Local and global dynamics of expectations in the Dutch niche development trajectory of micro-Combined Heat & Power boilers

Ralf Speek

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Summary

Expectations and promises are important in the development trajectory of new technologies and this is especially true for radical technologies that are able to cause widespread change in the socio-technical fields it is connected to. A typical feature of these technologies is that they are not yet able to compete with existing technologies due to high prices and reduced functionalities. In order for these technologies to get the change to develop, they need to be protected against market mechanisms in protected environments, so-called niches.

Special kinds of expectations that are important in the development trajectory of a technology are expectations that are shared by a number of actors in the niche, the global niche expectations. These global niche expectations are carried over a number of different projects and as the niche progresses while these expectations exist, the global niche expectations become more and more stable.

In this master thesis I have tried to show which elements influence the global niche expectations in the development trajectory of Stirling micro-Combined Heat and Power boiler. I have also tried to clarify which elements have impacted the global niche expectations. Early Strategic Niche Management literature focuses solely on internal niche processes and I have tried to show that also external niche processes should be included in the analysis. The research question of my thesis is: *Which internal and external niche elements influence the global niche expectations in the development trajectory of the Stirling micro-Combined Heat and Power boiler in The Netherlands?*

On the basis of 10 interviews conducted between 2010 and 2012, visited congresses, and literature research I have first sketched in chapter 4 an overview of the Dutch Stirling micro-CHP boiler-field. After describing the field, in chapter 5 I have presented which global niche expectations exist in the Dutch Stirling micro-CHP boiler niche while in chapter 6 I have described which elements have an impact on these global niche expectations.

From the analysis it became clear that there are a number of internal and external niche developments that have an impact on the global niche expectations. Not only internal niche developments played an important role, which it did, also external niche developments like developments in competing and complementing technologies, as well as developments in regimes played an important role.

Acknowledgements

When I started this thesis project at the end of 2009 I imagined that it would take me approximately 8 to 9 months to complete my thesis. It has taken me 2 years more than I expected due to unforeseen circumstances. When I failed to make my ten years deadline, I decided that I should put the thesis project on hold to work fulltime for a while in order to save some money. I re-started the thesis project in the spring of 2011 and after finishing my interviews in the summer, it took me nearly a year to write the thesis that is now in front of you. All of this time my supervisor Kornelia Konrad was extremely patient with me and for this patience I am extremely grateful. Time after time, she gave me good advice on how to proceed when I was stuck and although it probably was not easy for her, she refused to show me her door. I owe much to her, so I thank you from the bottom of my heart. I would also like to thank Fokko Jan Dijksterhuis who was first my tutor and later the second supervisor of this master thesis project.

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Enjoy reading my thesis.

Ralf Speek
Enschede, 15 August 2012

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Chapter 1 – Introduction

The emergence of new technologies is often accompanied by a lot of uncertainty for the actors involved. This is the case for those that are engaged in the creation of this new technology, as well as for the actors that are possibly influenced by this new technology. Uncertainty about the future of new technologies is closely linked to expectations and promises that are articulated about these technologies since these processes sketch a picture of a possible future world in which the new technologies will operate.

The type of technology also plays an important role in the perceived uncertainty. The more radical a technology is, the more uncertainty it will create. This is because radical innovations are able to cause wide-ranging changes to the structures of production and consumption. Because of this uncertainty, knowledge of the future is desired but since robust knowledge is impossible to acquire, actors have to rely on expectations instead. These new radical technologies are often technically and financially incapable of competing with existing technologies on the market place and these technologies therefore have to be developed in protected environments, so-called niches. Expectations that are shared in these niches by a wide community can be called global niche expectations and these expectations are carried over a variety of local test projects that together form the backbone of the niche.

