Biomass Boilers in the Netherlands

an adopter decision perspective

Final version

UNIVERSITY OF TWENTE.

NBKL

Nederlandse vereniging van Biomassa Ketel Leveranciers

MASTER THESIS

Paper and documentation

N.H.M. (Nick) Oude Vrielink BSc.

N.H.M. (Nick) Oude Vrielink BSc.
University of Twente, Faculty of Engineering Technology
Department of Construction Management & Engineering

Graduation Committee

Dr. ir. A.G. (Bram) Entrop
University of Twente, Department of Construction Management & Engineering

Prof.dr.ir. J.I.M. (Joop) Halman
University of Twente, Department of Construction Management & Engineering

External supervisors

Dr. ir. E.E. (Eppo) Bolhuis
Nederlandse vereniging van biomassa ketel leveranciers

24-7-2017

Preface

This research is the final proof of competence in obtaining the Master of Science (MSc.) degree in Civil Engineering Management (CEM), at the University of Twente. This research has been assigned by the 'Nederlandse vereniging van biomassa ketel leveranciers' and was executed at Tubro Filter-, Lucht- en Verbrandingstechniek. The supervision from the University of Twente was done by dr. ir. A.G. Entrop from the Platform for Research on Energy for a Sustainable Built Environment (PRESBE) and prof. dr. ir. J.I.M. Halman. The supervision from the NBKL was done by dr. ir. E.E. (Eppo) Bolhuis.

The research is shaped in the form of a research paper, which is presented to the reader in the next part of this report. The conducted research focusses on the adoption of biomass boilers in the Netherlands, and the factors influencing that adoption. I hope that this research can contribute to the diffusion of biomass boilers and thus improve the sustainability of the Dutch buildings.

Enschede, 02-06--2017
Nick Oude Vrielink

Management Summary

This research paper is about the adoption decision of potential adopters for biomass boilers in the Netherlands. Biomass boilers are promoted by the European Union and the Dutch government as environmentally friendly energy sources. In the Netherlands, this technique however, is not as widely used as in other countries. The main reason this research has taken place is because a lot of potential adopters decline to use biomass boilers. This is due to the fact that biomass boilers can provide an environmentally friendly alternative to fossil fuels. Currently the Netherlands is a long way behind in the amount of sustainable energy produced if compared to other European countries. Therefore biomass boilers can help creating the sustainable economy that is pursued by the Dutch government and the European Union.

The main question and several sub-questions are answered in this paper, to get an insight into the adoption decision of a biomass boiler. The main question is:

What is the perspective of potential adopters in the Netherlands on biomass boiler adoption?

First, a literature study has been carried out to determine the relevant factors for other environmental techniques and measures and the relevant factors in other European countries. The found factors were verified empirically, by interviewing adopters, non-adopters, suppliers and other actors in the sector for biomass boilers. In total, 24 interviews were held to verify the factors for the Dutch biomass boiler situation. This has led to several relevant factors and barriers for adopting biomass boilers. The main relevant factors found in the literature were the payback period, the biomass availability, the social acceptance, the missing knowledge and clear and stable legislation. Especially the payback period was emphasised in most researched papers.

A biomass boiler has some effects for the adopter such as lower fuel costs, higher investment costs, more maintenance, lower reliability and a lower carbon footprint. For every potential adopter these factors weigh differently, but some are more important than others for the adopters. Some of these effects are solved by using the right supplier, who can provide a carefree package, which includes operation and maintenance of the installation. This however, does requires substantial financial resources, making the project less profitable. Other adopters value the financial viability more and choose to do as much work as possible themselves. Because of the vast diversity of biomass boilers and their applications, there is not one standard implementation effect for adopters of a biomass boiler.

Most interviewed adopters consider a biomass boiler as a ‘green’ choice because of the low carbon footprint compared to other heating techniques. However, there are also people who do not have such a rosy view on biomass boilers. For example, the origin of the fuel is questioned as well as the air-quality around those boilers. Some neighbours are afraid of nuisance in the form of smoke and pollution. A lot of these fears are not well funded and can be partially prevented by providing good information. Other concerns such as the origin of the fuel can be ensured to be sustainable by using quality marks proving the wood comes from, for example, a well maintained forest or waste wood. These negative sounds can be traced back to the stories from the suppliers, while also a the non-adopters were critical towards the sustainability of biomass boilers.

The 24 interviews that were held are sufficient to get a clear view of the adoption decision, seen from several perspectives. During the interviews, some factors appeared not as important as the literature suggests, while other factors were confirmed to be important. The payback period was leading for most adopters. They often claim to buy a biomass boiler for other reasons, but if the payback period is too long or if the installation does not pay itself back at all they will not adopt a biomass boiler. That does not mean the other factors are not important, but according to the interviews, the financial viability is decisive in de adoption decision.

The following factors are identified as the most influential in the adoption decision for a biomass boiler installation:

- Subsidies / tax concession / feed-in tariff (such as SDE+, ISDE and EIA)
  - These ensure the financial viability of a biomass boiler is positive enough to adopt.
- The cost of gas/oil/etc. compared to biomass
  - If other fuels are more expensive, biomass gets more financially viable.
- Investment costs (payback period)
  - Currently, biomass boilers seem to be far more expensive in purchase than other techniques.

- Biomass availability (at competitive price)
  - Some actors are afraid that there is not enough wood available for sustainable fuel.
- Social acceptance/awareness
  - Not all potential adopters think of a biomass boiler as a sustainable alternative. As long as that is the case, they will never adopt such an installation.
- Missing knowledge (about operating)
  - If it is not clear how much work a biomass boiler requires to operate and maintain, potential actors will not adopt a biomass boiler
- Clear and stable legislation (for example emission requirements)
  - If the emission regulations, for example, get tightened often, the installation also needs to be upgraded regularly. This is something that is feared mainly by the suppliers.

If biomass boilers become more familiar to the general public, the possibility of potential adopters becoming adopters will grow. The potential is there because many adopters who were interviewed were very satisfied with their installation. However, there exist barriers and a biomass boiler cannot be applied in every situation. This means that projects need to be selected carefully before they are initiated and executed. As a general rule, the higher the heat demand gets, the better the financial viability.

The sector has to promote themselves more actively towards potential adopters. The focus must lie with companies who have a high heat demand and companies that pursue a green image. There are still many chances in areas that are not yet fully aware of the possibilities of biomass boilers. The easiest are the companies which have a stable high energy demand, but even the the energy demand varies, the latter can be solved by using heat buffers. Therefore there are chances in, for example, district heating, offices, industry and argricultural applications.

Some adopters buy a biomass boiler for its environmental impact, some for the image of their company and others for the money they save. How these factors are divided exactly cannot be answered based on the interviews held for this research. Because the financial viability is relevant for all adopters, mainly the sectors which have a high heat demand have an enormous potential for biomass boiler adoption. The high investment costs which have to be earned back are the main reason this high heat demand is needed. It can be concludes that the perspective of potential adopters in the Netherlands on biomass boilers is very diverse, but it can be influenced by providing better information.

Table of Contents

Definitions

Biomass boiler	-	A boiler that runs on wood chips or pellets, (in this research) ranging from an output of 100 kW up to 10 MW
(Wood)pellets	-	Compressed (wood/timber) matter used as fuel
RET	-	Renewable Energy Technique. In other words, an technique that reduces the fossil energy use.
NBKL	-	Dutch Association for biomass boiler suppliers (Dutch: Nederlandse vereniging voor Biomassa Ketel Leveranciers). The NBKL is the voice of all the suppliers of biomass boilers in the Netherlands
RVO	-	The Netherlands Enterprise Agency (Dutch: Rijksdienst voor ondernemend Nederland), the Dutch executive organisation for the ministry of economic affairs
Principal	-	The person who makes the adoption decision.
Adopter	-	A person who takes up something. In this paper, a person who has bought a biomass boiler.
Potential adopter	-	A person who might adopt a biomass boiler, because of a promising situation for adoption. This person might already have considered a biomass boiler but has not yet decided to buy one.
ESCO	-	Energy Service Company, a company that delivers energy such as heat in the form of hot water/steam. This creates a carefree package for the user because the installation is maintained and operated by the ESCO [1].
EPI	-	Energy Performance Index, an index that indicates the energy performance of a building or process compared to a set standard. This is calculated by a pre-set formula [2].

UNIVERSITY OF TWENTE.

NBKL
Nederlandse vereniging van Biomassa Ketel Leveranciers

Research Paper
Biomass boilers in the Netherlands: an adopter decision perspective

Nick Oude Vrielink BSc.

Department of Construction Management and Engineering, University of Twente

Abstract
The individual adoption decision for biomass boilers is the focus of this research. This research has been conducted in order to get a clear understanding of how the market for these boilers in the Netherlands can be improved. The main factors influencing the adoption decision are determined by a literature study and by interviews. This has led to the insight that multiple factors are relevant, such as the reliability of the installation, the reliability of the fuel supply, the level of social acceptance and the awareness and legislation on biomass boilers. These factors are all important, but of most importance is the financial viability of the project. If the payback period is short enough, most potential adopters proceed to adopt a biomass boiler installation.

1. Introduction

The use of renewable energy techniques is slowly gaining popularity in the Netherlands. However, the diffusion of these techniques is still behind most other European countries. If the Dutch government wants to reach its goal of 14% renewable energy in 2020, a lot has to change [3]. In 2050 the whole European Union even has to be carbon neutral. In 2016 the total amount of renewable energy in the Netherlands was only 5,9% [4].

The prime focus on renewable energy is currently in solar and wind energy. If the media mentions renewable energy, it is mostly about solar or wind electricity. However, not all fossil energy can be replaced by these types of energy. These techniques generate electricity, while the largest portion of the energy use in the Netherlands is taken by heating. Heating takes up to 39% of the total energy use in the Netherlands [5], of which about half goes towards high-temperature applications for which biomass and fossil fuels are currently the only options. For low-temperature applications, heat pumps are also a possibility. Therefore, the focus cannot be completely on solar and wind energy. Biomass could have a place in the energy transition. The heating is also the part of the energy usage in which the most environmental profit is gained because it concerns the largest part of the energy use.

This paper contains the findings of the research that is conducted. The research focusses on understanding how the adoption of biomass boilers in the Netherlands takes place and to determine if and how their adoption rate can be improved. The main reason for researching this now is because of the improvement of biomass boiler adoption in the upcoming energy transition.

Biomass is a form of renewable energy. Due to the carbon cycle, the carbon footprint of biomass is presumed zero. In consequence, biomass can help in reducing the carbon footprint in the Netherlands. Although biomass also causes other emissions, such as Nitrogen oxide, the regulations in the Netherlands are stringent, and so the biomass boilers covered in this research are not significantly affecting the air quality in the Netherlands.

A biomass boiler also has an effect on the user comfort. Such an installation is not as straightforward in usage as some other techniques, because the fuel needs to be refilled regularly and the ashes need to be removed. The installation runs itself, which means if the fuel bunker is filled, it automatically starts heating when needed. The fuel is cheaper than natural gas, which is most commonly used in The Netherlands. The price of biomass is about half of that of natural gas per kWh [6]. Other widely used techniques are gas boilers, oil boilers and heat pumps.

Oil boilers are comparable to biomass boilers, because they also need to be refuelled periodically and are therefore comparable in usage. Gas boilers are almost always connected to the gas network and are hence refuelled automatically. They also need very little maintenance. The final alternative is the heat pump. These types of installations are not suitable for high temperature heating purposes because they cannot heat water to high temperatures. However, a heat pump has low maintenance costs and if combined with, for example, solar panels the energy bill is very low.

2. Research Setup

To provide better insights into the adoption of biomass boilers in the Netherlands, the following research questions are answered in this paper.

What is the perspective of potential adopters on biomass boiler adoption in the Netherlands?

The research consists of two parts, the theoretical and empirical part. In the end, both are combined to create the best possible view on how the adoption of biomass boilers in the Netherlands takes place and how this can be influenced. The theoretical research is used as a stepping stone towards the empirical research. The used adoption-decision model is retrieved from the theoretical research, and the initial factors used during the empirical research are found in the literature as well.

The literature research encompasses multiple ETM's, not necessarily biomass boilers, and multiple European countries. For other techniques, a similar decision needs to be made. Therefore, the influencing factors and barriers are comparable and interchangeable.

The adoption of biomass boilers can be compared to the adoption of other renewable energy techniques. The adoption of those techniques also has an influence on the energy usage and comfort of the adopters. Because of these similarities, it is useful to look into possible barriers of adopting these other techniques.

The comparison is made by reviewing papers discussing the adoption of renewable energy techniques. Different papers were analysed, where central focus was put on the adoption of a renewable energy technique. If findings are the same between different papers, such as certain important influencing factors and possible barriers, they might also apply for the adoption of biomass boilers. This gives an indication of what should be researched for the adoption of biomass boilers. The used papers can be found in the references [4 – 39].

Another way of identifying possible influences of adopting a biomass boiler is to compare problems and solutions found in other countries regarding the adoption of biomass boilers. Compared to the Netherlands, some European countries have a much higher diffusion rate. Since it is possible that some barriers to adopting biomass boilers have already been overcome in these countries, these markets have already matured more than in the Netherlands. This means that it is necessary to examine their found barriers because they can be quite similar or even the same as in the Netherlands.

The empirical research consisted of interviews with the suppliers, adopters and non-adopters. Also, the head of the department of the RVO (Netherlands Enterprise Agency), who is responsible for the subsidy on biomass boilers, was interviewed. The findings are the result of all interviews held and the literature findings because the interviews were based on the findings in the literature. The interviews consisted of the following sample (Table 1):

Table 1 - Interview sample

STAKEHOLDER	PARTICIPANTS
SUPPLIERS	10
ADOPTERS	9
NON-ADOPTERS	3
RVO	2
TOTAL	24

Firstly, the interviews with the suppliers were held. These interviews were not only aimed at retrieving their own views on the adoption-decision, but also on their view on how potential adopters make their decision and what the most important reasons are to adopt or not adopt a biomass boiler. This ensured a broad view of the sector, and because the suppliers mostly ask their customers why they accepted or declined their offer, it gives a general view on potential barriers.

Secondly, the adopters were interviewed to gain a detailed insight into the reasons for adopting.

During every interview, the same questions were asked, but in-depth follow-up questions were used to determine if their initial answer really was the most important factor or reason. The general questions were used to determine if the factors previously found during the literature study are applicable in the Dutch cases, while the follow-up in-depth questions were used to ensure no factor was missed during the interview. The follow-up questions also gave a better insight into why certain factors are important to that potential adopter.

Lastly, for the non-adopters the interviews were held in the same way as with the adopters. Some of the questions, however, were answered exactly reversed. For example, the main reason why someone has bought a biomass boiler becomes the main reason why someone has not bought a biomass boiler.

Once all information from the different interviews and the theoretical research was gathered, the synthesis could take place. This was put in the adoption-decision model to explain the adoption decision for a biomass boiler in the Netherlands. This leads to finding the most important factors, which influence the adoption decision and the most important barriers, hindering a positive adoption decision. This model can be used by the RVO and the sector to improve the adoption of biomass boilers in the Netherlands and by that increase the amount of renewable energy used in the Netherlands.

Table 2 – Factors mentioned during interviews

FACTOR	TIMES MENTIONED
LOW MONTHLY COSTS	7
HIGH MONTHLY COSTS	5
SHORT PAYBACK TIME	7
LONG PAYBACK TIME	7
RELIABILITY	5

During the interviews, all interviewees were asked for the most important factors for adopting, or not adopting a biomass boiler. These factors can be found in Table 2.

3. Theoretical framework

To determine which framework is most suitable for this research, the initial literature study has been performed. This has led to the factors influencing the adoption decision according to the literature and according to studies performed abroad. The literature study not only focussed on biomass boilers but also on other ETM's because a similar adoption decision has to be made with those other techniques. Therefore, it is expected to find the same factors and barriers influencing this decision. Twenty-one different influencing factors have been identified from thirty-two different studies. A few factors were mentioned in several studies and thus deemed more important than the factors which were only mentioned in a single study.

Also, several studies about the adoption decision of a biomass boiler have been reviewed. There were twelve studies in twelve different countries in Europe that have been used to determine the factors that are relevant for the adoption decision. This has led to fourteen factors. Some of these factors have an overlap with the earlier mentioned twenty-one factors. During the interviews these factors were verified, resulting in the most influential factors mentioned in Table 2. On their own, however, these factors do not explain anything. That is why the adoption-decision needs to be analysed in a model.

According to different studies, not only the financial viability of a biomass boiler is important, but also some other factors which are difficult to calculate in advance. For example, the reliability of the fuel supply, the social awareness and acceptance, and the presence of clear and stable legislation are included in the adoption decision.

The reliability of the supply is something several principals point out as a problem because their company needs to operate continuously during work hours. Otherwise, they will lose profit. Also, some principals, who provide energy for their customers have to pay fines if the supply of hot water or steam is problematic due to an unreliable fuel supply.

The social awareness and acceptance are also important according to the reviewed literature. This can be because customers demand a 'green' image from their supplier or because the principal wants to have an environmentally friendly energy source because of environmental awareness. This can hinder the adoption of biomass boilers, but can also boost the adoption.

The presence of clear and stable legislation and regulations is important in the adoption decision according to several researched articles. If the regulations vary a lot in time, it is difficult to earn back the investment costs before new investments are needed. This can hinder the adoption of biomass boilers.

The framework, as proposed by Entrop [2, p. 16] is used as a model to explain the different relations between the identified factors and the adoption decision. The framework used is straightforward but comprehensive enough for this research. The framework can be found on the next page in Figure 3.

The framework proposed by Entrop fits best in the purpose of this research because it is straightforward enough for a small market such as the biomass boiler sector in the Netherlands. Because the market is small, not much data is available to validate a complex framework. This is why the framework of Entrop is suitable for this research. Other frameworks have been looked analysed, but this one fits the research the best. Furthermore, this model not only gives an insight into the technical aspects of an adoption decision, but it also provides the context in which the decision is made. Of course, the technical aspects are important, but the context determines what can be the final push for a positive the adoption decision. The framework consists of three parts.

The factors mentioned in Table 2 all can be fit into the model as proposed by Entrop once validated and supplemented by the empirical research.

4. Analysis

The findings are first explained by providing the most important factors as mentioned by the different interviewees. Then this is explained in the Model of Entrop [2, p. 16] using the same structure.

It is also assessed in the literature in which sector the most biomass boilers are placed by the suppliers. This is the Agricultural sector, followed by the Housing and Construction sector. This is mainly due to the high and stable energy demand in these sectors [7]. Also in the agricultural and construction sector, it is common that the companies have their own fuel supply. Their fuel is very cheap because they have it readily available, shortening their payback period and monthly costs. This has been mentioned multiple times during the interviews. On average, the payback period is estimated to be 6 years for the suppliers. About 30% of all offers from the suppliers lead to adoption, and in an estimated 25% of all projects, the environment is a factor in the decision. About a third of all interviewed principals also mention the visibility of their 'green' choice to adopt a biomass boiler as a factor. Given reasons for not adopting are a relatively long payback period and a low reliability. These factors were mentioned by 70% of the suppliers and the payback period was mentioned as important by all adopters and all non-adopters. If the payback period is too long, the heat demand is too low to compensate for the high investment costs. This is why the heat demand of a company is often decisive in the adoption decision. It is mentioned a few times that, even though a company wanted to invest in an environmentally friendly technique, a biomass boiler was not bought because of the long payback period.

During the interviews, the suppliers were asked to mention the positive and negative factors that are relevant for the adoption decision. The results of this question can be found in Figure 2.

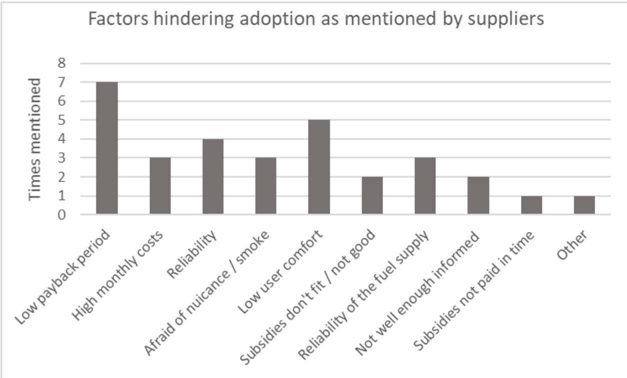


Figure 1 – Relevant hindering factors according to the suppliers

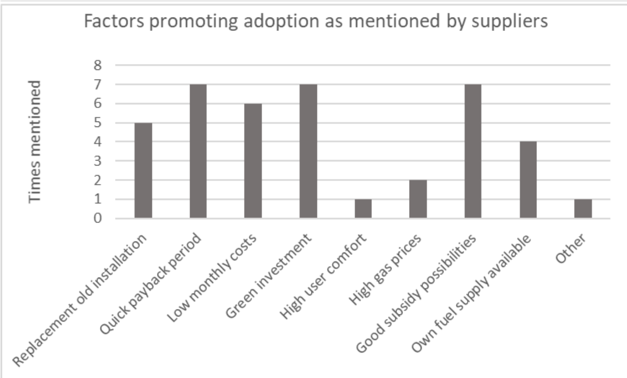


Figure 2 - Relevant promoting factors according to the suppliers

As seen in Figure 1 and Figure 2, the payback period, the user comfort and a green investment are factors often mentioned by the suppliers. The subsidies and high gas prices, however, are relatively less important, although it must be mentioned that these do influence the payback period a lot. Thus, indirectly they are still relevant.

