German recycling wood

However, the conversion ratio of 4.284 only corresponds to absolute clean AI material. AII and AIII recycling wood are contaminated wood and contain foreign particles as coting or metals (e.g. nails, or staples). The FNR (2007, p.163) says that AII-AIII recycling wood has about 7.5% of ash compared to 1.5-2.5% for clean wood chips. Ash material that has not been burned in the boiler and thus does did not contribute any energy for conversion. For this reason, the energy content of AII and AIII is assumed at 95% of that of AI recycling wood, corresponding to the 5% (7.5-2.5%=5%) more ash.

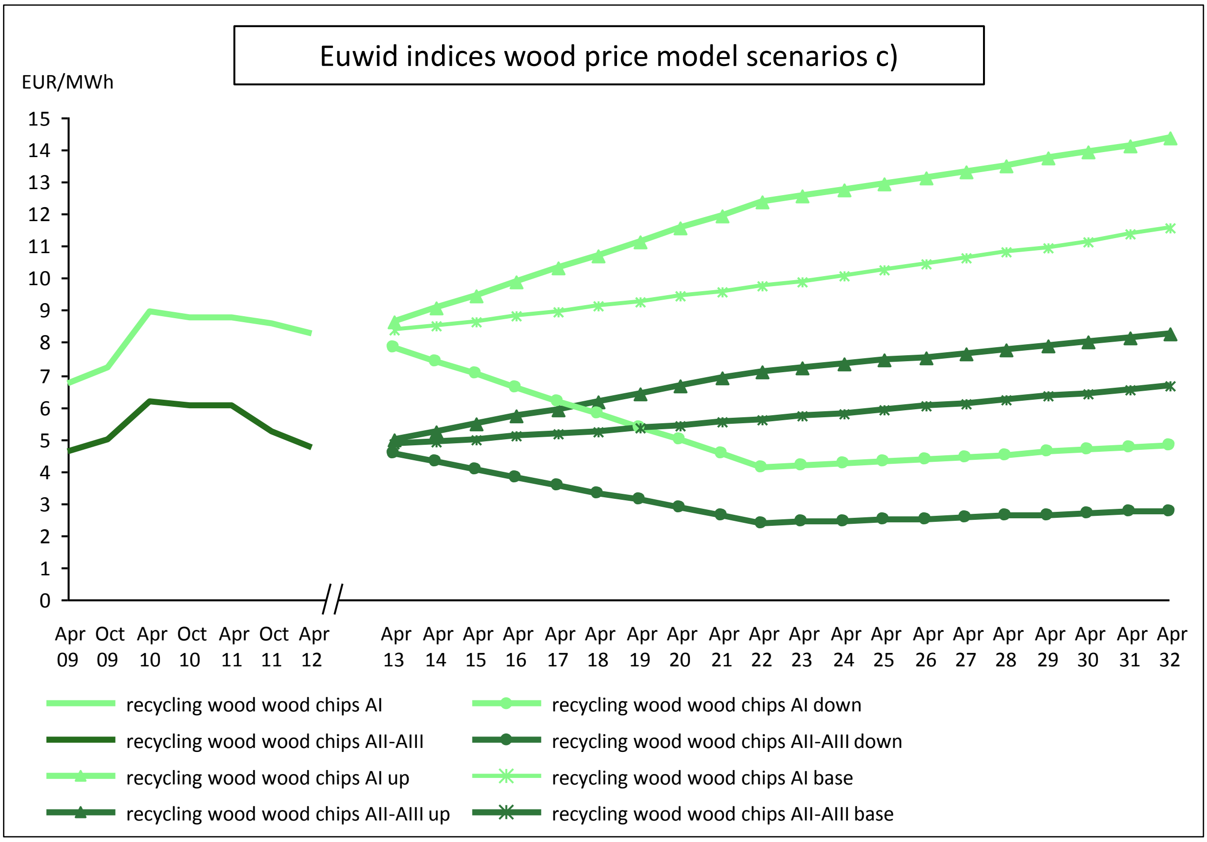
8.1 Wood price scenarios



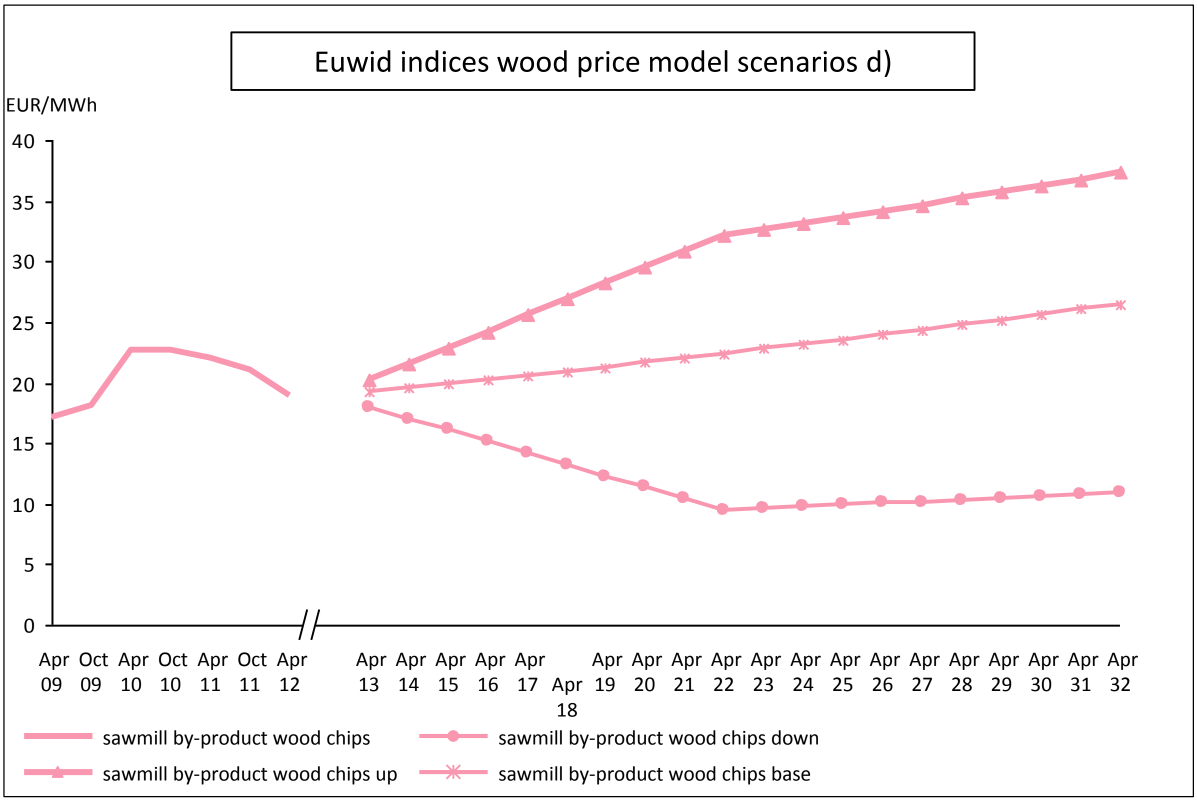
Graph 36



Graph 38



Graph 38


Euwid indices wood price model scenarios d)
EUR/MWh
40
35
30
25
20
15
10
5
0
Apr 09
Oct 09
Apr 10
Oct 10
Apr 11
Oct 11
Apr 12
Apr 13
Apr 14
Apr 15
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Apr 27
Apr 28
Apr 29
Apr 30
Apr 31
Apr 32
sawmill by-product wood chips
sawmill by-product wood chips down
sawmill by-product wood chips up
sawmill by-product wood chips base

Graph 39

9 Calculation feed-in tariff