The Stirling micro-Combined Heat and Power (micro-CHP) boiler is such a radical innovation that has been developed in the last 10 years. This boiler, besides its normal function to produce heat, has the capacity to generate electricity on a household level. When applied on a large scale, this innovation has the potential to for example have a large impact on the way energy is produced and distributed. The Netherlands has been a particularly interesting future market for this technology since the penetration of the claimed precursor of the micro-CHP boiler, the condensing gas boiler, is very high and the replacement market for these boilers is 350.000-400.000 boilers per year. The boiler has been positioned in the field of the de-central energy generating innovations together with for example technologies like solar-pv, windturbines, and heatpumps.

According to a common model of expectation dynamics, the hype cycle of the Gartner Group, the development of expectations in development trajectories is conceptualized as a one-dimensional process in which facts and expectations are checked in local projects. High hopes about a particular technology collapse when project results fail to live up to the high expectations (Gartner, n.d.). Other models of innovation sketched a more nuanced picture in which expectations are seen as social constructs that are possibly influenced by a number of factors. These include factors from outside the innovation field such as, among others, developments in competing and complementing technologies, changes in the environment in which the technology will be used, and decisions and actions of important actor groups that possibly have an impact on the expectations of other actors in the field (Van Lente, 1993; Van Lente and Rip, 1998; Borup et al., 2006; Geels and Raven, 2006; Konrad, 2006; Ruef and Markard, 2006). In my thesis I will look whether this more nuanced picture can also be found in the innovation field of the Stirling micro-CHP boiler in the Netherlands.

1.1 Research question

I will execute an analysis of the dynamic of expectations surrounding the development of a new technology. The research question that I will try to answer is the following:

Which elements influence the expectations in the development trajectory of the Stirling micro-Combined Heat and Power boiler and how do these elements influence the expectations?

In Geels and Raven's 2006 article 'Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973-2003)' it is shown that in contrast to earlier analysis of niche development trajectories, not only internal niche processes should be included in the analysis of these trajectories, but also external niche developments should be included in these analyses. In my thesis, I will show that while early studies into the development of radical technologies highlight that outcomes of local test projects have an impact on expectations (Van Lente, 1993; Kemp et al., 1998; Hoogma, 2000), external circumstances also play an important role for the expectations that relate to general aspects of the radical technology of Stirling micro-CHP boilers in the Netherlands.

1.2 Outline thesis

Before engaging in any form of research activity, I have to specify what I mean by my core concepts. In chapter 2, I will first focus my attention on the theoretical background of these concepts starting with a deliberation of literature about niches in which I will also make clear what I mean with global niche level and global niche expectation. Next, I will pay attention to the dynamics of expectations; I will show that expectations are embedded in a network of expectations and that these expectations can not only be influenced by activities, but also by other expectations. In chapter 3, I will present the methodology that I will use in order to answer the rest of my research questions. In chapter 4, I will describe the Stirling micro-CHP technology and the niche in which it develops and I will give a description of the actors involved in the niche. In chapter 5, I will present the expectations that are identified by the interviewees as being shared in the niche by multiple actor groups. In chapter 6, I will identify which elements in and around the developing niche have an influence on the expectations presented in chapter 5 and I will show how these elements influence these niche expectations. In the chapter 7 I will formulate an answer to my main research question; Which elements influence the expectations in the development trajectory of the Stirling micro-Combined Heat and Power boiler and how do these elements influence the expectations? In the final chapter I will discuss the most interesting findings and comment on this thesis project.

Chapter 2 – Theory

This chapter is about what has been written about the subject of my thesis, which is the dynamics of expectations in an environment that is protected from market influences, a niche. I will shed more light on these dynamics in the micro-CHP field in the Netherlands and I will approach this by looking at what elements have an impact on the niche expectations that carry the niche, the so-called global niche expectations.