Implementation potential of an biomass boiler

4.1. Asses the energy performance

4.1.A. Asses the effects of the ETM on the actual energy use of a building and its users, taking into account:

- Environmental characteristics;
- Occupational characteristics;
- Building characteristics;
- System characteristics;
- Influence of appliances/machines.

4.1.B. Asses the effects of the ETM on the theoretical Energy Performance Indicator (EPI) of a building:

- For new buildings use the EPC;
- For existing buildings use the EI_{new};
- Try avoid using EI_{old}.

4.2. Asses the financial impact

4.2.A. Asses the investment costs of the ETM in a building:

- For optimizing and adapting design;
- For physical products(s);
- For transport and installation.

4.2.B. Assess annual cash flows related to the ETM in a dwelling:

- Regarding energy costs;
- Regarding maintenance;
- Regarding reliability;
- Regarding user comfort;
- Regarding rebound effect;
- Regarding building value.

4.3. Assess stakeholders' interests

4.3. Asses the interests of the stakeholders to develop a strategy adapted to the institutional context by taking into account the:

- Design implementation by architects, advisors and principals focusing on project specific advantages and disadvantages of the ETM;
- Physical implementation of the ETM by contractors and principals in new and/or existing buildings;
- Marketing implementation by principals and owners based on the ETM's selling points in the project;
- User implementation by owners and residents reflecting the usage and maintenance of the ETM in the building.

Figure 3 - Framework as proposed by Entrop [2, p. 16]

4.1.A: Assess the effects of the ETM on the actual energy use of a building and its users

The environmental characteristics of a building can be important for biomass boilers. Several interviewees pointed out the nuisance of transport movements and air pollution, although this was not a standard question. About a third of the interviewees mentioned it as a relevant factor, whilst thinking about possible barriers. Therefore in an urban environment, these aspects need to be taken into consideration. To avoid too much nuisance, it is recommended to use a pellet boiler and not a chip boiler, because wood pellets are compact and need fewer transport movements. Pellets also burn cleaner than wood chips. If the boiler is well maintained and if it does not have to do a lot of start-up cycles, the nuisance for the neighbourhood is insignificant. If the boiler is not installed properly and the correct fuel is not used, there can be a nuisance issues for the neighbourhood. There are some examples of boilers which do cause nuisance, but in all these cases the installation does not function properly due to a bad boiler, bad installation or bad fuel. For a biomass boiler to operate correctly, it is necessary the fuel has a consistent moisture content and does not contain to many pollution such as sand.

The occupational characteristics of the building are important because the power of the installation depends on this. If the building needs a lot of heating, the installed boiler should have more power. However, if a boiler is too large for its demand, this will require too many start-up cycles and there will arise technical problems within the boiler itself. This means the advice of the supplier is very important to prevent problems.

Building characteristics influence a biomass boiler because these characteristics fuel the heating demand of the building. This means these characteristics also determine what power the biomass boiler should have and how large the heat buffer should be. If there is a lot of variation in the heat demand, a larger buffer is recommended.

The system characteristics are not very important because a biomass boiler can easily be connected to most existing heating systems. Thus the system characteristics of the building are expected not to be a decisive factor in the adoption decision for this reason.

The influence of appliances can affect the heating demand of the building. This influences the type of biomass boiler needed. Also, biomass boilers can be used for heating processes in factories or for hot tap water. This also influences the power of the installation. If there are machines in the building which require such heat, a larger biomass boiler is probably needed. This biomass boiler then produces hot water for lower temperature processes, or steam for higher temperature demands.

4.1. B: Assess the effects of the ETM on the theoretical EPI

All buildings need an EPC to ensure their footprint is within regulations. In new construction projects, it can be essential that the biomass boiler is also weighed in the EPC, because if it does not count for a lower EPC, why should a biomass boiler be installed. Currently, the use of a biomass boiler is not standardised into the EPC. However one can request an equivalence. This means that biomass boilers have the value zero [8]. In other words, a biomass boiler does not impact the environment at all in this calculation model. The model calculates everything in carbon dioxide, and the carbon emissions of a biomass boiler are assumed zero. This equivalence can be requested for all biomass boilers which fall within the 'activities decree' (Dutch = activiteitenbesluit). For biomass boilers that do not fall within the activities decree, the value 0,5 can be used. Currently, the rules are being changed, and it is announced that the use of a biomass boiler will be standardised within the EPC rules. This means it can be a huge incentive to use a biomass boiler instead of a natural gas boiler because a biomass boiler helps meeting the prescribed maximum carbon emission rules in construction projects.

4.2. A: Assess the investment costs of the ETM

The optimising and adapting of the design of the installation for the specific situation is important with biomass boilers, because of the high investment costs compared to other techniques. This is mentioned by all interviewees; even the non-adopters mentioned this as important. Also, the power of the boiler should 'fit' with the heat demand of the building and its installations. It can save a lot of money if the optimising of the boiler is properly done. The costs of optimising are relatively low because every supplier has standard formulas for determining the power of the boiler and the capacity of the heat buffer.

The physical product is the largest expense in the whole project. Such an installation is far more costly than a natural gas boiler. This can be earned back by cheaper fuel costs [9]. However, it is still a barrier for some potential adopters. The non-adopters who were interviewed all stated that the investment costs were too high for the cost-benefit analysis to become positive. This was also stated by all the suppliers and the RVO, most potential adopters who become non-adopters think the investment costs are too high. There are incentives for adopting a biomass boiler. For the installations smaller than 500 kW this consists of an investment incentive (ISDE subsidy). This is a fixed amount paid by the government once the installation is installed. Also, a tax exemption is available, in which the biomass boiler is tax deductible. This is also available for larger installations.

The transport and installation costs of small boilers can be considerable, but in the range this research focusses on (100 kW – 10 MW) which is not significant enough to withhold a company from adopting a biomass boiler. If the biomass boiler does not fit into the existing building, the costs can be an issue. Then an extension is required for housing the boiler and the fuel bunker. Also for biomass boilers larger than 140 kW, a fireproof boiler house is mandatory.

4.2. B: Assess annual cash flows

The energy costs of a biomass boiler are lower than the expenses for other techniques. This is one of the reasons most adopters have chosen for a biomass boiler. However, this has to outweigh the investment costs in the long run to get a positive business case. The energy costs can get even lower by using a subsidy, which is available for the boilers larger than 500 kW (SDE+ subsidy). This subsidy is paid proportionally to the amount of heat produced by the installation. This subsidy is for twelve years [10], which ensures low energy costs for those twelve years. The importance of financial viability is rated a 2.8 on a scale of one to five by the adopters themselves. Nonetheless, the suppliers often mentioned that the financial viability is a large breaking point for a lot of potential adopters. The most mentioned reason for non-adopters is the long payback period. This is also backed by the suppliers, of which 7 out of 10 have mentioned this as the main barrier. However, all adopters have mentioned the low costs as the most important factor for adopting a biomass boiler.

The maintenance costs of a biomass boiler are not very high, although still higher than for other techniques. This explains why the maintenance costs were never mentioned during the interviews.

The reliability of a biomass boiler is generally lower than for other techniques such as natural gas or heat pumps. This is partly because wood is a somewhat difficult fuel, which means a malfunction is more likely to occur. Gas, for example, is a homogeneous substance which can be easily pumped through pipes, whereas wood is a solid fuel with not always the same size and weight. Also, an often mentioned problem with wood is that it can contain contaminants such as metal or sand. Especially wood chips are not always of the same quality, while wood pellets are tested and only approved pellets are used by most adopters.

Often if a natural gas installation is replaced by a biomass boiler, the old installation is kept as a a backup. This improves the reliability compared to the old situation, due to the extra installation. The reliability is very important for some sectors, such as the industry in which the factory needs a biomass boiler to run, or in the housing sector in which people would like their homes to be heated and have warm water. The reliability of biomass boilers is mentioned by half of the suppliers as an important barrier. Of the adopters, only two mentioned reliability as a factor.

The user comfort is often the same for a biomass boiler and another type of installation, which means the user comfort is not relevant in the adoption decision. The user comfort is the same because the only thing different is the installation that generates the heat. However, only biomass and fossil fuels can reach higher temperatures. This can be perceived as a higher level of comfort by some users. The operating and maintaining of the installation requires more work than some of the other techniques, but this is not something the average user has to deal with. That is something covered by maintenance. Pellet fuelled boilers are more reliable than woodchip boilers. Pellets are a more homogeneous fuel and less likely to be contaminated with dirt or metal. The chance of a breakdown is smaller with wood pellets. In sectors in which the reliability is important, often pellets are used instead of woodchips. There is, however, a point of comfort which is relevant. If a biomass boiler is compared to for example a heat pump, the temperature which can be achieved by a biomass boiler is much higher.

For this reason, the comfort of a heat pump is lower, because the heating demand cannot always be met.

The rebound effect is seldom relevant because users do not have to adjust their behaviour for a biomass installation. In some cases, where the gas installation is still available, it is possible to use more gas and less biomass. This can be a decision based on the gas prices and user comfort. This means that the rebound effect is relevant sometimes.

The building value will not be affected significantly by a biomass boiler. Consequently, this is also not a relevant factor in the adoption decision. Although it is asked during the interviews, no interviewee mentioned that the building value would increase enough to be of relevance.

4.3.: Stakeholders' interests

The *design implementation* is can be problematic for some adopters, but for others it is not an issue at all. This depends on the sector in which the installation is installed, but also the environment in which it is installed. In an urban environment, it is almost always designed in a way that the fuel bunker is integrated into the building or in a cellar, while in an industrial or agricultural environment the fuel bunker is often built next to the building or even put in a shipping container or silo. Also, some adopters want to show their installation to everyone, while others want to put it away in the basement. Therefore many options are available, and it is not possible to state one simple solution for all adoption decisions. Furthermore, the nuisance of smoke can be something to be considered in an urban environment, while in an agricultural environment this poses no problem.

The *physical implementation* is often an issue for biomass boilers due to the fact that a boiler room is often built for a much smaller natural gas boiler. A biomass boiler is usually a multiple of the size of other installations. The space in existing buildings needs to be large enough or needs to be extended for a biomass boiler to fit. The fuel bunker also needs to be implemented, costing even more space. In an industrial or agricultural environment this is often not a problem, but in an urban environment where space is scarce, this can be an issue. Therefore in many cases in urban settings it is an issue, while it is not a relevant factor in industrial or agricultural settings.

The *marketing implementation* is for most of the interviewees not a factor. However, some mention it as important. Most interviewed suppliers have only one or two specific sectors from which they gain their customers. To supply other sectors, the use of biomass boilers has to be marketed better in those other sectors. They mention it is important to their customers that they have an environmentally friendly production. By the suppliers, it is estimated that about 35% of all clients think the visibility of their installation is necessary. The adopters themselves rated the importance of visibility 3,8 on a scale of one to five. Some adopters are obligated to have ETM's in their buildings. Otherwise their customers will not buy their products anymore, which might explain the high perceived importance. Another point often mentioned is the discussion of the renewability of biomass. Many adopters state the source of the biomass is very important. In the media, critics state biomass is not durable, and whole forests are being cut down to fuel or biomass boilers. This affects the adoption decision, because if the source of the wood is not 'good' (not a well-maintained forest), then the biomass boiler itself is not environmentally friendly. It can be stated that biomass from a European source is mostly from well-maintained forests. The amount of forest in Europe is even growing fast enough to fill a Belgium-sized forest every two years [11]. This is also a point often mentioned during the interviews. In the general media, biomass has been put in a bad light in the Netherlands. Because of that bad image, a lot of explaining needs to be done by the sector to convince potential adopters that biomass can be a good fuel source without harming the environment, even helping the environment. This is also concluded by van den Hoogen [12], who states wind- and solar-energy are perceived as 100% clean, while biomass is largely ignored by the mainstream public. In scientific research papers, there are a lot of contradictory perspectives on biomass. For example, Brack [13] states biomass does not benefit the environment at all, while Joselin and Krishnan [14] conclude biomass can reduce emissions. Orecchio, Amorello and Barecca [15] concluded the harmfulness of heavy metals in the ashes which are produced by burning biomass is not harmful to operators and can benefit soil if returned to nature.

The last factor is the *user implementation*. The user implementation can be a factor because the maintaining and operating of a biomass boiler is more complex than with other techniques. A way to improve the user comfort is to use an so called ESCO's (Energy Service Companies), which create a carefree package for the end user. These companies invest in the installation, they operate and maintain the boiler, and the only thing the end user has to do is buy the heat from the ESCO. This heat is cheaper than the price which would be paid if another technique is used, while the end user does not have to worry about the reliability. This is something which is already proven successful in other sectors, such as the solar panel sector. One of the interviewees was an ESCO, which was in their own words, fairly successful. If the installation runs without an external company involved, it can be more profitable, but also more risky and less carefree. An ESCO claims to be more secure than when the installation is run by the adopter self.

If not the individual adoption decision, but the market potential is considered, the technical potential for biomass boilers is the largest in the block heating, wholesale, wood industry, schools and universities, rubber and plastic industry, district heating and indoor pools. In these sectors, the financial viability is often good, due to the high and stable heat demand. If the use of biomass boilers is more often considered in these sectors, the adoption can potentially grow. This is all according to a report for the RVO provided by Koppejan [7]. In this report, the financial viability of different sectors is calculated and multiplied by the heat demand in those sectors. Such an market analysis is not performed in this research, but it is relevant for the adoption potential in the Netherlands.

In the literature, the most important factors in the adoption decision were as stated in Table 3. The table indicates how many papers found one of these factors relevant. The international studies were held specifically on biomass boilers in Europe [16], while the literature studies are from scientific articles about different ETM's. Only the factors deemed relevant when more than 3 papers are listed in the table. This is because these are probably the most relevant in the adoption decision.

The costs of energy are lowered, while the investment costs are higher than with other techniques. This means that the investment costs needs to be earned back by the lower monthly costs. Another point which is different for the adopter is the fact that a biomass boiler is less user-friendly than other techniques. The boiler needs more maintenance than a gas boiler and operating the installation is also more work. The fuel needs to be ordered regularly, and sometimes the ash needs to be removed.

Biomass boilers are seen as environmentally friendly, provided that the source of the biomass is environmentally friendly. Also, a lot of projects are currently executed in which beforehand the supply is secured with a local party such as the municipality. They have a lot of waste wood available due to pruning and green maintenance. These projects are generally seen as worthwhile. In the Dutch media, the last few months a lot of information about the use of wood pellets has been given. Although, mostly in a bad way. Despite the fact that the use of wood pellets in co-firing of coal power plants can be seen completely distinct from the use of pellets in biomass boilers, it has negatively influenced the public opinion in the Netherland. For example a broadcast of the program 'Zembla', which explains why wood pellets are not good for the environment [17]. This has been about the use of wood pellets in coal power stations mostly, not for biomass boilers. This is

Table 3 – Important factors influencing the adoption decision

Category	Factor	Endorsements by international studies	Endorsements in literature
Financial	Subsidies / tax concession / feed-in tariff	6 (Austria, Bulgaria, Croatia, Poland, Romania, Ukraine(	5 [19], [20], [21], [37], [22]
	Cost of gas/oil/etc.	3 (Croatia, Romania, Slovakia)	8 [19], [23], [20], [29], [35]–[37], [41]
	Investment costs (payback period)	5 (Austria, Croatia, Germany, Romania, Slovakia)	4 [19]–[21], [27]
Technical	Biomass availability (at competitive price)	6 (Bulgaria, Finland, Greece, Poland, Romania, Ukraine)	5 [23], [29], [30], [34], [37]
Organizational	Social acceptance / awareness	7 (Austria, Bulgaria, Germany, Greece, Poland, Romania, Slovakia)	6 [26], [31], [35], [41], [45], [46]
	Missing knowledge (about operating)	4 (Austria, Finland, Germany, Greece)	6 [19], [21], [26], [37], [38], [63]
Risk support	Clear and stable legislation (for example emission requirements)	6 (Finland, Romania, Germany, Poland, Slovakia, Ukraine)	4 [32], [37], [40], [41]

supposed to cause whole forests to disappear, but forests in Europe and North America are still growing according to the UN [11].

The factors with the most influence are those mentioned in Table 3 and, of course, the factors mentioned most in the interviews. However, the most decisive factor is the financial viability of a project, which is often explained by the payback period. Of course, other factors play part, but if the viability is low or uncertain, most potential adopters become non-adopters.

5. Discussion

Here, the different contributions of this paper are discussed.

5.1. Limitations

This paper is based on 24 in-depth interviews, which can be seen as not much compared to the whole Dutch sector. However, the sector in the Netherlands is not very large (yet), which made it difficult to interview a larger amount of experts. Currently only about 500 biomass boilers are placed each year [18]. That is why every interview was an in-depth interview. This means not only basic questions and answers were used, but the reasons behind these answers were also sought-after. This combined with the literature results does give a reliable insight into the adoption decision. The interviews also showed a lot of overlap, which resulted in similar findings. This is explicable because these overlapping factors are relevant in most biomass boiler projects in the Netherlands.

5.2. Recommendations

Some of the found barriers can be prevented or lowered by for example the use of an ESCO as mentioned before. The monthly savings are lower and the financial risk is also lower. Because a carefree package is delivered, there are also no issues with operating and maintaining the installation. But most importantly, the large investment does not have to be done because it is all covered by the price of the delivered heat. This is mainly an option if the principal is risk averse or if the principal does not want to operate the installation himself.

Another problem is that the technology is relatively unknown in the Netherlands, whereupon it is seen as a risk to implement a biomass boiler. If more successful projects are done and seen as successful, this could improve. Also, the information provided towards potential adopters could be improved, or potential adopters can be provided with the information even before they have ever considered buying an biomass boiler. Therefore marketing could help the diffusion of biomass boilers in the Netherlands. This has to be combined with an explanation of polluting factors and failing projects that give the technology a bad image. If it can be explained why such projects failed and how these failures can be prevented, it helps to overcome the barrier of adopting a biomass boiler.

An important point in the marketing needs to be the sustainability of wood pellets. Currently the sustainability of this fuel source is questioned by a lot of national and international media due to the co-fuelled combustion of pellets in coal power stations. If the potential adopters get informed about the sustainability of locally harvested pellets from well-maintained forests, it might persuade them to adopt a biomass boiler.

5.3. Practical contributions

The practical contributions of this research mainly consist of the finding and verifying of the relevant factors in the adoption decision for biomass boilers. These have led to a few recommendations for improving the diffusion of biomass boilers. For the scientific community, a lot of factors have been validated by the interviewees. This means they are not only applicable to other countries and other techniques but also for the biomass boilers in the Netherlands. The conclusion of this research can provide a starting point for creating a clear policy for the RVO, the NBKL and other parties operating in this sector.

5.4. Risks and opportunities

If the prices of biomass and natural gas can be predicted, it can also be predicted whether the diffusion of biomass boilers will increase in the Netherlands. Also if some of the recommendations are applied, the diffusion will increase as well. However, if the price for natural gas is lowered, the difference between the costs for biomass and natural gas is too low to speak of a realistic payback period. Even if the operating costs are still lower for a biomass boiler than for other techniques, the investment still needs to be earned back.

The largest risk for the sector is if malfunctioning boilers provide a bad image and if the image of biomass is affected by people claiming biomass is not environmentally friendly. If biomass has a bad image, no one will implement a biomass boiler system into their company. This is already put forward a lot in the mainstream media and during the interviews. It looks like a conflict is going on between the supporters and opponents of biomass. This is mentioned as a barrier by multiple interviewees.

A lot of satisfied adopters have been interviewed. This means the technology is suitable for many situations which are alike to those. The potential for biomass boilers in the Netherlands is therefore promising, but the relevant factors mentioned in this paper need to be taken into consideration.

The financial viability of a project needs to be positive for adoption, although companies do mention other factors as important. If the adoption needs to be higher in the Netherlands, some options are available. Firstly, the financial viability needs to improve, which means the difference between wood as fuel and other techniques needs to get larger. The investment costs for biomass boilers will not get much lower because it is already a fairly matured technique in other European countries. In consequence, R&D will not be enough to lower the investment costs significantly.

It is important for suppliers of biomass to be transparent and clear about the source of the biomass. Best is if the source is local or if waste wood is used. That way the environment is barely harmed. If the source is not local, transport of the fuel will be an issue.

Biomass boilers are a fairly unknown technique in the Netherlands. For this reason, a lot of potential projects are not executed because it is never considered as an option. This can be solved by marketing and by providing solid and reliable information towards potential adopters. In some sectors such as the agricultural sector and in construction, the technique is known well, while other sectors with a high heat demand still have a high potential to adopt biomass boilers.

6. Conclusion

The perspective of potential adopters on biomass boiler adoption in the Netherlands is very diverse. However, for potential adopters to come to a positive adoption decision the financial viability of the adoption is the most important factor. The perspective can be altered by better information for these potential adopters.