The following graph shows calculations of the feed-in tariff according to the EEG 2012 and under the solid biomass heating economics model fuel mix assumptions for the cogeneration plant. Calculations are based on the EEG 2012 and DBFZ, 2011b.

Feed-in tariff EEG 2012

Reimbursment	total (€/a)	ct/KWh
Basis tariff	513,714	13.0
EC I	142,643	3.6
EC I (lower ratet)	0	0.0
EC II	126,793	3.2
Total	**783,150**	**19.8**

Basis tariff

Feed-in level	Tariff for category (ct/kWh)	Category cap (kWh)	energy output from category (kWh)	Total sales from category (€/a)	Pro rata reimbursment (ct/kWh)
up to 150 kW	14.3	1,317,600	1,317,600	188,417	4.76
up to 500 kW	12.3	4,392,000	2,644,695	325,297	8.21
up to 750 kW	11.0	6,588,000	0	0	0.00
up to 5.000 kW	11.0	43,920,000	0	0	0.00
up to 20.000 kW	6.0	175,680,000	0	0	0.00
Total			3,962,295	**513,714**	**12.97**

Fuel

Fuel category	Reimbursment (ct/kWh)	Percent of energy (%)	Reimbursed energy (kWh)	Reimbursed total (€/a)	Pro rata reimbursment (ct/kWh)
FC 0	**0**	**0%**	**0**	**0**	**0.00**
FC I ges. up to 500 kW	6.0	60%	2,377,377	142,643	3.60
FC I up to 750 kW	5.0	0%	0	0	0.00
FC I up to 5.000 kW	4.0	0%	0	0	0.00
FC I (bark above 500 kW)	2.5	0%	0	0	0.00
Total FC I		**60%**	**2,377,377**	**142,643**	**3.60**
FC II	**8.0**	**40%**	**1,584,918**	**126,793**	**3.20**
Above 5.000 kW	**0.0**	**0%**	**0**	**0**	**0.00**
Total		60%	3,962,295	269,436	6.80

Graph 40