In the first section I will begin by introducing an insight from the niche literature in which a conceptual (analytic) distinction is made between a local niche level and a global niche level. I will use this distinction in order to conceptualize global niche expectation. Next, I will discuss literature that has focused on developments of technologies in niches and that has identified expectations as one of the three major processes in the development of new technologies (Geels & Raven, 2006). After introducing the niche literature, I will turn my attention to insights from the sociology of expectations. With these insights, I can show the dynamics in expectations that surround a developing technology. In the final part, I will combine various insights into a conceptual framework that I will use to answer my research question.

2.1 Niche literature

New technologies encounter problems when they have to compete with technologies that are currently embedded in the society, the reason for this is that they often do not form a reasonable alternative to these embedded technologies due to their relative high price and/or poor performance. When these technologies are able to change the entire system an actor is involved in, they bring a lot of uncertainty with them. When these technologies want to get the chance to develop they somehow need to be protected against selection mechanisms that are active in the open market place (Kemp et al., 1998). A protecting environment, or a niche, for a technology to develop in does not appear out of thin air and active work is needed in order to create and maintain such a space (Raven et al., 2008; Geels & Deuten, 2006). Promises and expectations are very important in forming the initial network from where the development of the technology can be launched. Such an initial promise can be used to find the first allies and to put down the diverse roles of (future) participants. Also agreements can be made about mutual obligations and a first agenda can be formed after which the first contours of a new niche appear. Once the development in niches results in robust technologies with better price/performance ratio, they can try to enter the mainstream markets (Geels & Raven, 2007).

In such a protected environment these technologies get the chance to develop slowly because of projects in which the technology improves its functional side. Next to these purely functional improvements, these projects also form testbeds for various user practices, regulatory structures, among others. Various elements are aligned in these test projects in order to make them ripe to enter the market.

2.1.1 Strategic niche management

An approach that has tried to map the processes that are active in a niche, to which expectations also belong, is strategic niche management (SNM). It is a method that has its origins in the Constructive Technology Assessment approach and which has as its initial premise that new radical technologies develop in shielded environments in which they are protected from the selection criteria of the free market (Kemp, et al., 1998). The goal of this method is predominantly to develop policy advice for the creation of a successful climate for the development of new technologies with the ultimate goal that these technologies will successfully penetrate the current socio-technical system. However the analytical core can also be used to show which processes are active during the development of such new technologies and to illuminate which role these processes play (Geels & Raven, 2006).

Within the SNM approach, different projects play an important role in the phase between research and development and the moment the technology enters the open market place. These projects provide interactions between the various actors; they allow user groups, policy makers, and special-interest groups to give feedback to the technology developers like researchers, firms, and engineers. These projects are central in three processes that are identified (Kemp et al, 1998) as playing an important part in the successful development of new technologies. The first is the *building of new social networks,* which is of importance to create a constituency behind the technology. Projects serve as a way to create space for interactions between relevant actors in order to provide for sufficient resources like knowledge, money, and people. Next to the building of networks, *learning processes* are important in the development of new technologies. Learning about the needs, problems and possibilities with respect to technical aspects and design specifications, market and user preferences, cultural and symbolic meanings, infrastructural necessities, regulation and policy issues, societal and environmental effects, etc., is important in order to overcome barriers to the introduction and use of a new technology (Kemp et al, 1998). The third process that is identified as playing a central role in the SNM approach is the idea that the articulation of expectations and visions is crucial for the development of the niche. This is because they give direction to the learning processes and development activities, they generate attention for the developments, and they legitimate further protection of the niche.

As Geels and Raven (2006) have convincingly argued, the three niche internal processes cannot be analysed completely separated, they are interlinked and their interaction is a major contributor to how innovation journeys take place. However, to conduct a full scale analysis of all these processes within the niche of micro-CHP falls outside the scope of this thesis project. Instead I will focus my attention on the dynamics of expectations surrounding the niche. These processes however cannot be, as I just claimed, analysed in isolation. Learning processes and the process of network building will be taken into account as they are of importance in the process of stabilisation and destabilisation of expectations, but they are not the focal point of this research project.