Acknowledgements

The author would like to express his gratitude towards all respondents, without whom the research would have never been possible. Furthermore, he thanks the NBKL and dr. ir. E.E. (Eppo) Bolhuis for initiating the research question and supporting the research, both financially and with their efforts. Last but not least, the author would like to thank Tubro B.V. for providing a workspace and all their support. Also the University of Twente and the supervisors dr. ir. A.G. (Bram) Entrop and prof.dr.ir. J.I.M. (Joop) Halman were very important for this research.

References

[1] RVO, "TFC-constructie: Energy Service Company (ESCO) | RVO.nl." [Online]. Available: http://www.rvo.nl/onderwerpen/innovatief-ondernemen/innovatiefinanciering/toolbox-financieringsconstructies/zoek-op-constructies/processen-organiseren/esco. [Accessed: 02-Jul-2017].

[2] B. Entrop, Assessing energy techniques and measures in residential buildings : a multidisciplinary perspective. *2013*.

[3] Rijksoverheid, "Europa 2020 | Europese Unie | Rijksoverheid.nl." [Online]. Available: https://www.rijksoverheid.nl/onderwerpen/europese-unie/inhoud/europa-2020. [Accessed: 09-Apr-2017].

[4] CBS, "Aandeel hernieuwbare energie 5,9 procent in 2016." [Online]. Available: https://www.cbs.nl/nl-nl/nieuws/2017/22/aandeel-hernieuwbare-energie-5-9-procent-in-2016. [Accessed: 02-Jul-2017].

[5] Ministerie van Economische Zaken, "Energieagenda," the Hague, *2016*.

[6] Houtpellets.info, "Houtpellets," 2016. [Online]. Available: http://www.houtpellets.info/kostenbesparing.html.

[7] J. Koppejan, "Inventarisatie van markttoepassingen van biomassaketels en bio-wkk Colofon," Enschede, *2016*.

[8] RVO.nl, "Energiemaatregelen op gebiedsniveau (EMG)." [Online]. Available: http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/gebouwen/wetten-en-regels-gebouwen/energieprestatie-epc/gebiedsmaatregelen. [Accessed: 23-Mar-2017].

[9] J. Koppejan, "Statusoverzicht Houtkachels in Nederland," *2010*.

[10] RVO, Stimulering Duurzame Energieproductie (SDE). *2016*.

[11] United Nations Economic Commission for Europe, "Forests in Europe and North America are growing but remain vulnerable to threats," 2011.

[12] W. van den Hoogen, "Meningen nieuwe energietechnologieën vaak ter plekke gevormd," *Energie+*, *vol. 27*, no. 6, *pp. 26–27*, *2007*.

[13] C. House, "The Impacts of the Demand for Woody Biomass for Power and Heat on Climate and Forests," *Environ. Energy Resour. Dep.*, no. February, *2017*.

[14] G. M. J. Herbert and A. U. Krishnan, "Quantifying environmental performance of biomass energy," *Renew. Sustain. Energy Rev.*, *vol. 59*, *pp. 292–308*, *2016*.

[15] S. Orecchio, D. Amorello, and S. Barreca, "II) Wood pellets for home heating can be considered environmentally friendly fuels? Heavy metals determination by inductively coupled plasma-optical emission spectrometry (ICP-OES) in their ashes and the health risk assessment for the operators," *Microchem. J.*, *vol. 127*, *pp. 178–183*, *Jul. 2016*.

[16] Bioenergy4Business, "European Level Figures," *2016*.

[17] Follow the Money, "Bos als brandstof voor onze kolencentrales [kijktip] - FTM." [Online]. Available: https://www.ftm.nl/artikelen/bos-als-brandstof-kijktip?share=1. [Accessed: 02-Jul-2017].

[18] Nederlandse vereniging voor biomassa ketel leveranciers, "NBKL," 2016. [Online]. Available: http://www.nbkl.nl.

[19] V. Vasseur and R. Kemp, The adoption of PV in the Netherlands: A statistical analysis of adoption factors, *vol. 41*. *Renewable and Sustainable Energy Reviews*, *2014*.

[20] P. Balcombe, D. Rigby, and A. Azapagic, "Motivations and barriers associated with adopting microgeneration energy technologies in the UK," *Renew. Sustain. Energy Rev.*, *vol. 22*, *pp. 655–666*, *2013*.

[21] W. J. V Vermeulen and J. Hovens, Competing explanations for adopting energy innovations for new office buildings, *vol. 34*, no. 17. *Energy Policy*, *2006*.

[22] M. Beerepoot, "Policy profile: Encouraging use of renewable energy by implementing the energy performance of buildings directive," *Eur. Environ.*, *vol. 16*, no. 3, *pp. 167–177*, *2006*.

[23] K. Arkesteijn and L. Oerlemans, The early adoption of green power by Dutch households An

empirical exploration of factors influencing the early adoption of green electricity for domestic purposes, *vol. 33*, no. 2. *Energy Policy*, *2005*.

[24] F. W. Hallmann and G. S. Amacher, Forest bioenergy adoption for a risk-averse landowner under uncertain emerging biomass market, *vol. 25*, no. 3. *Natural resource modeling*, *2012*.

[25] V. K. Verma, S. Bram, and J. De Ruyck, “Small scale biomass heating systems: Standards, quality labelling and market driving factors - An EU outlook,” *Biomass and Bioenergy*, *vol. 33*, no. 10, *pp. 1393–1402*, *2009*.

[26] M. C. Claudy, C. Michelsen, and A. O’Driscoll, “The diffusion of microgeneration technologies - assessing the influence of perceived product characteristics on home owners’ willingness to pay,” *Energy Policy*, *vol. 39*, no. 3, *pp. 1459–1469*, *2011*.

[27] R. Scarpa and K. Willis, “Willingness-to-pay for renewable energy: Primary and discretionary choice of British households’ for micro-generation technologies,” *Energy Econ.*, *vol. 32*, no. 1, *pp. 129–136*, *2010*.

[28] N. Schwarz and A. Ernst, “Agent-based modeling of the diffusion of environmental innovations — An empirical approach,” *Technol. Forecast. Soc. Change*, *vol. 76*, no. 4, *pp. 497–511*, *May 2009*.

[29] A. Toka, E. Iakovou, D. Vlachos, N. Tsolakis, and A. L. Grigoriadou, “Managing the diffusion of biomass in the residential energy sector: An illustrative real-world case study,” *Appl. Energy*, *vol. 129*, *pp. 56–69*, *2014*.

[30] K. Ericsson, S. Huttunen, L. J. Nilsson, and P. Svenningson, Bioenergy policy and market development in Finland and Sweden? (vol 32, pg 1707, 2004), *vol. 33*, no. 1. *Energy policy*, *2005*.

[31] M. Guidolin and R. Guseo, “The German energy transition: Modeling competition and substitution between nuclear power and Renewable Energy Technologies,” *Renew. Sustain. Energy Rev.*, *vol. 60*, *pp. 1498–1504*, *Jul. 2016*.

[32] L. Kranzl, M. Hummel, A. Müller, and J. Steinbach, Renewable heating: Perspectives and the impact of policy instruments, *vol. 59*. *Energy Policy*, *2013*.

[33] T. Persson, S. Nordlander, and M. Rönnelid, “Electrical savings by use of wood pellet stoves and solar heating systems in electrically heated single-family houses,” *Energy Build.*, *vol. 37*, no. 9, *pp. 920–929*, *2005*.

[34] W. Sierzchula, S. Bakker, K. Maat, and B. Van Wee, “The influence of financial incentives and other socio-economic factors on electric vehicle adoption,” *Energy Policy*, *vol. 68*, *pp. 183–194*, *2014*.

[35] B. M. Sopha, C. A. Klöckner, G. Skjevrak, and E. G. Hertwich, “Norwegian households’ perception of wood pellet stove compared to air-to-air heat pump and electric heating,” *Energy Policy*, *vol. 38*, no. 7, *pp. 3744–3754*, *2010*.

[36] B. Maya Sopha, C. A. Klöckner, and E. G. Hertwich, “Exploring policy options for a transition to sustainable heating system diffusion using an agent-based simulation,” *Energy Policy*, *vol. 39*, no. 5, *pp. 2722–2729*, *May 2011*.

[37] K. McCormick and T. Kaberger, Key barriers for bioenergy in Europe: Economic conditions, know-how and institutional capacity, and supply chain co-ordination, *vol. 31*, no. 7. *Biomass & Bioenergy*, *2007*.

[38] S. O. Negro, M. P. Hekkert, and R. E. Smits, “Explaining the failure of the Dutch innovation system for biomass digestion—A functional analysis,” *Energy Policy*, *vol. 35*, no. 2, *pp. 925–938*, *Feb. 2007*.

[39] R. Madlener, “Innovation diffusion, public policy, and local initiative: The case of wood-fuelled district heating systems in Austria,” *Energy Policy*, *vol. 35*, no. 3, *pp. 1992–2008*, *2007*.

[40] M. Perry and F. Rosillo-Calle, “Recent trends and future opportunities in UK bioenergy: Maximising biomass penetration in a centralised energy system,” *Biomass and Bioenergy*, *vol. 32*, no. 8, *pp. 688–701*, *2008*.

[41] M. Beerepoot and N. Beerepoot, “Government regulation as an impetus for innovation: Evidence from energy performance regulation in the Dutch residential building sector,” *Energy Policy*, *vol. 35*, no. 10, *pp. 4812–4825*, *2007*.

[42] K. Willis, R. Scarpa, R. Gilroy, and N. Hamza, “Renewable energy adoption in an ageing population: Heterogeneity in preferences for micro-generation technology adoption,” *Energy Policy*, *vol. 39*, no. 10, *pp. 6021–6029*, *2011*.

[43] E. Alakangas *et al.*, “EUBIONET III - Solutions to biomass trade and market barriers,” *Renew. Sustain. Energy Rev.*, *vol. 16*, no. 6, *pp. 4277–4290*, *2012*.

[44] P. A. Fokaides, E. A. Christoforou, and S. A. Kalogirou, “Legislation driven scenarios based on recent construction advancements towards the achievement of nearly zero energy dwellings in the southern European country of Cyprus,” *Energy*, *vol. 66*, *pp. 588–597*, *2014*.

[45] S. Breukers, M. Hisschemöller, E. Cuppen, and R. Suurs, “Analysing the past and exploring the future of sustainable biomass. Participatory stakeholder dialogue and technological innovation systems research,” *Technol. Forecast. Soc. Change*, *vol. 81*, *pp. 227–235*, *Jan. 2014*.

[46] S. Ruggiero, T. Onkila, and V. Kuittinen, “Realizing the social acceptance of community renewable energy: A process-outcome analysis of stakeholder influence,” *Energy Res. Soc. Sci.*, *vol. 4*, *pp. 53–63*, *Dec. 2014*.

[47] A. Darmani, N. Arvidsson, A. Hidalgo, and J. Albors, What drives the development of renewable energy technologies? Toward a typology for the systemic drivers, *vol. 38*. *Renewable and Sustainable Energy Reviews*, *2014*.

[48] M. de Gunst, “Overheidsregulering, de missende factor in de Nederlandse biomassaketen voor energieopwekking?! Een vergelijkend onderzoek naar de invloed van overheidsregulering op de biomassaketen in de Nederlandse en Duitse markt voor energie uit biomassa,” *BMS Behav. Manag. Soc. Sci. Univ. Twente*, *2013*.

[49] S. Wirth and J. Markard, “Context matters: How existing sectors and competing technologies affect the prospects of the Swiss Bio-SNG innovation system,” *Technol. Forecast. Soc. Change*, *vol. 78*, no. 4, *pp. 635–649*, *May 2011*.

[50] C. Egmond, R. Jonkers, and G. Kok, A strategy and protocol to increase diffusion of energy related innovations into the mainstream of housing associations, *vol. 34*, no. 18. *Energy Policy*, *2006*.

[51] European commission, “Biomass,” 2016. [Online]. Available: https://ec.europa.eu/energy/en/topics/renewable-energy/biomass.

[52] J. McKechnie, S. Colombo, J. Chen, W. Mabee, and H. L. Machlean, “Forest Bioenergy or Forest Carbon? Assessing Trade-Offs in Greenhouse Gas Mitigation with Wood-Based Fuels,” *Environ. Sci. Technol.*, *vol. 45*, no. 2, *pp. 789–795*, *2011*.

[53] Rijksoverheid, Activiteitenbesluit milieubeheer. *the Hague*: *Dutch Government*, *2016*.

[54] Rijksoverheid, Informatieblad Milieubelastingen. *2015*.

[55] RVO, “Subsidie voor biomassaketels (ISDE),” 2016. [Online]. Available: http://www.rvo.nl/subsidies-regelingen/investeringssubsidie-duurzame-energie/voor-welke-apparaten/biomassaketels.

[56] Rijksoverheid, Kamerbrief over de stimulering van hernieuwbare energieproductie in 2016. *2016*.

[57] Rijksoverheid, Ketel of kachel gestookt met biomassa. *2016*.

[58] European Commission, “Progress reports - Renewable Energy,” 2016. [Online]. Available: https://ec.europa.eu/energy/node/70. [Accessed: 25-Apr-2017].

[59] Eurostat, Share of renewable energy sources in heating and cooling. *2016*.

[60] European Biomass Association, “The basics of Biomass,” *2016*.

[61] Timax, “Worden verbrandingsinstallaties voor biomassa (houtpelletkachels voor woningen) ook in de NEN 7120 opgenomen? Zo ja, zijn daarvoor standaardwaarden in te voeren of moet men dan werken met (gecertificeerde) gelijkwaardigheidsverklaringen?,” 2015. [Online]. Available: http://www.epcberekening.nl/verbrandingsinstallaties-biomassa-houtpelletkachels-woningen-nen-7120/. [Accessed: 31-Mar-2017].

[62] Bureau Kent, “Biomassaketels meegenomen in energieprestatie – bureau Kent,” 2015. [Online]. Available: http://www.bureau-kent.nl/biomassaketels-meegenomen-in-energieprestatie/. [Accessed: 31-Mar-2017].

[63] C. Dieperink, I. Brand, and W. Vermeulen, Diffusion of energy-saving innovations in industry and the built environment: Dutch studies as inputs for a more integrated analytical framework, *vol. 32*, no. 6. *Energy Policy*, *2004*.

Appendices

During the research, a lot of information which is useful for the sector is gathered. This is not direct relevant for the paper but has been used as background information during the research. This information can be found in the appendices. Some of it has been used in the paper, some of it did not make the cut. The used interview questions, the influencing factors, rules and regulations regarding biomass boilers, it can all be found in the appendices. The first appendix starts off with the initial research proposal. This proposal has not been strictly followed, due to new insights. However, it has been a good start for this research.

The appendices the continue with the literature study, which also was the first step in the research. Using the results of the literature study, the research framework was set-up, and the empirical research was shaped by the information gained during the literature study.

Then some background information is given about the questions asked during the interviews in Appendix F - and Appendix G -. The first round interviews where exploratory, so nothing which was missed in the literature study would be missed during the empirical research. The insights gained during these interviews were used to shape the second round interviews. However, the second round interviews were also very open. This means the questions prepared were a guideline of which was deviated continuously. This helped to gain an insight in the real reasons lay behind a principals adoption decision.

This all together is explained by the model, as proposed in the research paper.

Appendix A - - Initial research proposal

A1. Introduction

This part of the report will elaborate about how the research was started and will give some practical information about the subject.

A1.1. Background of the research

This research investigates the adoption of biomass boilers in the Netherlands. The research has been initiated by the NBKL (Nederlandse vereniging voor biomassaketel leveranciers). They approached the University with the question if the adoption of biomass boilers in the Netherlands could be researched and how this could be improved, due to the fact that the adoption rate in the Netherlands is far lower than in other European countries.

Boundaries

It is necessary to determine the boundaries in which this research takes place. The research is about biomass boilers, which are the same as gas boilers, only fuelled by biomass. Therefore the surrounding system is not very different from a conventional system. These boilers are used to heat water and buildings. This research focuses on industrial sized biomass boilers, which run on mainly wood chips or on wood pellets. These are the most common types used in the Netherlands and probably have the largest potential of adoption in the Netherlands. These boilers can be used in industrial buildings, but also at for example swimming pools, greenhouses or large offices. The range in which this research will take place is for boilers with a capacity ranging from 100 kW to 10 MW. Because biomass boilers do not function very well if started and stopped very often, a heat buffer is needed to keep the system running at full capacity most of the time. Other general and technical information about biomass boilers specifically in the Netherlands can be found in Appendix M.

Organisational structure

The organisational structure of the thesis is that the original question has been set out by the NBKL to the University of Twente. This has led to the setup of this master thesis. The research will be done on location at the office of one the members of the NBKL that is established in the city of Enschede, namely Tubro. Tubro is a company which imports and installs biomass boilers of a medium size. The main coaching from the University comes from A.G. Entrop and J.I.M. Halman. They will offer guidance during the research and will grade the end product.

NBKL

The NBKL represents 12 out of 15 companies that operate in this sector. Therefore it is representative for the Dutch sector as whole. One of the three companies that are not a member of the NBKL however, has close contact with the NBKL. The other three companies supply installations outside of the scope of this research, because they deliver biomass boilers of 10MW and larger.

RVO

Once the research was getting started, the RVO (Rijksdienst voor Ondernemend Nederland / The Netherlands Enterprise Agency) wanted to participate because of their mutual interest in the research. The RVO is an organisation that supports entrepreneurs in the Netherlands. They have a lot of knowledge about subsidies, finding business partners and all applicable rules and regulations. They therefore also have a lot of knowledge of the adoption of biomass boilers in the Netherlands, because it is their job to support possible adopters. The RVO is already busy with the adoption of biomass boilers in the Netherlands, together with the biomass4business project, which is a European initiative to improve the biomass usage in Europe. This project can prove to be a useful source of information.

Multiple parties are involved in creating the eventual master's thesis, and all have their own interests that are to be considered. Therefore regular appointments have to be made, to make sure everyone involved will be satisfied with the results.

Biomass boilers

There are several rules and regulations regarding biomass boilers, for example, there is an emission standard, which must be met. If a biomass boiler is adopted, one can apply for a subsidy from the government through different regulations, but a more extensive explanation about these subsidies and other rules/regulations can be found in the Appendix N.

Biomass could be regarded as an attractive alternative for fossil fuels due to its carbon neutral footprint and because it can be harvested locally. This reduces the environmental impact and transport costs significantly. This is why the use of biomass boilers is subsidised by the Dutch national government. The European Union has signed the 2020-strategy, which includes several environmental goals. These goals can only be achieved if multiple sustainable techniques are used. Therefore biomass boilers are also important for not only the NBKL but also the government as shown in Appendix L.

Innovation

According to Kemp [1], an innovation starts at a niche market. This is where it is initially applied and where the learning starts. Because it is being used, people think about how to improve the technology to better adapt it to the users' needs. This helps firms by providing the necessary financial means and experience to further improve the product. This is exactly the point where we currently are with the adoption of biomass boilers in the Netherlands because they are used almost exclusively in a niche market of carpenters and other firms that produce waste wood. This means the market could have a lot of potential if the experience and finances provided by the niche market are used to improve the adoption of biomass boilers.

A1.2. Adoption of biomass boilers across Europe

To determine the influence of several factors on the adoption rate, it is necessary to first create a model, which needs verification and validation. This can be done by using comparable situations, thus using the adoption rate of countries in Europe compared to the Netherlands is a logical step. The several factors that have influenced the adoption in other countries is determined by using literature. Another source of information could be the Bio-energy4Bussiness project. This project is part of the Horizon 2020 framework programme by the European Community and aims at the same goals as this thesis. Already some statistics are available, which show the poor adoption of biomass boilers in the Netherlands compared to other European countries. This data can be found in Appendix L.

In the research within comparable countries, probably some barriers will be found. These barriers are likely to exist also in the Netherlands. Therefore it is important to document and categorise these barriers. After this is done, it is necessary to determine possibilities of removing these barriers. That can be partially be done by using the experience gained in the other countries, but part has to be done by thinking out and applying new methods and solutions to these problems.

A lot of information about the adoption of biomass boilers can possibly gathered by the collaboration with the RVO because they also participate in an European program [2] to increase the biomass usage in Europe. This European program will have information about all countries which participate in the program, as well as connections which can be used to gather all information not readily available. This resource could be used to determine barriers and advantages of biomass boilers across Europe, thus determining factors that are possible also applicable in the Netherlands.

A1.3. Adoption of biomass boilers in the Netherlands

Already some biomass boilers are used (about 7500 active [3]), and some companies are active in this sector (about 15 suppliers [4]) in the Netherlands. In this section, a small outline will be given of current views on the sector. Currently most biomass boilers are used within companies who have wood as waste material available, for example, carpeting or horticulture companies [5, p. 7]. These companies otherwise have to dispose of their waste wood, which is quite expensive. Now with a biomass boiler, they have found a useful technique of disposing of their waste in a cheap way. If the wood needs to be bought for fuelling the biomass boiler, it would be a quite expensive investment which cannot be done without subsidy or making loss.

Some public buildings, such as swimming pools also slowly start to adopt biomass boilers. These companies require large quantities of heat, which makes it attractive to adopt a biomass boiler. The initial investment is quite high compared to a gas installation, but the cost of wood is lower than the cost of gas. Therefore large biomass installations which are partially financed with subsidies are attractive for these kind of situations. (Wood costs about €30,52/kWh and gas €65,16/kWh assuming €0,145/kg for wood and €0,60/m3 for gas [6]).

A1.4. Stakeholders

There are several stakeholders involved in this research. The adoption of biomass boilers is done ultimately by a principal, but this principal is not always the owner or even the user of the installation. Furthermore, the supplier is involved by installing the system, possibly an architect or engineer for the surrounding (possibly already existing) construction and lastly possible advisors such as the RVO or consultancy firms. Lastly, the government is involved due to the different subsidies and taxes involved in using a biomass boiler. This is all summarised in Figure 4. A more extensive description of all stakeholders can be found in Appendix I.

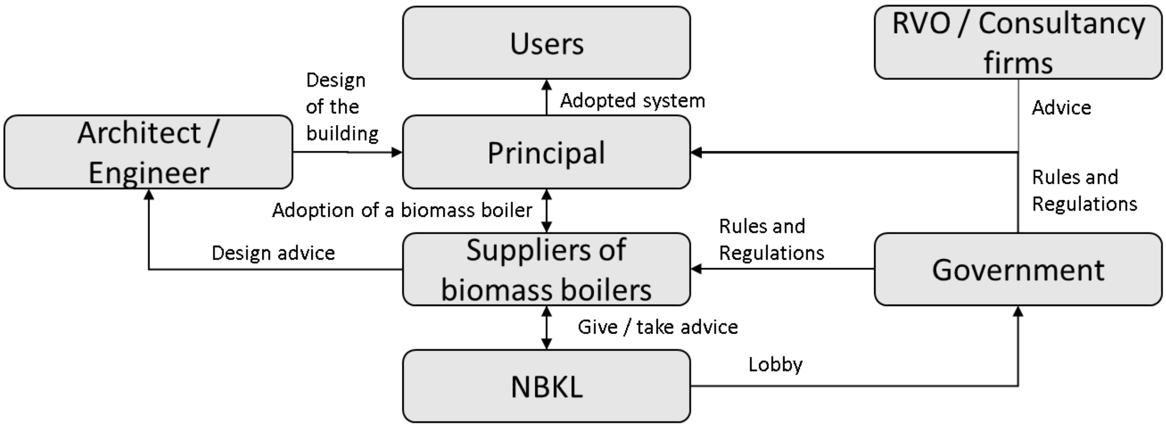


Figure 4 – Relationships between different stakeholders

A2. CONCEPTUAL RESEARCH PROPOSAL

The research will start with the theoretical background on innovations and their diffusion and adoption, which will be followed by a study which determines the adoption and diffusion of biomass boilers in other European countries. This study will partially be a literature study, but it is also possible to use information of the bioenergy4business project and possibly their contacts. Then the research method for the Dutch situation is being explained, followed by the research itself. This all should result in a model, which can describe how the adoption of biomass boilers in the Netherlands works and what 'buttons' there are and how the adoption changes if these buttons are turned.

A2.1. Problem

The perceived adoption of biomass boilers is very low, especially compared to other European countries such as Germany, Denmark and France. Only a few dozen biomass boilers are sold by the members of the NBKL every year, while in for example Germany thousands are sold every year. The NBKL sees a lot of potential in the market for biomass boilers in the Netherlands but does not know how to get the adoption going. The full potential of biomass boilers is not used in the Netherlands. This not only means a lot of money is wasted by companies, but also the environment could benefit a lot because of the carbon cycle which is far shorter for wood than the currently used fossil fuels. **Therefore the problem is the low sales rates of biomass boilers in the Netherlands.**

A2.2. Goal

The goal within this research is to get a better understanding in the adoption decision of biomass boilers in the Netherlands, by creating a model which explains this adoption decision. This model will be created for the NBKL and the RVO because they are the principals in the research. This means the model should focus on the market level and not on a project level how the adoption decision is made. **The goal of this research is higher sales rates of biomass boilers.** It will be researched when a company decides to adopt a biomass boiler, and what factors influence this decision. This should lead to a better understanding about the adoption of such a sustainable innovation. This will lead to a better understanding how the NBKL and possibly other parties positively can influence the adoption of these biomass boilers. The model will focus on the market as a whole and separate market sectors because although different sectors can adopt biomass boilers, the adoption decision is made differently for all sectors. These influencing factors can include barriers and incentives. "The term barrier is a metaphor for the constraining factors that affect the implementation of bioenergy systems" [7]. The research can be used not only for biomass boilers but also for gaining a general understanding about the implementation of sustainable energy solutions. This will include the relevant factors influencing the adoption decision and the dynamics between these factors. Furthermore, this will not only become a static model, in which the current situation is explained but also how this can change. Thus it will become a dynamic model which works with different future scenarios. It will be possible to 'turn the knobs' within the model, after which the new scenario will automatically be calculated by the model.

A2.3. Research Questions

To achieve the goals set in the previous paragraph, a few research questions have been made. These questions cover the goal and should solve the problem as mentioned in paragraph 2.1. The main research question will be:

How can the adoption of biomass boilers in the Netherlands be modelled?

This main question will be answered by finding answers on a few sub-questions. This is also because the influencing factors can be traced back to many different reasons, ranging from government rules and regulations to perceptions of possible adopters. This research tries to give an insight into all different factors affecting the adoption rate of biomass boilers by using different research techniques.

The sub-questions are build up by starting with the actual measurable (dis)advantages of a biomass boiler in comparison to other systems. This should already give an answer if it is profitable to adopt a biomass boiler. The second set of sub-questions answers the opinion and perception of people/companies towards biomass boilers. The last set of sub-questions answers how the actual adoption decision is made. The sub-questions are as follows:

Question 1. What can be found in the literature about the adoption decision of biomass boilers or other environmentally friendly techniques?

1.1. What can be concluded from research of other techniques?
1.2. What can be concluded from comparable countries and their experience with biomass boilers?
1.3. Why is the adoption rate much higher in other European countries?

This first question will be used to determine initial factors influencing the adoption decision model which will be created. Also, different models for other sustainable techniques will be looked into to determine if they can be (partially) used to create a model for biomass boilers. Some information is already given in Chapter A5.4 and Chapter A5.5. Other countries have done similar studies for biomass boilers. These studies can be used to determine if there are comparable factors in the Netherlands which also are relevant for this research.
The last question in this part, namely why is the adoption rate in other countries in Europe much higher than in the Netherlands still needs to be answered during the research, because not all barriers and other influences have been identified for the Dutch situation. Once this is known, a well-founded answer can be given.
Question 2. What are effects of implementing a biomass boiler?

2.1. How does a biomass boiler affect the energy performance of a construction?
2.2. What are the financial effects of a biomass boiler?
2.3. What other effects can be identified?

Before it is possible to determine what influence certain effects have on the adoption decision of biomass boilers, it is necessary to determine what the effects of implementing such a system actually are. The effects can be measured by using the finances and the technical effects because the technical effects are for example the energy usage and the difference in user comfort. The financial effects are the monetary benefits of implementing a biomass boiler.
These questions will be answered by using a few example projects. All technical and financial aspects of these projects will be covered to give a good view of the impacts of adopting a biomass boiler. The answers to the sub-questions can also be used to create an article, which promotes the use of biomass boilers in the Netherlands. This can then be used to find possible adopters for interviews in later parts of the research. The focus should lay on interviewees who belong to the early majority ([8], because once this group starts adopting the innovations will start to be implemented exponentially.
The example projects will be retrieved from Tubro and possibly other companies supplying biomass boilers in the Netherlands. These cases are readily available, and therefore this part of the research should pose little problems.
Question 3. What is the perception of (potential) adopters on the adoption of biomass boilers?

3.1. What do potential adopters know about biomass boilers?
3.2. Do (potential) adopters have previous (negative/positive) experiences with biomass boilers?
3.3. What are the positive and negative points perceived by potential adopters?

Not all variables are perceived the same as they actually are. Therefore it is important to determine the perception of these effects by the principal as mentioned by Vermeulen and Hovens [9, p. 2730]. The main perception is formed by what is already known about biomass boilers, and this is influenced by possible positive or negative effects. After all, this is known, it is necessary to determine what positives and negatives are perceived about biomass boilers. This can be used to influence the actual adoption decision and determine how the adoption decision is changed by these factors.
The perceptions of different adopters and potential adopters is acquired by interviewing different experts. These experts are interviewed about projects, and these projects should not only be example projects in which everything went well. It is necessary to also gain information about failed projects because this helps determining why projects fail or why a principle does not adopt a biomass boiler.
Before these interviews can be held, first the literature study needs to be completed. This should identify different influencing variables beforehand. This information can then be used to determine if the variables mentioned in the literature are also relevant in the adoption of biomass boilers in the Netherlands. A summary of the different variables found is already made in 0 (scientific articles) and 0 (international reports about biomass boilers).

The variables found in the literature will be used during the interviews, because possibly already all variables are known. It needs to be verified if these variables are also relevant in the case of the adoption of biomass boilers in the Netherlands, with help of these interviews. All variables will be discussed in the different sub-questions, which should give a complete image of the empirical findings about biomass boilers. It is possible extra variables surface during the interviews. When this happens, they will be processed into the adoption decision model.
All interviews will be held with experts, who can be contacted through the NBKL and its members. This will be logistically challenging, but it is possible if not too much interviews are done within the time limitations.

Question 4. How is the adoption decision of a biomass boiler made?

4.1. How do the different measurable effects influence the adoption decision?
4.2. How does the perception of (potential) adopters influence the adoption decision?
4.3. What is the combined influence of all these different effects?

Once all variables are known from the previous questions, it can be determined how much they influence the adoption decision. The variables will be used to determine their individual influences, which means the adoption decision influence can be determined if a single factor is changed. Then a combined model will be made, to determine if this explains the effect on the adoption decision better than the individual factors. This model should be tested statistically, which means all factors will also be quantified in this phase of the research.
The model created will be verified by using information gained by experts and will be validated by a workshop in which experts will give their opinion about the subject. This is mainly because of a lack of time to gather enough information about different projects in the Netherlands and the lack of projects that are available. During the workshop, data will be gained from the experts, after which the data will be standardised into a database. This is needed to quantify all different factors influencing the adoption decision.
All these sub-questions together lead towards a decision-making model of potential adopters of biomass boilers in the Netherlands. In this model different influencing factors will be processed, based on comparative studies and interviews with both adopters and potential adopters. The resulting decision model makes it possible to create scenarios for the future and derive predictions from those scenarios. If certain assumptions and changes are made for a future situation, the impact of those changes can be determined with the help of the decision-making model. This could help improve the adoption rate of biomass boilers in the Netherlands and gaining a better insight into the workings of such an adoption decision. This insight is meant for the sector as a whole, which means the research will not focus on individual projects. However, all data which will be gathered will come from individual projects.

A3. Technical research proposal

This part of the research proposal will describe the steps needed to perform the research. Also, a first version of the adoption decision model is proposed in this part, as well as a planning in for the research.

A3.1. Research strategy

The end product of this research will be an adoption decision-model, by using the theoretical background and the information gained from other countries. Also, the information gained with interviews and by comparing other similar studies will be used to create this decision model. This will all be used to determine the adoption rate of biomass boilers in the Netherlands. To be able to say anything about the Dutch situation, it is needed to gather information. This will be done with the help of questionnaires which will be held with (potential) adopters of biomass boilers.

These questionnaires will cover several aspects, which are partially inspired by the innovation-decision model as proposed by Rogers [8], the model described by Hekkert [10], and partially made for this specific research. After all, information is gathered, the research will focus on laying connections between the aspects and determining their influence on the decision of adopting/rejecting the use of biomass boilers. Once these connections are made, it is possible to determine the potential of the Dutch market by extrapolating the current adoption and diffusion rate with the influencing factors.

A3.2. Research Material

There are about a thousand potential adopters per year in the Netherlands who request a quote at one of the members of the NBKL. The research will try to gather information from these potential adopters. The questionnaire will be made by using the literature and a few in-depth interviews. These interviews will be used to determine potential factors influencing the decision. If these factors are determined by the in-depth interviews, their actual amount of influence will be determined by using a few questionnaires held with experts in the field. Because of the time restrictions, it is not possible to have a large scale questionnaire. This also means not a whole range of variables can be identified. Therefore only the most important variables will be determined.

To be able to create a working decision model, which can also practically be used, it is important to also determine all technical aspects of biomass boilers. This should encompass the technical capabilities in different situations, as well as all financial aspects. This is all needed to determine in what situation it is profitable to use biomass boilers over gas boilers and what sub-markets have the largest potential of growth. This information will be gathered from the members of the NBKL, who have this kind of information available.

The result should be a decision model, in which is described how and when a potential adopter makes the decision to buy a biomass boiler system for his company/organisation/etc. This model will be used to create several scenarios for the future, which can be used by the NBKL, supplies and possibly the Dutch government to prepare for the future and possibly decide how to adjust their policies. Therefore it is needed to be able to 'turn the buttons' in the model. This could be used to determine the result of possible changes in policy or other possible changes, such as the information provided towards the principle.

A3.3. Research model overview

The research model is actually quite straight-forward. It consists of finding possible factors influencing the decision of adopting a biomass boiler, putting these factors in a decision making model, determining their influence by adding weights to them and concluding with a influencing strategy per factor which can be used by for example the NBKL, suppliers and RVO to influence the adoption of biomass boilers in the Netherlands.

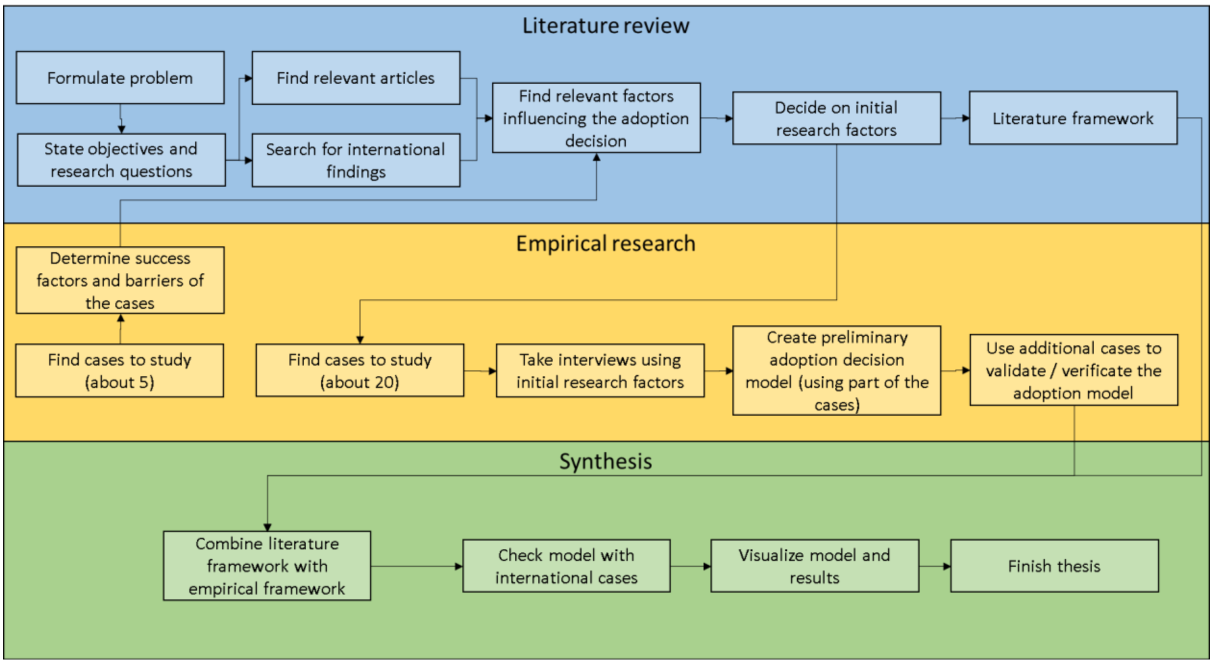


Figure 5 - Research process model

The research model consists of three different parts, namely the literature review, the empirical research and the synthesis of those two as seen in Figure 5. The first part is already partially done because a lot of literature is already looked into and the international reports with their findings are also already mentioned in this research proposal. The factors found will be used in the actual research, which will mainly be an empirical research and the synthesis with the literature. The literature results are used as a basis for making the empirical research possible.

A3.4. Research planning

Several things need to be done to perform this research. The first steps are made in this proposal; the remaining steps are already planned. The literature study and the initial adoption-decision model are already finished. The following steps need to be done during the research:

1) Find case studies for determining the adoption decision factors

To get more information about the adoption process, a few cases will be used to write an article in a professional Dutch journal. It is intended to get this article published in a relevant professional journal. This should lead to the confirmation of the theoretically found factors, and possibly, even more, factors will be found. The publication of an article is mostly because it can be used to reach potential adopters for the next phase in the research and to already gain more awareness of biomass boilers in the Netherlands.

2) Publish article

Once a few cases have been found, the article, of course, needs to be written. In this article, the focus should lay on different incentives and barriers of adopting a biomass boiler. These possible barriers could be refuted by giving different strategies to overcome them. This ensures enough information is available to make an initial adoption-decision-model, while also helping the sector with a bit of promotion of the technology.

3) Determining the preliminary adoption-decision-model

Once all information from the initial case studies is known, it is possible to work out the adoption-decision-model. This model is the main product of this research, which should lead to a better understanding in how the adoption decision can be altered or influenced (positively).

4) Interview experts involved in the case studies

When the model is finished, it is necessary to ask the right questions to expert in order to determine if the initial assumptions about the model are right. The initial case studies used to publish the professional journal article probably lack certain information, which can be gathered during these expert interviews. Part of the interviews will be used to improve the initial model into a preliminary model, and part of the interviews will be used to verification the preliminary model.

5) Work out weights of the influencing factors with some of the cases (10/20 cases)

With the information gained from the expert interviews, it is possible to work out the weights of all influencing factors. Because in the short time available not a lot of interviews can be done, it is also not possible to determine a lot of influencing factors.

6) Verification model with the remaining cases (5/10 cases)

Once the weight are determined, these can be verified by using the remaining case information. This can be done by simple statistical tests.

7) Validate model with workshop with several experts

Once the model is verified, also validation is needed. This will be done by using a workshop involving several experts. They can all bring their own information and cases, which will be used to (statistically) prove the model is correct.

8) Finish writing the research report

After all, information is gained, and the definitive model is made, it is needed to report everything. Although the writing of the report will start the minute the research is started, in the end, some time is needed to finish all documents.

9) Perform Colloquium

The research will finish with a colloquium, in which all results will be presented and discussed.
All steps mentioned above are put into a bar chart, which can be found in Figure 5. This bar chart shows how the activities are planned in the research. The research start will be the first week in April, and after 20 weeks it will be finished. This will be the end of August 2016.

A4. Results

This part will elaborate on both the scientific and practical contributions which are to be expected from this research. Also, some limitations, which can be identified beforehand will be explained in this part.

A4.1. Scientific contributions

The proposed research should result in a comprehensive model, which describes how the adoption of biomass boilers is influenced by different variables. This will be based on different interviews with experts and be validated by with a few case studies. Although a lot of research has been done which determines the influence of different variables on the implementation of environmental friendly and energy saving measures, no literature can be found specifically about biomass boilers in the Netherlands. Furthermore, this research will find out some possible barriers which hinder the adoption of biomass boilers in the Netherlands. Once known, possible solutions can be given to overcome these barriers.

A4.2. Practical contributions

The result of the research wild give solutions for improving the adoption of biomass boilers in the Netherlands. These solutions can be used by the individual companies and the NBKL to improve their sales. The government might use the results to rethink their policy regarding biomass boilers, and the RVO might rethink their strategy of helping entrepreneurs implementing these installations. This should lead to a higher adoption rate and therefore less gas usage in the Netherlands. It might even lead to a reduction of carbon dioxide emissions in the Netherlands, giving the government a better chance of reaching the 20/20/20 goals.

This can be done by creating or using already available scenarios and changing these according to the insights gained by the end result of this research. Then by filling in the changes in the model, possible influences of the changes should become clear. This might help policy makers, the NBKL and even individual biomass boiler suppliers to make the right decisions and improve sales of these systems.

A4.3. Risks and opportunities

Due to the fact this research will only take up six months, the validation phase will not be done with a lot of cases. This is not possible in the given time. As an alternative, a workshop with a few experts who can be interviewed about a few case studies will have to suffice. However, due to the fact that this is a workshop with experts who have a lot of knowledge the information gained in this workshop should give enough insight to be able to state what factors are important in the adoption of biomass boilers in the Netherlands.