2.1.2 Local niche level versus Global niche level

The SNM literature has contributed heavily to an increasing understanding of why certain technologies were successful and others were not, in their journey through the phase between research and design and their market introduction. The early SNM literature focused on single projects and they conceptualized these local projects as places to build so-called 'proto-markets' that could jumpstart the development of 'market niches' (Schot & Geels, 2008). These markets are meeting places of users, producers, and other relevant actors in order to interact, to learn from each other, and to exchange experiences. Protection of the new technologies is provided by markets with special selection criteria, or by technical niches, like demonstration projects (Kemp et al., 1998).

Later SNM-literature broadened the scope from single projects to an emerging community (Geels & Raven, 2006). This was done when Van Mierlo (2002) and Raven (2005) added the crucial insight that it was necessary to make a distinction between local socio-technical projects and a more global niche level in which an emerging community appeared that shared certain cognitive, formal, and normative rules. The development of a technology in a niche could from then on be conceptualized as developing on two levels simultaneously. A string of local projects gradually adds up to form an emerging community at the global niche level. Figure 2a presents a simple conceptualization of the two niche levels while figure 2b present a conceptualization of a technical trajectory carried by local projects.

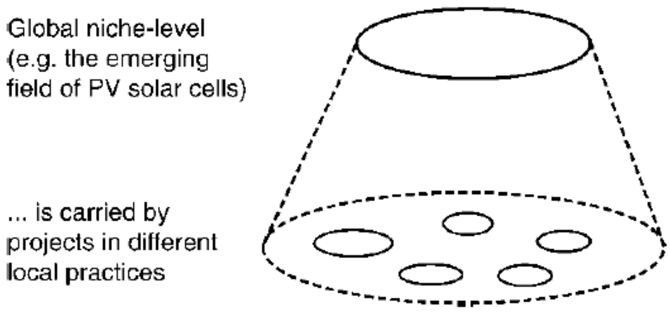

Figure 2a - Local projects and global niche-level (Geels & Raven, 2006)

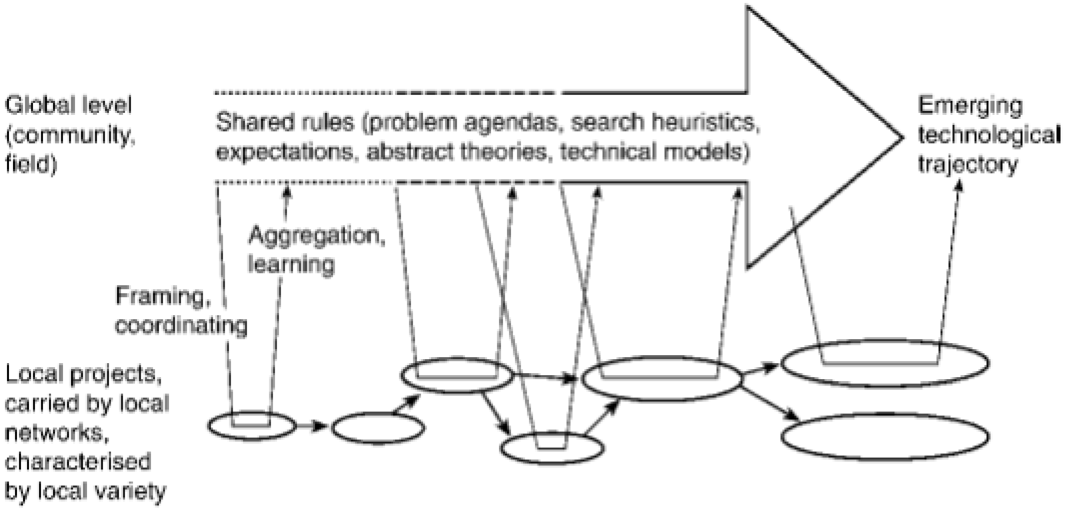

Figure 2b - Conceptualization of technical trajectory carried by local projects (Geels & Raven, 2006)

Both global level and local level have an impact on each other. Initially the local projects are individually testing expectations and promises created especially for these projects. The outcomes of these experiments can have a direct impact on the next project that is being executed by actors in local networks but it also can have an impact on the slowly emerging community on the global niche level. This second kind of impact comes in the form of learning processes that can stabilize or destabilize rules that exist at the global niche level.