A5. Theoretical Background

Before the actual research takes place, it is necessary to determine what information is already available in the literature and how this can be applied in this research. This part discusses several theories, which are used to determine the adoption level of biomass boilers in the Netherlands. First, the diffusion theory of Rogers will be discussed, after which the government regulations influence on innovations is being discussed by using the theory of Beerepoot [11].
Some of the different theories have been handed over by the professors of the University and others by the Netherlands Enterprise Agency (RVO). These papers have been useful in the beginning to start to understand how the adoption of a new technology takes place. Then this knowledge has been expanded by searching for papers using SCOPUS and Google Scolar. Used search terms include biomass boiler, biomass, adoption, environmental, energy, technique and wood pellets. These search terms have been used in different combinations to find all necessary papers. A more extensive explanation can be found in Appendix Q.

A5.1. Diffusion of innovations theory

Innovation can be described on the highest level by using the diffusion theory of Rogers [8]. This theory focusses on four aspects, the innovation itself, the communication between (potential) adopters, the time and the context in which the innovation is placed. Using these four aspects, the adoption and diffusion of any innovation can be described. However, this theory is very general and thus other theories are needed for this specific research. A more complete explanation of the theory can be found in Appendix O. This theory has also been expanded by Egmond, Jonkers and Kok [12] in their article explaining how the diffusion of energy related innovations can be increased into the mainstream of housing associations. They have used the theory specifically on a subject very much alike the one researched here. Their main focus is on the chasm as described by Moore [13] which needs to be crossed for an innovation to be successful. Moore uses the theory of Rogers about innovators and early adopters, which start an innovation to describe how after enough people start to use the innovation it gains a critical mass. After this chasm has been crossed, the innovation starts to become mainstream and the diffusion will grow exponentially.
According to Egmond, Jonkers and Kok [12], to reach the mainstream adopters the most pragmatic actors need to be persuaded. These are niche segment of the early majority. This is something which can also be taken into consideration in the model produced in this research.

A5.2. Technological innovation system

Hekkert [10] describes how a technological innovation system works from the early start of someone with an idea till the moment the innovation has gained the critical mass in which it starts to grow exponentially. His model describes seven function that influence the development of the innovation, which all influence each other. For our case of biomass boilers, the earliest phases of creating the technology are not interesting, but how the technology grows is very interesting. An explanation of the theory can be found in Appendix P. The use of of TIS frameworks has the potential to address many different issues [14]. Currently at least four major areas of development can be identified, which can all be used in this research.

A5.3. Government regulations influencing innovations

The government has a large influence on the adoption of biomass boilers in the Netherlands, due to the fact they need to reach their emission goals. The government obviously influences the market on both a macro and a micro level, but to what extend the government really affects the adoption rate is not known. Therefore the influence of the government on the adoption of other sustainable techniques is being reviewed. This should give an insight in the possible factors affecting the adoption of biomass boilers by comparing the situations. Most obvious influences are of course the subsidies and regulations, but it is not yet known to what extend they influence the adoption. Blesl, Kober, Bruchof and Kuder [15] have written an article about the effects of energy policies and political targets on the European energy system in 2020. This research states the energy usage in the EU-27 is far more influenced by policy than available technology. Furthermore if the 2020 goals are to be achieved, all available technologies should be used according to Blesl et al. This means biomass is also needed, which is in favour of our research.
Ericsson et al. [16] have researched government policies influence on the development of the bioenergy market in Sweden and Finland. Currently these countries have succeeded to make biomass an integrated part of modern energy systems. Particularly in Sweden, the long-standing policy commitments to biomass have facilitated this change from fossil fuel to biomass. In Sweden even a carbon tax has been used to make fossil fuel less attractive for users. They conclude with the statement that although all measures taken in these both countries might not

be applicable in all European countries, it has shown how policies can be effective in situations when there are actors that have the ability to respond constructively.
Hallmann and Amacher [17] state, not only the policy of governments is important. If the policy is not known, potential users will not be able to benefit from the advantages. Also the transaction costs are a factor that cannot be ignored. Others have also researched the influence of policy instruments on Environmental Techniques and Measures, for example Renewable Heating [18]. This research also investigates the impact of policy instruments on the development of renewable heating technologies. The variables found in this research are possibly useful in the search for variables influencing the adoption of biomass boilers in the Netherlands.
According to Ragossnig [19], the use of biomass is most efficient when used as a heat source and biomass is a scarce resource competing with food production for land use. Governments therefore need to make wise decisions, and political support for this sector should be increased. Mainly the high investment costs are an important barrier, which can be solved by incentives made by the government.

A5.4. Other studies about the adoption of environmental techniques / measures

There are some comparable studies available, for example the study of Vasseur & Kemp [20]. The study of Vasseur & Kemp is about the adoption of PV panels in the Netherlands, which is also a sustainable technique to improve a building. By comparing the adoption of PV panels, it might be possible to determine shared influencing factors, which can be used to work out the research of biomass boilers. These other studies will be used to check if the found influencing factors in this study can also be explained by comparable sustainable techniques and measures.
Another comparable study is the one done by Arkesteijn & Oerlemans [21]. They've researched the adoption of green electricity in the Netherlands amongst consumers. They used empirical methods to determine which variables are important in changing towards green energy. This research therefore has a lot of similarities with the research about the adoption of biomass boilers in the Netherlands. The main difference is the fact that they focussed on consumers, where this research focusses on companies, however the variables found in their model could be applied in the case of the biomass boilers. This of course needs validation.
Balcombe, Rigby and Azapagic [22] have researched the motivations and barriers associated with adopting microgeneration energy technologies in the United Kingdom. This is again an environmental technique of which is determined how the adoption can be adjusted. Some other studies have been done to determine how to overcome barriers for bioenergy [7]. There are different barriers, which all require different strategies to overcome them. For example the economic conditions can be altered by investment grants or policy measures, while know-how and institutional capacity can be overcome by pilot projects or local initiatives. These possible strategies will be taken into consideration when de definitive model is made.
According to Vasseur & Kemp, the category Complexity is not a reason to adopt if it is low, but it is a reason not to adopt even though the relative advantage is positive if the complexity is high. Arkesteijn & Oerlemans [21] also state that the complementation of economic variables with variables derived from the cognitive sciences is a fruitful strategy. However, all four papers used state that economic variables are most important when making the adoption decision. Therefore the (perceived) financial benefits should be the most important factor in making the adoption decision model, with the other factors such as complexity and environmental responsibility complementing the model. The environmental responsibility is mentioned in multiple papers, but is never the main driver for adoption environmental friendly techniques. Therefore it is possible this factor can be neglected. This has to be found out during the research.
According to the research done by Vermeulen and Hovens [9, p. 2733] "subsidies are the strongest explanation for the differences in the economic assessment of the 'young' innovations". The use of biomass boilers in the Netherlands is also relatively new, therefore this could also be a factor in this research. Furthermore the model which explains the adoption of energy innovations changes if the innovations matures, therefore in the article a two-level strategy is advised. The strongest causal relations found by Vermeulen and Hovens are the local policies, requests by partners, perception of benefits, use of subsidies, and characteristics of the technology. These factors will be taken into account in this research.
All results of the different comparable studies can be used to find variables, which could also be applicable in the research of the adoption of biomass boilers in the Netherlands. Most studies are about comparable techniques, which also are environmentally friendly but require an initial investment. Because these studies are comparable, a lot can be learned from them.

A5.5. International reports about the adoption of biomass boilers

The RVO currently is involved in a European initiative called Biomass4Business. This initiative looks into the implementation of more biomass in Europe as an energy source. Therefore they have a lot of useful information, which could be used to improve this research.

There are several reports available in which the different countries involved in Biomass4Business are discussed. Not only influencing variables but also promising markets for the adoption of biomass boilers are identified in those reports. The variables will be used for the initial identification of relevant factors influencing the adoption decision, as mentioned before. The factors can be found in Appendix C and Appendix D

A5.6. Initial adoption model

The adoption model has been made, using different influencing factors found in the literature, as can be read in Chapter A5.4. These factors have been translated to the case of biomass boiler adoption in the Netherlands.

Firstly it is necessary to know how a decision of adopting a biomass boiler is made. A decision like this is made by using the knowledge that is available to the principal and weighing all advantages and disadvantages of the decision. However, not all knowledge is known and not all knowledge is actually correct because the perception of the principal can differ from the actual facts. This is very important in the decision making process of entrepreneurs [23]. Therefore the adoption decision is made based on the limited knowledge available. The model uses these three types of knowledge to categorise the different variables found in the papers mentioned in this chapter. Of course these three categories influence each other, which needs to be taken into consideration during the quantification of the different variables.

Of the three categories, the first are the actual measurable factors. These can be measured by looking into the data and actually calculating everything. The second category is the perception of these numbers. Not always is everything calculated, which means an estimation is made. This perception might give an incorrect view of the actual variables. The last category consists of the variables that are not known. Even though these variables are unknown they can be important, which means the principle has to take a risk or do more research to get more information.

The most important variables found in the literature mentioned in this chapter have been divided amongst these three categories. The first category has then also been divided into financial, technical and other variables. This is because most adoption decisions are made based on finances and technical specifications. Therefore these categories are the most important within the measurable variables.

This results in the initial adoption-decision-model as seen in Figure 6. This is still the initial model, which will be expanded and improved during the empirical research. Then the different variables will also be quantified and be given a weighing factor, until the final model is finished.

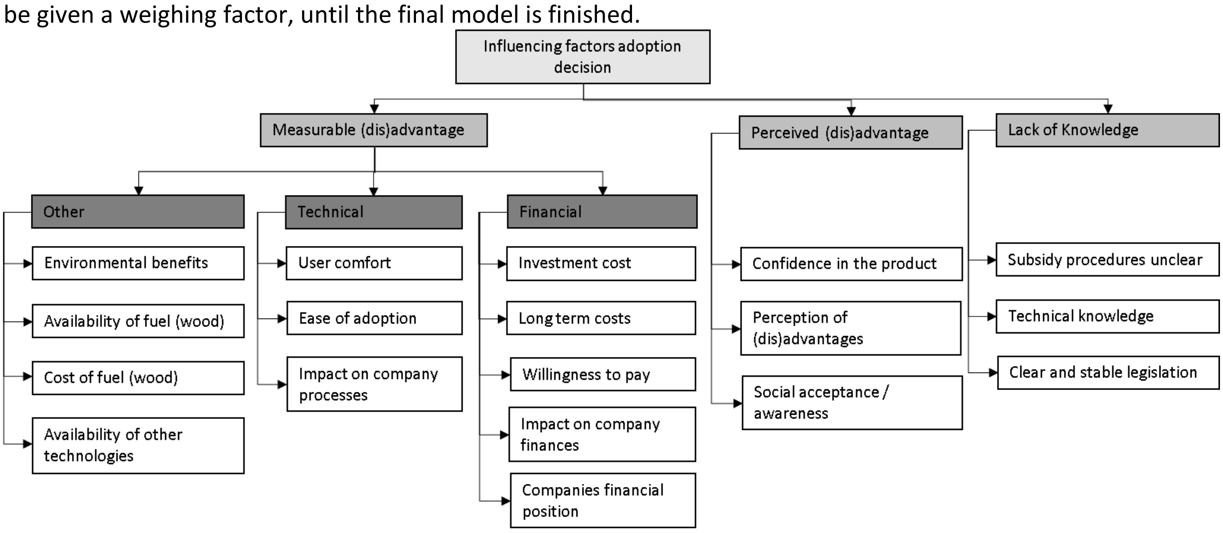


Figure 6- Initial adoption decision model

Because not much case studies (probably between 20 and 30) will be held due to time limitations, it is not possible to determine the influence for each sub-factor but only for the main factors. Therefore only the three main factors will be quantified in the model, and the measurable main factors will be quantified during the empirical research.

These factors can be sub-divided in other factors. The research will focus on these influencing factors, while during the research possibly some will be added or removed. With all this information a model will be created such as the one proposed by Dieperink, Brand and Vermeulen [24]. They have created an integrated analytical framework for all energy-saving innovations, which can be used and adapted to our situation. They propose a model in which a few different categories of aspects are used to determine how an innovation is diffused in the Netherlands. Such a framework is also made by Tsoutsos and Stamboulis [25], in which other aspects are used to explain how sustainable innovations are diffusing but also a model is created. This model not only explains all variables, but also the dynamics between them. This is also something which will be used in this research, because if a change is needed, a static model is not enough to explain everything.

Some influencing factors have a higher influence than others. For all the ones found in the literature, their influence is categorised ranging from low, medium to high (0). During the empirical research, the focus should lay on the ones with the high influence. However, the ones with a lower influence for comparable techniques and situations can be of a high influence in the case of the adoption of biomass boilers. Therefore they should also be taken into consideration.

The model can be used to determine a market potential for the adoption of biomass boilers, if the different variables for different markets sectors are known. The model should be able to give an estimation for companies if it profitable for them to adopt a biomass boiler and if they are likely to commence adoption if they are aware of the possibilities.

The next steps are to perform the empirical research and the synthesis of both, which should lead to the definitive model. This model can later be used to estimate a market potential for the adoption of biomass boilers and how to improve this potential.

A. References

[1] R. Kemp, „Technology and the transition to environmental sustainability," *Futures,* pp. 1023 - 1046, 1994.

[2] bioenergy4business, „about the project," 2016. [Online]. Available: http://www.bioenergy4business.eu/.

[3] Centraal Bureau voor de Statistiek, „Hernieuwbare energie in Nederland in 2014," Studio BCO, Den Haag, 2015.

[4] Nederlandse vereniging voor Biomassa Ketel Leveranciers, „NBKL," 2016. [Online]. Available: www.nbkl.nl.

[5] Rijksdienst voor Ondernemend Nederland, „Scenariostudie Marktpenetratie en Emissies Biomassaverbranding," Procede Biomass BV, Enschede, 2015.

[6] Houtpellets.info, „Kostenbesparing," 2016. [Online]. Available: http://www.houtpellets.info/kostenbesparing.html.

[7] K. McCormick en T. Kaberger, „Key barriers for bioenergy in Europ: Economic conditions, know-how and institutional capacity, and supply chain co-ordination," *Biomass & Bioenergy,* pp. 443 - 452, 2007.

[8] E. M. Rogers, Diffusion of Innovations, 5th Revised edition red., Simon & Schuster Ltd, 2003, p. 512.

[9] W. Vermeulen en J. Hovens, „Competing explanations for adopting energy innovations for new office buildings," *Energy Policy,* pp. 2719 - 2735, 2006.

[10] Hekkert, „Functions of innovation systems: A new approach for analysing technological change," *Technological forecasting and Social change,* pp. 413-432, 2007.

[11] M. Beerepoot en N. Beerepoot, „Government regulation as an impetus for innovation: Evidence from energy performance regulation in the Dutch residential building sector," *Energy Policy,* pp. 4812-4825, 2007.

[12] C. Egmond, R. Jonkers en G. Kok, „A strategy and protocol to increase diffusion of energy related innovations into the mainstream of housing associations," *Energy Policy,* pp. 4042-4049, 2006.

[13] G. Moore, Crossing the Chasm, New York: Harper Collins, 2002.

[14] J. Markard, M. Hekkert en S. Jacobsson, „The technological innovation systems framework: Response to six criticisms," *Environmental Innovation and Societal Transitions,* pp. 76 - 86, 2015.

[15] M. Blesl, T. Kober, D. Bruchoff en R. Kuder, „Effects of climate and energy policy related measures and targets on the future structure of the European energy system in 2020 and beyond," *Energy Policy,* pp. 6278 - 6292, 2010.

[16] K. Ericsson, S. Huttunen, L. J. Nilsson en P. Svenningsson, „Bioenergy policy and market development in Finland and Sweden," *Energy policy,* pp. 1707 - 1721, 2004.

[17] F. Hallmann en G. Amacher, „Forest bioenergy adoption for a risk-averse landowner under uncertain emerging biomass market," *Natural resource modeling,* pp. 482 - 510, 2012.

[18] L. Kranzl, M. Hummel, A. Müller en J. Steinbach, „Renewable heating: Perspectives and the impact of policy instruments," *Energy Policy,* pp. 44 - 58, 2013.

[19] H. A. Ragossnig, „Heating up the EU biomass market," *Renewable Energy Focus,* pp. 56 - 58, 2007.

[20] V. Vasseur en R. Kemp, „The adoption of PV in the Netherlands: A statistical analysis of adoption factors," *Renewable and Sustainable Energy Reviews,* pp. 483-494, 2015.

[21] K. Arkesteijn en L. Oerlemans, „The early adoption of green power by Dutch households: An empirical exploration of factors influencing the early adoption of green electricity for domestic purposes," *Energy Policy,* pp. 183 - 196, 2005.

[22] P. Balcome, D. Rigby en A. Azapagic, „Motivations and barriers associated with adopting microgeneration energy technologies in the UK," *Renewable and Sustainable Energy Reviews,* pp. 655 - 666, 2013.

[23] A. Minkes en G. Foxall, „Herbert Simon and the concept of dispersed entrepreneurship," *Journal of Economic Psychology,* pp. 221 - 228, 2003.

[24] C. Dieperink, I. Brand en W. Vermeulen, „Diffusion of energy-saving innovations in industry and the built environment: Dutch studies as inputs for a more integrated analytical framework," *Energy Policy,* pp. 773-784, 2004.

[25] T. Tsoutsos en Y. Stamboulis, „The sustainable diffusion of renewable energy technologies as an example of an innovation-focused policy," *Technovation,* pp. 753-761, 2005.

[26] Rijksoverheid, „Kan ik subsidie krijgen voor een zonneboiler, warmtepomp, pelletkachel of biomassaketel?," 2016. [Online]. Available: https://www.rijksoverheid.nl/onderwerpen/energie-thuis/vraag-en-antwoord/subsidie-zonneboiler-warmtepomp-pelletkachel.

[27] Rijksdient voor ondernemers, „Stimulering Duurzame Energieproductie (SDE),” 2016. [Online]. Available: http://www.rvo.nl/subsidies-regelingen/stimulering-duurzame-energieproductie-sde.

[28] Rijksoverheid, „Kamerbrief over de stimulering van hernieuwbare energieproductie in 2016,” 2016. [Online]. Available: https://www.rijksoverheid.nl/documenten/kamerstukken/2015/12/07/kamerbrief-over-de-stimulering-van-hernieuwbare-energieproductie-in-2016.

[29] Rijksoverheid, „Ketel of kachel gestookt met biomassa,” 2016. [Online]. Available: http://www.rvo.nl/subsidies-regelingen/milieulijst-en-energielijst/eia/ketel-kachel-gestookt-met-biomassa.

[30] Eurostat, „Europe 2020 indicators - climate change and energy,” 2016. [Online]. Available: http://ec.europa.eu/eurostat/statistics-explained/index.php/Europe_2020_indicators_-_climate_change_and_energy.

[31] European Biomass Association, „The basics of Biomass,” 2016.

[32] Greenmatch, 2015.

[33] Court of the Hague, „Klimaatzaak,” Rechtbank Den Haag, the Hague, the Netherlands, 2015.

[34] FSC Nederland;, „Certificering,” 2016.

[35] Kenniscentrum InfoMil, „Handleiding over de eisen aan grote stookinstallaties,” 2016. [Online]. Available: http://www.infomil.nl/onderwerpen/klimaat-lucht/stookinstallaties/grote/.

[36] Kenniscentrum InfoMil, „biomassa in het Activiteitenbesluit,” 2016. [Online]. Available: http://www.infomil.nl/onderwerpen/klimaat-lucht/stookinstallaties/biomassa-0/biomassa-verstaan/.

[37] Sociaal-Economische Raad;, „Welke thema's?,” 2016. [Online]. Available: http://www.energieakkoordser.nl/thema.aspx.

[38] Rijksoverheid, „Informatieblad Milieubelastingen,” 2015. [Online]. Available: https://www.rijksoverheid.nl/onderwerpen/belastingplan/documenten/brochures/2015/09/15/informatieblad-milieubelastingen-belastingplan-2016.

[39] Rijksoverheid, „Afvalstoffenbelasting,” 2015. [Online]. Available: https://www.rijksoverheid.nl/onderwerpen/milieubelastingen/inhoud/afvalstoffenbelasting.

[40] A. Darmani, N. Arvidsson, A. Hidalgo en J. Albors, „What drives the development of renewable energy technologies? Toward a typology for the systemic drivers,” *Renewable and Sustainable Energy Reviews,* pp. 834 - 847, 2014.

[41] R. R. Harmon en K. R. Cowan, „A multiple perspectives view of the market case for green energy,” *Technological Forecasting & Social Change,* pp. 204 - 213, 2009.

[42] UGB, „Vyncke Biomass,” March 2015. [Online]. Available: http://www.ugaatbouwen.com/fr/news/199.

[43] NBKL, „Leden,” 2016. [Online]. Available: http://nbkl.nl/over-de-nbkl/leden.

[44] Eurostat, „Share of renewable energy sources in heating and cooling,” 2016. [Online]. Available: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Share_of_renewable_energy_sources_in_heating_and_cooling_%28%25%29.png.

Appendix B - Published article in VV+

During the initial research, the first findings were used to publish an article into a technical magazine. This was to widen the knowledge about biomass boilers and to gain more potential interviewees due to that widened knowledge. A copy of the article can be found below. The article is in Dutch, because it is written for a Dutch audience. The article has appeared in VV+, an technical magazine for the installation sector.

DUURZAME KLIMAATTECHNIEK

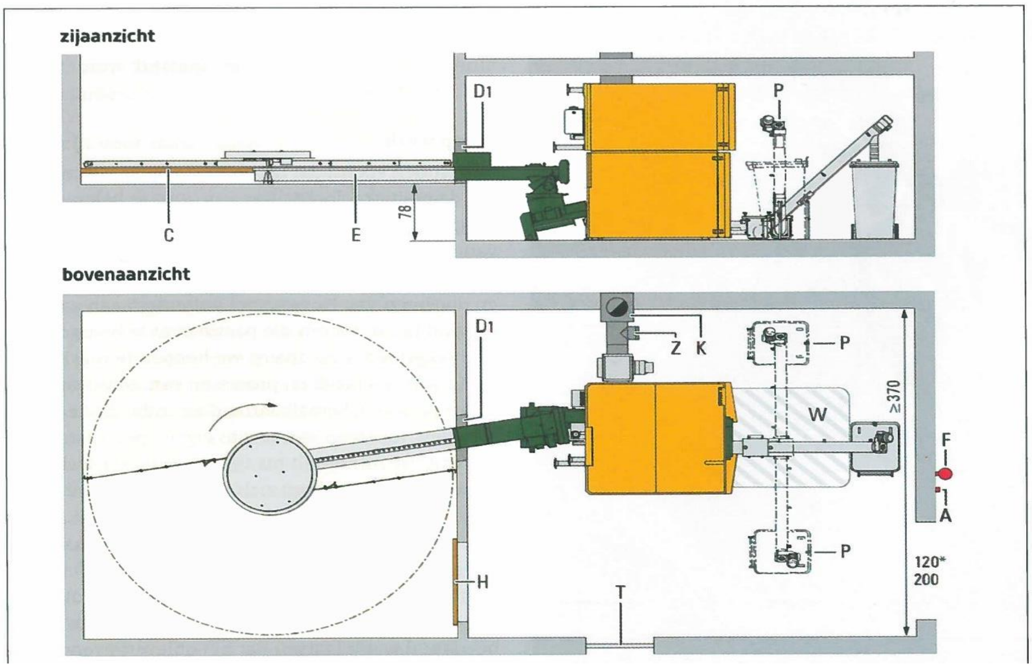
De overgang naar houtgestookte ketels

VERWARMEN MET HOUT

Het toepassen van hernieuwbare energie wordt steeds belangrijker. Op hout gestookte ketels zijn ook in een 'aardgasland' een aantrekkelijk alternatief, niet alleen voor het milieu, maar ook financieel. De Universiteit Twente heeft in samenwerking met de Nederlandse vereniging van Biomassa Ketel Leveranciers (NBKL) onderzoek gedaan naar de adoptie van houtketels in Nederland.

Tekst: N.H.M. Oude Vrielink BSc., dr.ir. A.G. Entrop, prof.dr.ir. J.I.M. Halman, dr.ir. E.E. Bolhuis.
Fotografie: Industrie

Nederland is een aardgasland bij uitstek. Sinds de gasbel bij Slochteren is gevonden, is hier het meest uitgebreide gasnetwerk ter wereld aangelegd. Toch is er een kleine verschuiving gaande naar het gebruik van hernieuwbare energietechnieken. In 2013 was slechts 3,5 procent van alle gebruikte energie afkomstig uit biomassa. In 2015 is dit opgelopen tot 3,91 procent [1].
In Nederland wordt jaarlijks ruim 26.109 m³ gas verbruikt door bedrijven [1]. Dit komt neer op 48.109 kg CO_2. Een groot gedeelte hiervan is te besparen door (verouderde) gasketels te vervangen door een ketel gestookt met biomassa, zoals houtchips (snippers) of houtpellets (samengeperste houtkorrels).
Een houtketel werkt hetzelfde als een gasketel, alleen wordt de brandstof met een vrachtwagen geleverd. Deze brandstof wordt vanuit een lokale opslag vervolgens



2. Bunker met houtsnippers voor automatische toevoer naar de ketel.

automatisch de ketel in getransporteerd. Ook moet de aslade eens in de paar weken of maanden worden geleegd. Een houtketel moet bij voorkeur zoveel mogelijk constant branden vanwege de langzame opstartcyclus. Daarom wordt meestal een warmtebuffer geplaatst (figuur 1), waardoor de ketel minder vaak aan en uit hoeft.

Onderzoek

In andere Europese landen, zoals Duitsland, Italië, Noorwegen, Oostenrijk en Zweden, worden deze op hout gestookte ketels al veelvuldig toegepast, maar in Nederland nog slechts mondjesmaat. Gemiddeld worden er in Nederland jaarlijks in bedrijven slechts zo'n vijfhonderd ketels geplaatst, terwijl er elk jaar duizenden gasketels worden vervangen.
In het onderzoek van de Universiteit Twente en de NBKL is gekeken hoe het verschil in gebruik met een aardgasgestookte ketel in de praktijk wordt ervaren, mede met hulp van een aantal casestudies.
In de literatuur zijn enkele aspecten te vinden die kunnen verklaren of iemand wel of niet overstapt op een duurzame techniek, zoals houtgestookte ketels. Zo wordt de onduidelijkheid en beschikbaarheid van subsidies vaak genoemd [2,3, 4, 5], maar ook de investeringskosten [2, 4] en de verwachtte haalbaarheid van het project [3,4, 6] zijn erg belangrijk.
In het onderzoek is empirisch onderzocht of deze en andere factoren ook van invloed zijn bij de aanschaf van houtketels in Nederland. De literatuur is gebruikt bij het voorbereiden van de interviews
In het onderzoek is uitgezocht hoe bedrijven tot de beslissing komen een houtketel aan te schaffen en wat in hun ogen de voor- en nadelen daarvan zijn ten opzichte van andere systemen. Op deze manier kunnen barrières worden

	boomkwekerij Huiting	campus Easy Street	sportcomplex De Beemd
vermogen [kW]	150	1.200 (2x600)	500
besparing aardgas [m³/maand]	2.000	22.000	2.300
soort materiaal	eigen houtsnippers	houtpellets	houtpellets
subsidies	EIA	EIA, MIA	-
vollast [h/a]	4.000	2.200 (veel deellast)	3.500
in gebruik	twee jaar	vier jaar	twee jaar

Tabel 1. Algemene projectinformatie van de drie cases.

voordelen	nadelen
kostenbesparing door lage brandstofprijs	voorzichtig zijn met welk materiaal er de ketel in gaat (niet te grote stukken)
goed voor het milieu	
eigen materiaal (en materieel) beschikbaar	
genoeg ruimte voor schuurtje beschikbaar	
minder afhankelijk van externe leveranciers	

Tabel 2. De voor- en nadelen die zijn genoemd bij noomkwekerij Huiting.

gevonden, die mensen ervan weerhouden om een houtketel aan te schaffen. Hiervoor zijn ook drie cases – een boomkwekerij in Vianen, een wooncomplex in Breda en een sportcomplex in Lochem (tabel 1) – onderzocht, waarbij de ervaringen van de gebruikers door via interviews is bepaald. Uit deze cases moet blijken welke factoren belangrijk zijn bij de keuze voor een houtgestookte ketel.

Cases

De eerste case is boomkwekerij Huiting te Vianen, waar sinds twee jaar alle ruimtes in het bedrijf worden verwarmd met een houtketel gevoed met houtsnippers uit eigen productie (figuur 2). Hierdoor is de brandstof nagenoeg gratis. Volgens de eigenaar is besparing van brandstofkosten, circa 2.000 euro per maand, een belangrijk voordeel (tabel 2). Bij deze case is niet alleen een aanzienlijke kostenbesparing verwezenlijkt – de investering wordt naar verwachting in vijf jaar terugverdiend – maar is ook een grote stap gezet richting het verduurzamen van de boomkwekerij en tuincentrum.

De tweede case betreft het wooncomplex Campus Easy Street in Breda waar 338 appartementen en studentenwoningen met twee pelletketels worden voorzien van warmte en warm tapwater. De rookgassen worden gefilterd met doekenfilters en een buffer zorgt voor een efficiënter gebruik van de ketels. Verder is de opslag van hout ondergronds uit het zicht weggewerkt (figuur 3). De projectleider geeft aan dat de ketels inmiddels al vier jaar draaien zonder technische storing. Doordat er vanaf het begin van dit bouwproject rekening was gehouden met de houtgestookte ketels, was al in het eerste ontwerp de ruimte, de opslag en een rookkanaal voor de installatie verwerkt. Hierdoor was de installatie makkelijker te plaatsen dan het geval zou zijn geweest voor een bestaand gebouw (tabel 3).

De laatste case is sportcomplex De Beemd in Lochem. Dit werd tot 2012 verwarmd met een wkk-installatie. Deze installatie bleek uiteindelijk vrij duur te zijn in gebruik,

3. De toegang tot de ondergrondse pelletbunkers bevindt tussen de parkeerplaatsen.

waardoor werd besloten om alternatieven te bekijken. De gemeente heeft na afweging van de alternatieven gekozen voor een pelletketel die het gehele complex – inclusief kantine, kantoren, zwembad en sporthal – voorziet van warmte, warm zwemwater en warm tapwater.

Na een aanbesteding met meerdere partijen is de ketel geplaatst in het bestaande ketelhuis. De facilitymanager geeft aan gelukkig te zijn met de installatie, die hem interessante data terug levert om zijn vastgoedobject energie-efficiënt te laten zijn. Met de komst van deze installatie kon de gemeente Lochem haar duurzaamheidsdoelstellingen ten dele verwezenlijken en wordt geld bespaard op de kosten van het sportcomplex (tabel 4).

Hout als brandstof

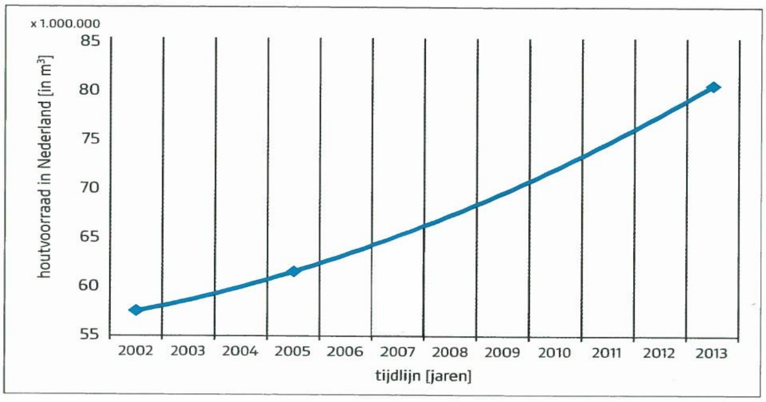
Hout als brandstof is niet alleen circa 10 procent goedkoper dan aardgas (per kWh) [7], maar is ook milieuvriendelijker en minder afhankelijk van de wereldmarkt. Hout kan lokaal worden gewonnen, waardoor de gebruiker minder afhankelijk is van bijvoorbeeld Russisch of Gronings aardgas.

voordelen	nadelen
groen project	hoge investeringskosten
makkelijk te implementeren doordat het een nog te bouwen gebouw was	binnenstedelijk, dus de opslag moest goed (ondergronds) worden weggewerkt
terugverdientijd is kort in vergelijking met de technische levensduur van de ketel	
lage brandstofprijs	

Tabel 3. De voor- en nadelen die zijn genoemd bij campus Easy Street.

voordelen	nadelen
goed voor het milieu en CO_2-neutraal	hoge investeringskosten
goedkoper dan de wkk-installatie door lage brandstofprijs	bang voor rookoverlast (uiteindelijk niks aan de hand)
gebruik lokaal gewonnen materiaal als brandstof mogelijk	iets meer werk dan een gasketel
niet afhankelijk van gasleveranciers	

Tabel 4. De voor- en nadelen die zijn genoemd bij sportcomplex De Beemd.



4. De houtvoorraad in m^3 in Nederland in onder andere bossen (bron: stichting Probos).

Het feit dat hout lokaal kan worden gewonnen, kan daarnaast de lokale economie stimuleren. Dit maakt het tot een betrouwbaardere en minder aan prijsschommelingen onderhevige brandstof.

Ook kan een houtketel gewoon branden als het windstil is of de zon niet schijnt. Hierdoor kan een houtketel als een betrouwbaardere energievoorziening worden bestempeld dan menig andere duurzame energiebron. Hout dat in de Nederlandse bossen en parken op de grond wegrot, creëert evenveel uitstoot van CO_2 als hout dat wordt verbrand. Het verschil is dat als het hout wordt verbrand, het nog een nuttige toepassing heeft voordat er uitstoot plaatsvindt. Snoei- en resthout is dus na droging geschikt voor verbranding.

In Europa groeit elke drie jaar genoeg hout aan om een bos ter grootte van België te vullen [8]. Ook in Nederland groeit de voorraad hout in de bossen (figuur 4) [9]. Het gebruik van hout gaat dus niet ten koste van onze bossen. Het laatste argument is de prijs van houtpellets, deze is volgens de betrokken lager dan de prijs van aardgas. Ook is de prijs van houtpellets veel stabieler dan die van aardgas [10]. Dit komt onder andere omdat deze minder afhankelijk is van de wereldmarkt en lokale productie veel belangrijker is.

Als er schoon materiaal van constante kwaliteit wordt gebruikt en de ketel correct wordt onderhouden, is het mogelijk met een rendement van 90 – 95 procent water te verwarmen. Met een condensor kan door te rekenen met de calorische onderwaarde, het rendement zelfs het theoretisch maximum van 100 procent iets overstijgen, net als bij een gasketel.

Hogere dichtheid

Het besturingssysteem van de ketel regelt ook de aanvoer van pellets of snippers vanuit de bunker. Ondanks het feit dat snippers goedkoper zijn, hebben in een dicht bebouwde omgeving pellets de voorkeur doordat er minder rookgassen ontstaan. Pellets hebben tevens een hogere dichtheid en verbrandingswaarde, waardoor er minder transportbewegingen nodig zijn.

De investering in een houtketel kan aantrekkelijker worden door gebruik te maken van subsidies. Er zijn verschillende subsidies beschikbaar voor ketels gestookt op biomassa, zoals de SDE+-regeling (stimulering duurzame energieproductie) voor ketels groter dan 500 kW [11]. Sinds dit jaar is er ook de ISDE-regeling (investeringsregeling stimulering duurzame energieproductie) voor ketels kleiner dan 500 kW [11]. Een andere mogelijkheid is de EIA (energie investeringsaftrek) [11]. Verder kan in bepaalde gevallen ook nog de MIA (milieu investeringsaftrek) worden gebruikt [11].

IN NEDERLAND WORDEN JAARLIJKS SLECHTS VIJFHONDERD KETELS GEPLAATST

De SDE+-subsidie is gekoppeld aan de gasprijs, waardoor deze altijd hoog uitvalt bij een lage gasprijs of vice versa. Voor grootverbruikers is weliswaar de businesscase vaak lastiger rond te krijgen, omdat deze minder energiebelasting betalen (0,01212 €/m^3 aardgas voor grootgebruikers tegen 0,25168 €/m^3 voor kleingebruikers [12]).

Analyse

De cases tonen aan dat er verschillende uitvoeringsvarianten van houtgestookte ketels zijn. Het onderhoud en de storingsgevoeligheid van een ketel is lager bij een hogere kwaliteit brandstof. Dit betekent dat ondanks dat pellets duurder zijn dan houtsnippers, het onderhoud en de hoeveelheid storingen juist minder zijn. Evenzo zijn er door de geïnterviewde partijen verscheidene voor- en nadelen benoemd (tabel 5). Deze voor- en nadelen zijn gedeeltelijk, voor wat betreft investeringskosten en economische haalbaarheid, terug te vinden in de literatuur. De geïnterviewden noemden weliswaar niet direct het belang van subsidies, maar de eco-

voordelen	nadelen
lage brandstofprijs (drie keer genoemd)	hoge investeringskosten (twee keer genoemd)
hout is hernieuwbaar en CO_2-neutraal (drie keer genoemd)	er is veel ruimte nodig voor onder andere brandstofopslag (een keer genoemd)
minder afhankelijk van externe partijen, zoals gasleveranciers (twee keer genoemd)	iets meer werk/onderhoud dan een gasketel, vooral bij gebruik snippers (een keer genoemd)
lokaal gewonnen brandstof mogelijk (twee keer genoemd)	kwaliteit van brandstof moet altijd gelijk zijn (een keer genoemd)
terugverdientijd is kort in vergelijking met de technische levensduur (een keer genoemd)	

Tabel 5. De voor- en nadelen van een houtketel ten opzichte van een gasketel.

nomische haalbaarheid leunt uiteraard wel hierop.
Een van de genoemde barrières is de hoge investeringskosten. Uit de cases blijkt echter dat deze kosten, eventueel met subsidies, terug zijn te verdienen binnen de technische levensduur van de ketel. Zonder een dergelijk positief financieel resultaat was de adoptie van de ketel niet tot stand gekomen. De directe beschikbaarheid van hout als brandstof, zoals in het geval van boomkwekerij Huiting (case 1), is zeer voordelig. Case 2 leert dat ook de locatie van de ketel van belang is voor de hoogte van de investering. Zo moeten er in de bebouwde kom meer investeringen worden gedaan om alles passend in gebouw en omgeving te installeren. Wanneer buitenaf de installatie wordt geplaatst, is vaak meer ruimte beschikbaar. Binnen de bebouwde kom moet eveneens de schoorsteen hoger worden en wordt alleen een esthetisch verantwoorde opslag voor de brandstof geaccepteerd.

Conclusies

Uit de drie cases van het onderzoek blijkt dat men vooral tevreden is met de lagere kosten van hout ten opzichte van aardgas en het feit dat hernieuwbaar hout milieuvriendelijker is. Hout kent als brandstof een stabielere prijsontwikkeling dan menig fossiele brandstof en dit zal naar verwachting ook in de toekomst zo blijven. Dit beperkt het risico van een investering in houtgestookte installaties ten opzichte van gasgestookte installaties.
Organisaties die al beschikken over voorraden (rest-)hout dat als brandstof kan dienen, kunnen een kortere terugverdientijd tegemoet zien, dan organisaties die hier niet over beschikken. Twee van de bestudeerde cases tonen echter aan dat investeringen ook voor andere organisaties dan boomkwekerijen, hoveniers, gemeentewerven, timmerfabrieken en dergelijke, economisch verantwoord kunnen zijn. Recente ontwikkelingen in de sector moeten leiden tot verdere ontzorging in de vorm van een totaalcontract, waarbij de gebruiker geen omkijken meer heeft naar het onderhoud van de ketel en waarbij zelfs de brandstofleveringen worden geautomatiseerd. <<

Auteurs

- N.H.M. (Nick) Oude Vrielink is master-student Civil Engineering & Management aan de Universiteit Twente. Hij doet zijn master-onderzoek naar adoptie van houtketels in Nederland bij de NBKL.
- Dr.ir. A.G. (Bram) Entrop is universitair docent Duurzaam Bouwen bij de vakgroep Bouw/Infra van de Universiteit Twente. Hij is betrokken als begeleider van dit onderzoek.
- Prof.dr.ir. J.I.M. Halman is hoogleraar Innovatie en risicomanagement bij de vakgroep Bouw/Infra van de Universiteit Twente. Hij is betrokken als begeleider van dit onderzoek.
- Dr.ir. E.E. Bolhuis is voorzitter van de Nederlandse vereniging van Biomassa Ketel Leveranciers (NBKL), de opdrachtgever van het onderzoek. Hij is betrokken als begeleider van dit onderzoek.

Referenties

1. CBS, 'Biomassa; verbruik en energieproductie uit biomassa per techniek', http://statline.cbs.nl, 2016.
2. Vasseur V., Kemp R., 'The adoption of pv in the Netherlands: a statistical analysis of adoption factors', Renewable & Sustainable Energy Reviews 41, 2014.
3. Balcombe P., Rigby D., Azapagic A., 'Motivations and barriers associated with adopting microgeneration energy technologies in the UK', Renewable & Sustainable Energy Reviews 22, 2013.
4. Vermeulen W.J.V., Hovens J., 'Competing explanations for adopting energy innovations for new office buildings', Energy Policy 34(17), 2006.
5. Beerepoot M., 'Policy profile: encouraging use of renewable energy by implementing the energy performance of buildings directive', European Environment 16(3), 2006.
6. McCormick K., Kaberger T., 'Key barriers for bioenergy in Europe: economic conditions, know-how and institutional capacity, and supply chain co-ordination', Biomass & Bioenergy 31(7), 2007.
7. Kostenbesparing, www.houtpellets.info, 2016.
8. United Nations Economic Commission for Europe, 'Forests in Europe and North America are growing but remain vulnerable to threats', 2011.
9. Stichting Probos, 'Kerngegevens Bos en Hout in Nederland', www.probos.nl, 2016.
10. Laat P. de, Boer M. de, 'Onderzoek naar de mogelijkheden van monitoring van de prijs van biomassastromen als beleidsinstrument', www.rvo.nl, 2015.
11. Rijksdienst voor Ondernemend Nederland, 'Subsidies & financiering', www.rvo.nl, 2016.
12. Belastingdienst, 'Tabellen tarieven milieubelastingen', www.belastingdienst.nl, 2016.