The cognitive, normative, and formative rules that govern the global niche level are initially very broad and unstable and they thus do not have a strong position to guide the local projects. Local experiments test certain expectations and the outcome of these experiments can stabilize or destabilize the rules or introduce new ones. Learning processes play an essential part in this process of stabilizing and destabilizing.

Conceptualisation of niche trajectory

With the distinction between a local and global niche level, the developments of the niche could from then on be conceptualised as taking place simultaneously on two levels. The result of this was that the development of a new technology could be conceptualised as being an aggregation process of local projects that all (one way or another) contributed to the emerging field. Geels and Raven (2006) have conceptualised this process in the following manner: d*evelopments start in one or a small number of projects that are carried by a local network of actors. These actors are directly involved in the local projects and they are guided by cognitive rules that are present at the global level. These cognitive rules, and expectations are one of these, are in the beginning of the niche development very broad, unstable, and diffuse. Local projects are used to test and create these diffuse ideas and in the begin phase of the development they do not form a unity and therefore every project is guided by different rules and every project in the beginning is searching for different solutions. On the local level, for every project expectations are articulated that originated at the global level and these guide the local search process. The results of these local projects are being used to change previous expectations and to convince more actors to join the network in order to expand and strengthen it. When the outcomes of the local projects and the learning processes that are generated from it are compared and accumulated, cognitive rules on the global level, including expectations, are slowly becoming more articulated, more specific, and more stable.*

The most important point of section 2.1.2 is that global niche expectations can be perceived as cognitive rules that are carried over various local projects. Within the niche development they can be influenced by local project outcomes. As the niche progresses, the global niche expectations may become more and more specific and stable.

2.1.3 Multi-Level Perspective

As claimed by supporters of the SNM approach, the local project outcomes potentially have an impact on the niche dynamics. This is however only the side of the story from inside the niche**.** The question is whether there are also further elements that can have an impact on the global niche expectations, and which potential elements can be identified.

In order to show alternative influences I will introduce the concept of Multi-Level Perspective (MLP) that conceptualizes transitions and system changes as a continuous process simultaneously occurring on three interdependent levels; niche innovations on a micro-level, sociotechnical regimes on a meso-level, and a sociotechnical landscape on a macro-level (Geels and Schot, 2006). Niches are not located into thin air; they can be conceptualized as being embedded in a regime; that on its turn is embedded in a socio-technical landscape. Multiple regimes are embedded in a landscape, and multiple niches are embedded in a particular regime (Rip and Kemp, 1998; Geels, 2002).