Appendix C - Influencing factors found in the literature

Several influencing factors, which affect the adoption decision have been found in literature. These variables are all from comparable studies, but the actual research has to decide whether they are also applicable in the adoption decision of a biomass boiler. All relevant variables and the articles they are found in are shown in the table below (Table 4). Also the amount of articles endorsing a certain variable is given.

Table 4 – Adoption decision affecting variables

Variable	Influence level	Source	Endorsements
Subsidy procedure is clear and reliable	High	[19]–[22]	4
Availability of information for the principal / awareness	High	[19]–[21], [23]–[25]	6
Technical knowledge of the principal	High	[19], [21], [26]	3
Investment costs / Payback period	High	[19]–[21], [27]	4
Environmental benefits	Little	[19], [28], [29]	3
Perception of price	High	[20], [23], [30]	3
Confidence in the product	High	[23], [31], [32]	3
Ease of adoption / compatibility with alternatives	High	[20], [23], [27], [30], [32]–[36]	9
Willingness to pay	High	[23], [26]	2
Know-how / experience in the sector	High	[21], [37], [38]	3
Sound energy policies	High	[32], [37], [39], [40]	4
Availability of fuel (wood chips / pellets)	Medium	[29], [34], [37]	3
Competition for resources (subsidy / wood) / Price stability	Medium	[29], [35]–[37], [41]	5
Perceived viability	High	[20], [21], [25], [28], [32], [35]–[37], [42]	9
Non-technical barriers (such as learning)	High	[37]	1
Handling of the (bulky) Fuel	Medium	[43]	1
Energy Performance coefficient / rules on maximum emissions	Medium	[22], [41], [44]	3
Social acceptance / Observability	High	[26], [31], [35], [41], [45], [46]	6
Political framework	High	[47]–[49]	3
Pragmatism / being an early adopter	High	[50]	1

As seen in the table, the availability of information, the ease of adoption and compatibility with existing systems and the perceived viability of such a project and last but not least, the social acceptance and observability are the most endorsed factors influencing the adoption of RET's. Also the price stability and competition for fuel (affecting this stability) is a factor which is often mentioned in the different articles. Therefore, it is assumed these are also the most important and therefore these factors have especially been taken into consideration during the initial interviews.

Appendix D - Influencing factors found internationally

In the reports provided by the RVO and created by Bioenergy4Business [16], the different factors that influence the adoption of biomass boilers are divided into the categories Financial, Technical, Organizational and Risk support. All given risks have been summarized and categorized in Table 5.

Table 5 – Internationally influencing factors for the adoption of biomass boilers

Category	Factor	Found in which country	Times mentioned
Financial	Subsidies / tax concession / feed-in tariff	Austria, Bulgaria, Croatia, Poland, Romania, Ukraine	6
	Cost of gas/oil/etc.	Croatia, Romania, Slovakia	3
	Investment costs (payback period)	Austria, Croatia, Germany, Romania, Slovakia	5
	Purchasing power	Poland	1
Technical	Biomass availability (at competitive price)	Bulgaria, Finland, Greece, Poland, Romania, Ukraine	6
	Availability of gas network	Austria	1
	Storage	Croatia	1
Organizational	Social acceptance / Awareness	Austria, Bulgaria, Germany, Greece, Poland, Romania, Slovakia	7
	Missing Knowledge (about operating)	Austria, Finland, Germany, Greece	4
	Building codes	Croatia	1
	Entrepreneurs services and marketing, Contracting solutions	Finland, Slovakia	2
Risk support	Political commitment	Austria, Bulgaria	2
	Bank loans	Austria, Ukraine	2
	Clear and stable legislation (for example emission requirements)	Finland, Romania, Germany, Poland, Slovakia, Ukraine	6

As seen in the table, not all countries agree with what influences the adoption of biomass boilers the most. Not all countries give the same answers. However, some factors are mentioned more often than others. The ones most mentioned are likely to also have an influence in the Netherlands. Furthermore, the ones most mentioned are also mentioned in the literature as seen in Appendix C -. This can be seen in Table 6.

Table 6 – Combination International important factors and literature studies

Category	Factor	Endorsements by Bioenergy4Business	Endorsements in literature
Financial	Subsidies / tax concession / feed-in tariff	6	4
	Cost of gas/oil/etc.	3	9
	Investment costs (payback period)	5	4
Technical	Biomass availability (at competitive price)	6	5
Organizational	Social acceptance / Awareness	7	6
	Missing Knowledge (about operating)	4	6
Risk support	Clear and stable legislation (for example emission requirements)	6	3

All factors mentioned more than twice in the bioenergy4business study, are also mentioned multiple times in the literature study. Therefore, it is very likely these factors are the most important ones. This has to be verified by an empirical research.

Appendix E - Promising markets internationally

The reports of Biomass4Business [16] also give promising markets for the adoption of biomass boilers for the different countries. These different markets have been identified, categorized and summarized in Table 7. The number of occurrences is very important; this means more countries think the sector is important.

Table 7 – Promising markets internationally for adoption of biomass boilers

Category	Factor	Found in which country	Number of occurrences
Public buildings	In-house	Austria, Poland, Slovakia	3
	Hospitals, schools and nursing homes	Bulgaria, Croatia, Germany, Romania, Slovakia, Ukraine	6
	Swimming pools	Germany	1
	Vacation villages	Germany	1
Commercial buildings	Hotels	Austria, Bulgaria, Greece, Romania	4
	Shopping centres	Romania	1
Industry	Food-processing	Austria, Croatia, Finland	3
	Wood-processing factories	Bulgaria, Germany, Greece	3
	Metal industry	Finland	1
	Agriculture and forestry	Austria, Bulgaria, Croatia, Greece, Slovakia, Ukraine, Ukraine	7
District Heating	-	Croatia, Poland, Romania, Slovakia, Ukraine	5

As seen in the table, the most mentioned and thus most promising markets for the adoption of biomass boilers are Agriculture and forestry, Hospitals/Schools/Nursing homes and District heating. Also some countries mention hotels, but this is mostly in areas where no gas network exists.

Appendix F - First round interview questions

During the initial interview round the following topics were discussed. These topics come from the literature study, in which all these topics were found. They have been structured a bit, so the interview is also more structured.

Measurable aspects

a) Technical aspects
   i) User comfort
   ii) Ease of adoption
   iii) Impact on company processes
b) Financial aspects
   i) Investment cost
   ii) Long term cost
   iii) Willingness to pay
   iv) Impact on company finances
   v) Financial position of the company
c) Other aspects
   i) Environmental benefits
   ii) Availability of fuel (wood)
   iii) Cost of fuel (wood)
   iv) Availability of other technologies

Perceived aspects:

d) Perceived influences on the adopting decision
   i) Confidence in the product
   ii) Social acceptance
   iii) Awareness
e) Lack of knowledge of biomass boilers
   i) Subsidy procedure unclear
   ii) Technical knowledge
   iii) Clear and stable legislation

Appendix G - Second round interview questions

These questions were used during the second round of interviews. For all questions also an explanation was asked, which is used for an in depth analysis, while the numbers between 1 and 5 were used for quantification of the different variables. These questions were chosen because they encompass the most important aspects of the three factors chosen after the first interview round. Because the interviews are held in Dutch, the questions are also in Dutch.

Project specifieke informatie

1. Op welke locatie staat de ketel?
2. Hoe groot is de ketel (vermogen)?
3. Waarvoor is de ketel bedoelt?
4. Is degene die de adoptie-beslissing heeft gemaakt ook degene die hem beheerd?
5. Zijn er nog andere bijzondere project specifieke aspecten die interessant zijn?

Algemene aspecten

6. Was u al bekend met hout ketels voordat u er zelf een hebt aangeschaft? Zo nee, hoe heeft u er voor het eerst van gehoord?
7. Wat was voor u de belangrijkste reden om over te stappen op een hout gestookte ketel?
8. Indien er enige twijfel was, wat was hier de belangrijkste reden voor?
9. Was er genoeg informatie beschikbaar om een goede afweging te maken voor het wel of niet aanschaffen van een houtketel?
   Van totaal niet tot zeer belangrijk (getal tussen 1 en 5):
10. In hoeverre heeft het gebruiksgemak meegespeeld in de beslissing om wel of niet een houtketel aan te schaffen?
    Van totaal niet tot zeer belangrijk (getal tussen 1 en 5):
11. In hoeverre heeft het meegespeeld dat de ketel ‘past’ binnen de vorige installatie?
    Van totaal niet tot zeer belangrijk (getal tussen 1 en 5):

Milieu aspecten

12. Hoe belangrijks is het om een duurzame energievoorziening te hebben binnen uw bedrijf?
    Van niet tot zeer belangrijk (getal tussen 1 en 5):
13. Hoe vergelijkt u biomassa ten opzichte van andere duurzame energietechnieken?
    Van totaal niet duurzaam tot zeer duurzaam (getal tussen 1 en 5):
14. Heeft u of uw bedrijf veel affiniteit met duurzame technieken?
    Van totaal niet tot zeer veel (getal tussen 1 en 5):
15. Is het belangrijk dat de installatie zichtbaar is voor anderen, zoals uw klanten/buurt/branchegenoten?
    Van totaal niet tot zeer belangrijk (getal tussen 1 en 5):
16. Is het belangrijk dat de brandstof lokaal gewonnen wordt?
    Van totaal niet tot zeer belangrijk (getal tussen 1 en 5):

Financiële aspecten

17. Hoe belangrijk is het dat de terugverdientijd kort is voor een investering?
    Van niet tot zeer belangrijk (getal tussen 1 en 5):
18. Is het een barrière om een grote investering te doen, waarvan de subsidie pas later uitbetaald wordt?
    Van zeer moeilijk tot geen probleem (getal tussen 1 en 5):

Economische aspecten

19. Hoe belangrijk is het dat de subsidie de investering grotendeels dekt, dan wel zorgt voor een korte terugverdientijd?
    Van niet tot zeer belangrijk (getal tussen 1 en 5):
20. Is de subsidie-procedure duidelijk en simpel genoeg en is deze ook betrouwbaar genoeg in verband met het wel of niet toegewezen krijgen van de subsidie?
    Van niet tot zeer duidelijk (getal tussen 1 en 5):

Appendix H - Biomass boilers as renewable technique

Biomass can be used to create a more sustainable energy production in the European Union. The following text is found on the website of the European Commission [51]:

Biomass is derived from organic material such as trees, plants, and agricultural and urban waste. It can be used for heating, electricity generation, and transport fuels. Increasing the use of biomass in the EU can help diversify Europe's energy supply, create growth and jobs, and lower greenhouse gas emissions. In 2012, biomass and waste accounted for about two-thirds of all renewable energy consumption in the EU.

This means it is viewed as a sustainable source of energy, however only if certain criteria are met. For example, the EU forbids the use of biomass from land converted from forest, and other high carbon stock areas, as well as highly biodiverse areas. Also biofuels should emit at least 35% less greenhouse gases over their lifecycle when compared to fossil fuels. These and other criteria need to be monitored to ensure the sustainability of the biomass.

On the internet, several stories about deforestation of North American forests for use in European power plants can be found. However, these woods were to be deforested due to other reasons, for example deceases in the trees. Even if forests are harvested solely for the purpose of producing energy, the payback time for the carbon is between 18 and 38 years [52]. Therefore, within 38 years the production of energy will be carbon neutral.

Deforestation however creates a lot of carbon by releasing not only the carbon stored in the trees, but also the carbon stored in the soil. A lot of bio-material is stored in the soil, which disappears when the forest disappears. Therefore, the European Union only allows sustainably harvested material for use in power plants and other energy techniques.

Appendix I - First round interview Stakeholders

Different stakeholders are involved in the adoption of a biomass installation, the ones relevant for this research can be found in the table below (Table 8):

Table 8 – Adoption of biomass boilers stakeholders

Stakeholder	Description
Buyer / Owner	This is the person who actually pays for the installation and is the owner of the building in which the installation is placed. This is not necessarily the person who makes the decision to adopt a biomass boiler.
Principal	The Principal is the one who makes the decision to adopt a biomass installation. He might be an employee or otherwise authorized person which is not necessarily the owner.
Supplier / Installer	This is the company who installs and supplies the installation. Most of the time, the installation is imported and thus not build by this company.
Architect / Engineer	The person who decides how the building will look in the future or has decided how the installation needs to fit in the existing plans.
Advisors	This could be a consultant who advices about the usage of biomass boilers instead of other types of installations. Another advisor is the RVO, which is the executive organisation for the Ministry of Economic Affairs. They give entrepreneurs advice.
Users	The people who benefit from the installation and have to make sure the biomass boiler works properly. The users' opinion is therefore influenced by user comfort.
Government	All rules and regulations, as well as subsidies come from the government. This means they have a lot of influence in the adoption decision, however they are not actively involved in individual adoption projects. The main drivers to influence the adoption decision for the government are environmental agreements

Appendix J - Rules and regulations in the Netherlands

- Once every two years a biomass boiler (up to 150MW) needs to be inspected for safety, optimal combustion and energy efficiency. Boilers between 20-100 kW need inspection once every 4 years.
- At the commissioning, the emissions need to be measured.
- The emission is measured when the installation is running, so during the start-up the emission can be higher.

Table 9 - Emission norms in the Netherlands [53]

Maximum emissions biomass boilers	NOx (mg / m^3)	SO_2 (mg / m^3)	PM (mg / m^3)
< 400 kW	300	200	40
400 kW - 1 MW	300	200	40
1 MW < 5 MW	275	200	20
> 5 MW	145	200	5

The energy tax in the Netherlands is as follows [54]:

Consumption	Rate in 2015 in eurocents	Raise in eurocents	Raise in percentage	Rate in 2016 including inflation correction
Natural gas				
0 – 170.000 m^3	19.11	0.858	4.49	20.064
170.000 – 1.000.000 m^3	6.77	0.150	2.21	6.954
1.000.000 – 10 mln. m^3	2.47	0.055	2.21	2.537
> 10 mln. m^3	1.18	0.026	2.21	1.212
Natural gas in greenhouses				
0 – 170.000 m^3	3.069	0.138	4.49	3.222
170.000 – 1.000.000 m^3	2.278	0.050	2.21	2.339
1.000.000 – 10 mln. m^3	2.47	0.055	2.21	2.537
> 10 mln. m^3	1.18	0.026	2.21	1.212
Electricity				
0 – 10.000 kWh	11.96	0.000	0.00	12.020
10.000 – 50.000 kWh	4.69	0.283	6.04	4.996
50.000 – 10 mln. kWh	1.25	0.075	6.04	1.331
> 10 mln. kWh non-business	0.10	0.006	6.04	0.107
> 10 mln. kWh business	0.05	0.003	6.04	0.053

Appendix K - Support measures for Biomass Boilers in the Netherlands

Subsidies are a form of positive regulation. by financially aiding the use of biomass boilers. There are different subsidies available for biomass boilers, due to the fact they are more environmentally friendly then fossil fuels. This is why the government supports the implementation of more biomass boilers.

ISDE

Currently the ISDE regulation (Investeringssubsidie Duurzame Energy) subsidizes the adoption of biomass boilers by giving a minimum of €2500, - for small biomass boilers if the installation complies with certain norms and standard regarding for example a maximum emission norm. This subsidy can get higher for larger installations [55]. This subsidy is a onetime investment subsidy for installations smaller than 500kWh. The subsidy amount ranges from €2500, - up to €53.100, - (€110, - per kWh with a minimum of €2500,- for a ≤40kWh boiler).

SDE+

Another subsidy available is the SDE+ regulation (Stimulering duurzame energie), which is a total amount of about €12 billion for 2017. This will be divided amongst projects who register for a certain round. The first round gives the least money, but because the full sum is still available the highest chance of being accepted. The fourth and last round gives the highest compensation per kWh, but also the highest chance of rejection [10]. The amount of money to be paid by the government to the adopter is set at a fixed rate, but can differ if the gas prices change. If the gas prices drop, the SDE+ subsidy is also increased by using an correction rate. The SDE+ subsidy is a yearly recurring subsidy, and requires a minimum amount of full load hours that the installation runs. Then, combining the output of the installation in kWh and the full load hours, the total output is calculated and multiplied by the correction price. This results in the total subsidy, which changes every year, because of the different correction prices. In 2016 the provisional correction prices are set at €0.026 for installations between 0.5 and 5 MWe and €0.031 for installations larger than 5 MWe [56].

E.I.A.

The last subsidy is the EIA (Energie Investerings Aftrek) which is actually a tax reduction for companies that invest in sustainable techniques. They can get a maximum of 58% tax reduction for adoption a biomass boiler. This tax reduction lowers the initial investment costs [57]. This subsidy cannot be combined with the SDE+ regulation anymore. Therefore, this subsidy is not very attractive anymore, because the SDE+ regulation spreads over multiple years and is therefore more profitable.

Appendix L - Wood chips/Pellets as renewable energy source in Europe

The Netherlands had a 5.2% share of renewable energy in 2014, but this has to increase a lot to achieve the goals set in the 20/20/20 agreement. The different shares of different European countries can be seen in the figure below (Table 10) [58]:

Table 10 - Share of renewable energy sources in heating and cooling

	RES-all								Transport (with multipl. Counting)	
Member State	RES Share 2013	Average RES Share 2013/2014	RED indicative trajectory (2013/2014)	RES Share 2014	RES Share 2015 (proxy)	RED indicative trajectory (2015/2016)	projected RES Share 2020 (PRIMES Ref 2016)	RES 2020 target	RES-T shares 2014	RES-T shares 2015 (proxy)
	% final consumption								% final consumption	
AT	32.3%	32.7%	26.5%	33.1%	33.6%	28.1%	35.2%	34.0%	8.9%	8.3%
BE	7.5%	7.8%	5.4%	8.0%	7.3%	7.1%	13.9%	13.0%	4.9%	3.3%
BG	19.0%	18.5%	11.4%	18.0%	18.4%	12.4%	20.9%	16.0%	5.3%	5.3%
CY	8.1%	8.5%	5.9%	9.0%	9.1%	7.4%	14.8%	13.0%	2.7%	2.2%
CZ	12.4%	12.9%	8.2%	13.4%	13.6%	9.2%	13.5%	13.0%	6.1%	6.0%
DE	12.4%	13.1%	9.5%	13.8%	14.5%	11.3%	18.5%	18.0%	6.6%	6.4%
DK	27.3%	28.2%	20.9%	29.2%	30.6%	22.9%	33.8%	30.0%	5.8%	5.3%
EE	25.6%	26.0%	20.1%	26.5%	27.9%	21.2%	25.7%	25.0%	0.2%	0.2%
EL	15.0%	15.2%	10.2%	15.3%	15.5%	11.9%	18.4%	18.0%	1.4%	1.4%
ES	15.3%	15.8%	12.1%	16.2%	15.6%	13.8%	20.9%	20.0%	0.5%	0.5%
FR	14.0%	14.2%	14.1%	14.3%	14.5%	16.0%	23.5%	23.0%	7.8%	7.8%
FI	36.7%	37.7%	31.4%	38.7%	39.5%	32.8%	42.4%	38.0%	21.6%	22.0%
HR	28.1%	28.0%	14.8%	27.9%	27.5%	15.9%	21.1%	20.0%	2.1%	2.1%
HU	9.5%	9.5%	6.9%	9.5%	9.4%	8.2%	13.0%	13.0%	6.9%	6.7%
IE	7.7%	8.2%	7.0%	8.6%	9.0%	8.9%	15.5%	16.0%	5.2%	5.9%
IT	16.7%	16.9%	8.7%	17.1%	17.1%	10.5%	19.8%	17.0%	4.5%	4.7%
LT	23.0%	23.4%	17.4%	23.9%	24.3%	18.6%	24.0%	23.0%	4.2%	4.3%
LU	3.6%	4.1%	3.9%	4.5%	5.0%	5.4%	8.3%	11.0%	5.2%	5.9%
LV	37.1%	37.9%	34.8%	38.7%	39.2%	35.9%	40.3%	40.0%	3.2%	3.3%
MT	3.7%	4.2%	3.0%	4.7%	5.3%	4.5%	11.8%	10.0%	4.7%	5.0%
NL	4.8%	5.2%	5.9%	5.5%	6.0%	7.6%	13.0%	14.0%	5.7%	5.6%
PL	11.3%	11.4%	9.5%	11.4%	11.8%	10.7%	15.1%	15.0%	5.7%	5.9%
PT	25.7%	26.3%	23.7%	27.0%	27.8%	25.2%	33.4%	31.0%	3.4%	6.7%
RO	23.9%	24.4%	19.7%	24.9%	24.7%	20.6%	26.0%	24.0%	3.8%	3.9%
SE	52.0%	52.3%	42.6%	52.6%	54.1%	43.9%	56.2%	49.0%	19.2%	24.2%
SI	22.5%	22.2%	18.7%	21.9%	21.8%	20.1%	25.0%	25.0%	2.6%	2.6%
SK	10.1%	10.9%	8.9%	11.6%	11.9%	10.0%	14.3%	14.0%	6.9%	6.5%
UK	5.6%	6.3%	5.4%	7.0%	8.2%	7.5%	14.8%	15.0%	4.9%	4.2%
EU-28	15.0%	15.5%	12.1%	16.0%	16.4%	13.8%	21.0%	20.0%	5.9%	6.0%

As seen in Table 10 [59], the Netherlands is behind most other European countries. This has to change within the next three years, and biomass boilers could help achieve these goals.

The government should not only take the costs of going green into consideration, but also the external costs of not going green [37]. If these are also taken into consideration, the green alternatives such as biomass boilers become a lot more attractive than for example fossil fuel and nuclear power. Other positive impacts such as promoting regional development and creating energy security are neglected in most calculations [37].

Currently a lot of wood for renewable energy is being produced in Europe and the Netherlands. This is not only good for the environment, but also for the local economy. The wood is being produced locally in well-maintained forests. Enough space is available for producing even more wood. Therefore, using wood as a fuel source has a lot of potential, even in the densely populated Netherlands. [60]

Appendix M - Biomass boilers in the Netherlands

A biomass boiler is a system which is used to heat buildings. Some systems are also able to heat water for example in a swimming pool. The system can be adjusted to the wishes of the client. A biomass boiler works in a very similar way as a natural gas boiler does. It uses fuel to heat water, which is pumped throughout the building, where it emits the heat into the building using radiators. The only difference is the type of fuel used.
In Figure 6 a setup for a small system can be seen. The steps used in the system for heating the building / water are as follows:

Wood chips or pellets are brought to the location.

1. Wood chips are stored in the building, after which they are transported automatically to the boiler.
2. The boiler uses the wood to heat water. Only ash remains (maximum 1% of the total start weight)
3. The heat is transported to a buffer, which reduces emissions and increases efficiency.

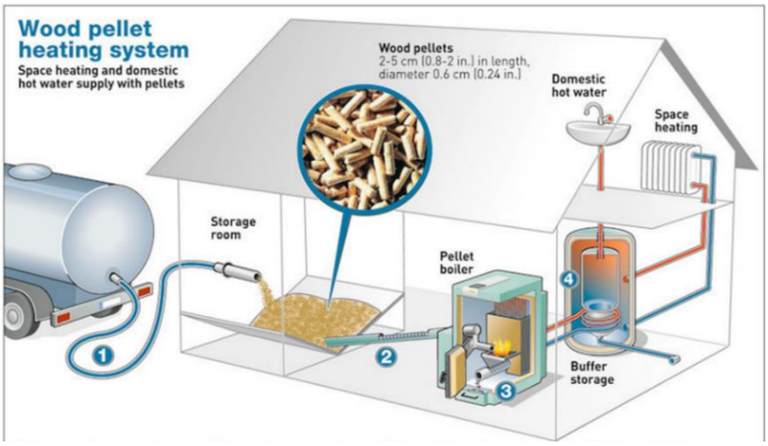


Figure 7 –A pellet boiler system (Greenmatch, 2015)

In the Netherlands, mainly wood chips are used for biomass boilers, but also wood pellets are an option or other types of biomass, but this is less common. It is very important what quality of wood chips is used and where these chips come from. If the correct quality chips is used with the correct settings on the biomass boiler, almost no harmful gasses and dust will come free but if bad quality chips with a lot of moisture or bark and stuff is used, then the emissions will be much higher. This can also be seen at the chimney, which will emit a lot of smoke instead of nearly no smoke. In the Netherlands mostly larger installations are used by companies, such as carpenters or swimming pools. An example of a larger system can be found in Figure 7. In the figure, the storage, the transportation belt and the installation itself can be seen. Also the chimney that emits the gasses can be seen. An installation such as this one can be built within an existing building, or a new building can be made around the installation.

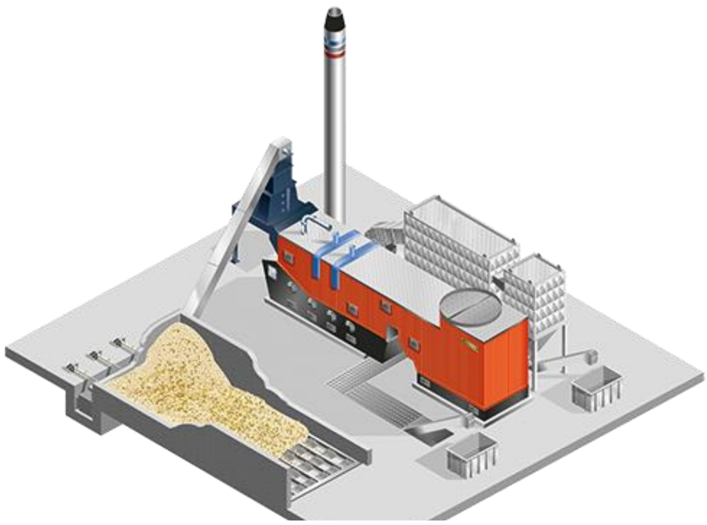


Figure 8 - Large wood chip boiler (UGB, 2015)

A list of the members of the NBKL and their brands can be found in Table 11. This covers most of the systems which are currently in use in the Netherlands. Only a few other companies exist, but they make larger systems starting from 10MW. The companies mentioned here supply systems ranging from 100kW up to 10MW. This is also the range the research focusses on. Most of their boilers are produced in Austria, Italy and Germany and imported and installed by the members in Dutch companies.

Table 11 – Members of the NBKL [26]

Member		*Website*	*Brands*
	Aitec BV	http://www.aitec.nl/	Veto, Tatano, Hapero en Atmos.
	Atechpro	http://atechpro.nl/	KWB, biomassasystemen.
	Bijvoet Energie	http://www.bijvoetenergie.nl/	Ecopower, ÖkoFEN
	Bio Energie op maat BV	http://www.bioenergieopmaat.nl/	HDG en Endress
	BIO Verwarming	http://www.bio-verwarming.nl/	NBE en HDG
	Colar	http://www.calor.nl/	Gilles, Lindner & Sommerauer en Nestro
	Estufa BV	http://www.estufa.nl/	Hargassner en Mawera
	F&H Crone BV	http://www.fhcrone.eu	F&H Crone
	Heat Plus BV	http://www.heatplus.nl/	Herz
	Tubro	http://www.tubro.nl/	Kolusan, Binder, Kohlbach en FireFox.
	Wes Wood Drying & Energy Systems	http://www.weswood.nl/	Vyncke, KÖB Brucks-Klöckner

The source of the wood chips / pellets is very important. For a sustainable biomass chain it is important that the source of these wood chips is also sustainable. This means they should come from waste wood which has no other use or from well-maintained forests.
Amongst the earliest adopters of biomass boilers are wood processing companies. This is because disposing of waste wood costs money and using it to heat your own production buildings is free. This also reduces the energy bills, but in the Netherlands gas is still very cheap. Therefore investing in a biomass boiler is still not profitable without subsidy.
Currently large users of energy such as swimming pools and large care homes or apartments also slowly start to adopt biomass boilers for heating their buildings and water. Because of the large energy consumption, the high investment costs can be regained in situations where a lot of heat is needed.
A biomass boiler systems only works if it can run continuously most of the time, because it cannot be switched on or off at the flick of a switch like a gas installation. It takes some time to heat up and only then the optimum burning will be reached. Therefore it is needed to install a heat buffer, which is drained if the heat demand of the user is high and which will be filled if the heat demand is low. In a lot of cases, a gas installation will also be present to cope with the peak heat demands. This gas installation can be retained if a biomass boiler is installed in an already functioning building, or a small gas installation can be installed next to the biomass boiler in new buildings. Because the investment costs of a small gas installation are not very high, this is not financially unattractive, however the fixed fee for owning a gas connection must be paid for, although it is sparsely used.
The Dutch government have set themselves some goals to reduce emissions in the future and has made agreements with other European countries about emissions. For example the 20-20-20 goals. These goals have to be achieved by the Netherlands in 2020 and include an emission reduction of 20% CO^2 compared to 1990. In the Netherlands there has also been a lawsuit of an environmental organisation called “Urgenta” which lead to the statement that the Dutch government should reduce the CO^2 emissions by at least 25% compared to the

1990 situation [27]. This is supported by scientific research done by the IPCC. The use of biomass boilers could help achieve these goals because the use of biomass is carbon neutral.
Another energy agreement signed by the Dutch government is the SER agreement [28]. This agreement includes for example the ambition to use renewable energy for at least one million households and SME companies, which amounts to a total of 40PJ in 2020. Biomass boilers could be a large portion of this 40PJ, mainly within the SME companies.
If a biomass boiler needs to be sustainable, it is important that the used fuel is also sustainably won. This means that the wood chips need to be won from sustainably maintained woods or from waste wood, which would otherwise be discarded in an unsustainable way such dumping or by burning without regaining the energy. This is very important, because it is stated that biomass boilers are environmental friendly compared to other installations. This will be researched by determining the origin of the used wood. This can be done by looking for sustainable labels such as the FSC label [29]. If waste wood is used, it is also important it is not treated with harmful chemicals.

Appendix N - Rules and regulations

Several rules and regulations for biomass boilers can be found in the 'activiteitenbesluit'. This regulates safety, emissions and inspection.

- Once every two years a biomass boiler (up to 150MW) needs to be inspected for safety, optimal combustion and energy efficiency. Boilers with less than 400kWh do not need inspection, but are regulated by an approved list of devices used for the ISDE regulation.
- At the commissioning, the emissions need to be measured.
- The emission is measured when the installation is running, so during the start-up the emission can be higher.
- A biomass boiler room with a boiler larger than 130kW needs to be fireproof.

Table 12 - Emission norms in the Netherlands [53]

Maximum emissions biomass boilers	NOx (mg / m^3)	SO_2 (mg / m^3)	PM (mg / m^3)
< 400 kW	300	200	40
400 kW - 1 MW	300	200	40
1 MW < 5 MW	275	200	20
> 5 MW	145	200	5

Another government regulation influencing the adoption of biomass boilers is the energy tax. The higher the tax is on for example natural gas, the more attractive a biomass boiler gets. Therefore for the biomass boiler business it would be good if the tax on fossil energy gets higher. The energy tax in the Netherlands is as follows [54]:

Consumption	Rate in 2015 in eurocents	Raise in eurocents	Raise in percentage	Rate in 2016 including inflation correction
Natural gas				
0 – 170.000 m^3	19,11	0,858	4,49	20,064
170.000 – 1.000.000 m^3	6,77	0,150	2,21	6,954
1.000.000 – 10 mln. m^3	2,47	0,055	2,21	2,537
> 10 mln. m^3	1,18	0,026	2,21	1,212
Natural gas in greenhouses				
0 – 170.000 m^3	3,069	0,138	4,49	3,222
170.000 – 1.000.000 m^3	2,278	0,050	2,21	2,339
1.000.000 – 10 mln. m^3	2,47	0,055	2,21	2,537
> 10 mln. m^3	1,18	0,026	2,21	1,212
Electricity				
0 – 10.000 kWh	11,96	0,000	0,00	12,020
10.000 – 50.000 kWh	4,69	0,283	6,04	4,996
50.000 – 10 mln. kWh	1,25	0,075	6,04	1,331
> 10 mln. kWh non-business	0,10	0,006	6,04	0,107
> 10 mln. kWh business	0,05	0,003	6,04	0,053

Biomass boilers are not (yet) included in the EPC regulations, however an equivalence statement may be obtained. If this is done, a boiler which fall under the activities Decree can be calculated with a factor zero, other boilers with a factor 0,5. This means it is a lot better than a gas boiler [61] and [62]. This is beneficial because the required EPC gets lower and lower, until all buildings in the Netherlands have an environmental footprint of zero. This regulation is thought to get more important in the coming years, when the EPC needs to be lowered even further for construction projects.

Appendix O - Diffusion of innovation theory of Rogers

Adoption of innovations is described by Rogers [8]. He defines diffusion and communication as follows: *"Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas. Communication is a process in which participants create and share information with one another in order to reach a mutual understanding."* [8] The use of biomass boilers in the Netherlands is currently 'diffusing' and the benefits are being communicated towards increasingly more people. This is exactly as described by Rogers. Innovation is described by the following quote: *"An innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption. It matters little, so far as human behaviour is concerned, whether or not an idea is "objectively" new as measured by the lapse of time since its first use or discovery."* [8] This definition of innovation means that, although biomass boilers are not new in the Netherlands, they can be considered an innovation because for most Dutch people they are measured as new. In the diffusion theory, there are four main elements: which describe the adoption of an innovation. These are discussed in the next section.

The innovation

The innovation describes characteristics of the innovation itself. Several perceived attributes of innovation are used to determine the success of an innovation. These attributes are [8] (page 213):

1. Relative advantage – the degree to which an innovation is perceived as being better than the idea it supersedes
2. Compatibility - the degree to which an innovation is perceived as consistent with the existing values, past experiences and needs of potential adopters
3. Complexity - the degree to which an innovation is perceived as relatively difficult to understand and use
4. Trialability - the degree to which an innovation can be experimented with on a limited basis
5. Observability - the degree to which the results of an innovation are visible to others

These attributes can already be discussed for biomass boilers.

The communication channels

If participants create and share information with one another, they reach mutual understanding. The communication channel is the means by which messages are transferred. This information can influence and change attitudes towards the innovation, thus influencing the adoption decision. Near-peer evaluation is very important in the decision process.

Time

Time influences the adoption decision in several ways, first in the mental process through which an individual passes from first knowledge of an innovation to making the decision to adopt or reject the innovation. This mental process can be described as a five step process with the following steps: Knowledge, Persuasion, Decision, Implementation and Confirmation.

The second way is the adoption lifecycle phase the innovation is in. This is described in Figure 8. As time passes, the lifecycle phase also changes. As time passes, the steepness of the curve changes, thus the adoption rate changes.

The last way in which time is involved in diffusion in the rate of adoption is the relative speed with which the members of a system adopt the innovation.

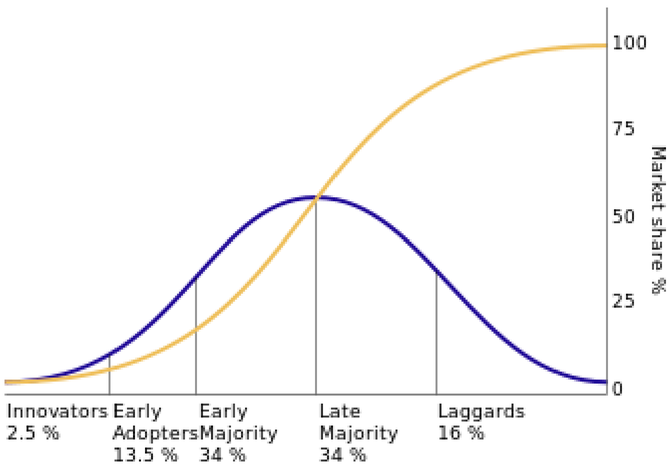


Figure 9 – Adoption model of Rogers (2003)

These factors can be used to determine the current state of adoption of biomass boilers in the Netherlands, and thus they can also be used to determine the potential growth of adoption.

The social system (context)

The last element in the diffusion theory is the context in which an innovation is placed. If an innovation is placed in an organisation or group, the social system influenced the boundary in which the innovation diffuses. Also the norms which are established within the sub-system affect behaviour patterns. Lastly, the opinion leadership is important. This is the degree to which an individual is able to influence informally other individuals' attitudes towards the innovation.

These four elements discussed will be used to determine different aspects of the biomass boiler adoption within the Netherlands, ranging from the current adoption levels to potential adoption levels in the future.

Deciding to adopt or not

Rogers describes three different actions in his decision model: accepting the adoption, active rejection and passive rejection [8] Page 173. The passive rejection is a group of potential adopters who are not aware of the innovation and thus do not adopt the new technology. Active rejecters make a decision based on their perception of the product, and do not adopt the innovation. It is important to cover all three types of potential adopters in the research to get the best view of how to improve the adoption rate.

Appendix P - Technological Innovation System

The theory of Hekkert [10] describes different changes that are necessary to make technological innovations sustainable. Not only the technology, but also social dimensions such as user practices, regulation and industrial networks are inevitable. Another important aspect is the dynamics of an innovation system. Furthermore, the central idea behind the innovation system approach is that innovation and diffusion of technology is both an individual and collective act. Therefore the micro and macro level are both important.

The technological innovation system uses a systemic approach, which means every aspect both technological and social, within the context will be used to determine the system characteristics. Nowadays a technological innovation has not a single location from which it originated, but it is often the product of different progresses made in different countries. The diffusion of an innovation is then influenced by national factors. The theory of Hekkert tries to use a systemic approach to explain how this works. Because a technology specific innovation usually has a smaller network and less relevant institutions and actors than a Network specific innovation, it is possible to create a dynamic analysis. In our case of the biomass boilers, it is indeed a smaller network with less institutions and actors.

For a systems analysis, it is important to manage all interfaces between subsystem borders and to know how the system as a whole is organised. In order to develop well, a new technology has to become part of that system, part of an incumbent regime or even overthrow that regime. This has happened in Germany in the biofuel industry, where the government subsidised the production of biofuel and the market started an active lobby to promote biodiesel. In 2003, more than 1300 commercial gas stations sold biofuel. This could also happen with our situation of biomass boiler systems. Once the new technology 'gets a foothold' in the market, it might get the momentum to grow and expand.

The whole innovation system can be described by using different functions. The paper of Hekkert uses the following seven functions and their interactions with each other to explain the system:

- Entrepreneurial activity: How actively entrepreneurs are and how risky their experiments are is very decisive for the innovation.
- Knowledge development: Without new knowledge, there are no developments in innovation
- Knowledge diffusion through networks: With more knowledge diffusion, more parties can work on the technology
- Guidance of the search: If the search for innovation is guided properly, the use of resources is more efficient. This can be done for example by setting national goals, which leads to development to reach those goals.
- Market formation: New technology is not always fully compatible with embedded technologies. Therefore the initial advantages can be small.
- Resources mobilization: Resources, both financial and human capital, are necessary as a basic input to all activities within the innovation system. How these resources are used and allocated is therefore very important.
- Creation of legitimacy / counteract resistance to change: In some cases, parties form coalitions to put a new technology on the agenda. They can counteract resistance against the change.

All these functions influence each other, and influencing one is likely to influence others as well. Therefore, the model is non-linear with multiple interactions between functions. There are many interactions possible, but most innovations have only three starting functions. These starting functions then pull the other functions, initiating a virtuous cycle. For the case of the biomass boilers, mainly the lobby for market formation, together with entrepreneurial activity are probably most important. To create a virtuous cycle, first a certain threshold of fulfilment needs to be reached.

The virtuous cycle model does explain how different functions interact, but to describe how an innovation has emerged and evolved, one can better use the process approach or sequence analysis. This approach conceptualizes the development and change by describing the sequences of events. These events explain the outcome of the model. Therefore, this not only describes the influence of a function, but also the underlying mechanisms that determine the technological change.

This method can be applied by mapping all events and linking them to the seven functions described earlier. Once these events are all known, they can be plotted on a timescale, thus showing the evolving of the technology in time. If patterns are be found in the figures, this can be used for a cross case analysis, to determine if these patterns are general or case specific. Using the insights gained from these analyses, the step towards policy recommendations can be made. For some projects, the threshold of continuous growth, or critical mass, is never reached, while others start to grow exponentially once the threshold is reached. Therefore it is important to determine how this threshold can be reached.

During the analysis of the different functions, one outcome may be that one or more of the functions are not relevant for the specific case. Also, some functions can negatively relate to the functioning of an innovation system. This all together forms a ‘story line’, which can be used to describe the role of different functions within the development.

The model that results from this method is a model based on social factors, which cannot be fully reliable. But by comparing the model with the empirical evidence, it should be able to approach different functions and their influence of the system. This insight can all be used to determine future policy and to determine how to stimulate and influence the technological change.

Appendix Q - Research techniques

In this appendix the different search techniques and results will be explained.

Search engines

The following search engines are used for the literature study:

- Scopus
- Sciencedirect
- Google Scolar
- UT library
- Google
- CBS statline

The first four were used for the scientific part, while google and CBS statline were used to find some facts and numbers which were needed. The search started with search words like biomass boiler, adoption, diffusion, innovation, wood, fuel. Then, after the first few papers were found, they were used to find even more papers by using their references and papers referring to that paper. For every paper it is decided whether it is relevant or not by deciding whether or not it is about a renewable energy technique, an innovation in that field, or about biomass boilers itself. Also some other papers were found, looking for different scientific techniques, such as interviewing techniques or how to use a model in predictions.

The research started off as a literature study, focussing on different articles already written. A lot of articles about renewable energy techniques and adoption theories can be found, however non about biomass boilers in the Netherlands. Therefore this research is innovative and can contribute scientifically.

Once the literature study was done, the empirical part of the research was the most important part. This was to make sure everything found in the literature could be proven empirically. This has resulted in a synthesis of both the literary and empirical results.

The model created in this research is mainly to gain an insight in how the adoption decision of a biomass boiler is made. However, the RVO and NBKL wanted to see some kind of prediction. This meant the model is also used to estimate an diffusion potential for biomass boilers. This is done by using the different statistical data provided by the RVO and inserting that in the model. If the adoption decision of a company could be positive according to the model, that company is a potential adopter. Therefore the total potential could be calculated.