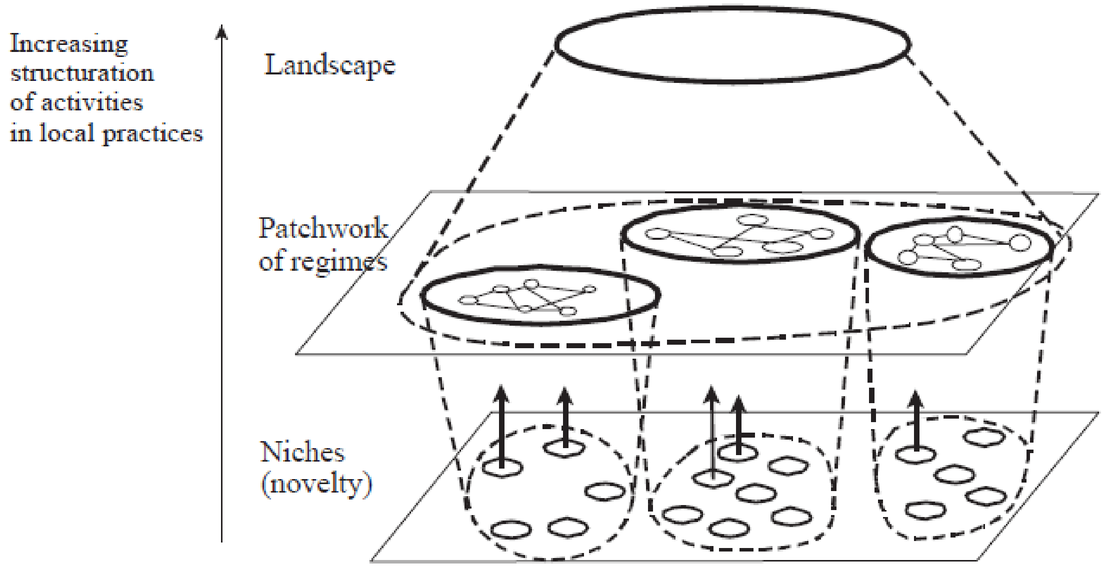

Figure 2c - Multiple levels as a nested hierarchy (Geels. 2002)

In the framework used in the multilevel perspective the activities of people are important as well as the rules which provide context for these activities. People act on the basis of rules (and as stated above, expectations are part of the cognitive rules), but they also are able to learn from their actions and change the rules. The three levels provide various levels of structuration and stability for activities (Geels, 2005). On the niche-level rules are vague and they do not provide a strong coordination for the activities of the actors involved. An example is that there are various diffuse promises and expectations about the potential use of the technologies and various ideas about the best direction of research. On the regime-level the activities in local practices is much more structurered and stable. The rules are much stronger on this level and these thus have a much stronger coordination effect on the activities. Social conventions and community rules are not easy to change, it is possible but it takes a lot of effort. On the landscape-level the structuration and stability of the local activities is the strongest. Rules like widely shared cultural beliefs, symbols and values are hard to change.

Expectation dynamics in the Multi-Level Perspective

The MLP understands the emergence and diffusion of new technologies as being a dynamic process in which an interaction occurs on various levels. The main point for my thesis is that the developments on the regime level and on the landscape level also govern the processes in the niche. Changes on the landscape level can for example put pressure on the regime which can spur incremental developments of embedded technologies in regimes as well as that it can influence the developments of promising new radical technologies in niches (Geels, 2002; Geels and Schot, 2006; Hoogma, 2000). The development of micro-CHP boilers is for example strongly influenced by the increasing need for cleaner technologies to generate energy in order to solve environmental problems created by the fossil fuel regime. In this example the environmental problem is a slowly moving landscape development which puts pressure on the existing fossil fuel regime.

This pressure provides an opportunity for incremental innovations to develop, for example more efficient power plants, but also for new promising radical technologies to develop in niches, like for example micro-CHP boilers. For the incremental innovations the rules on the various dimensions of the socio-technical need not to be changed much, there is an ongoing process of constant adjustment of these rules. For radical technologies this is very different, these technologies need windows of opportunities in order to break through in the existing regimes because the rules that govern the niche development deviate from the rules of the socio-technical regime and thus this first needs to be aligned before a breakthrough can be reached.

MLP scholars argue that broader regime and landscape developments influence the niche via expectations and networks. This means that the perceptions of the niche actors and the size of support networks are impacted by these niche external influences (Geels and Schot, 2006). Since in early stages of developments the advantages of a new technology are not evident, actors often make promises and raise expectations about new technologies in order to get the new technology on a developing agenda (Geels, 2002). Landscape developments and regime problems are often used as legitimizations of these promises and expectations. These developments and problems are not only current and past problems but they can also be envisioned expected future developments and problems.

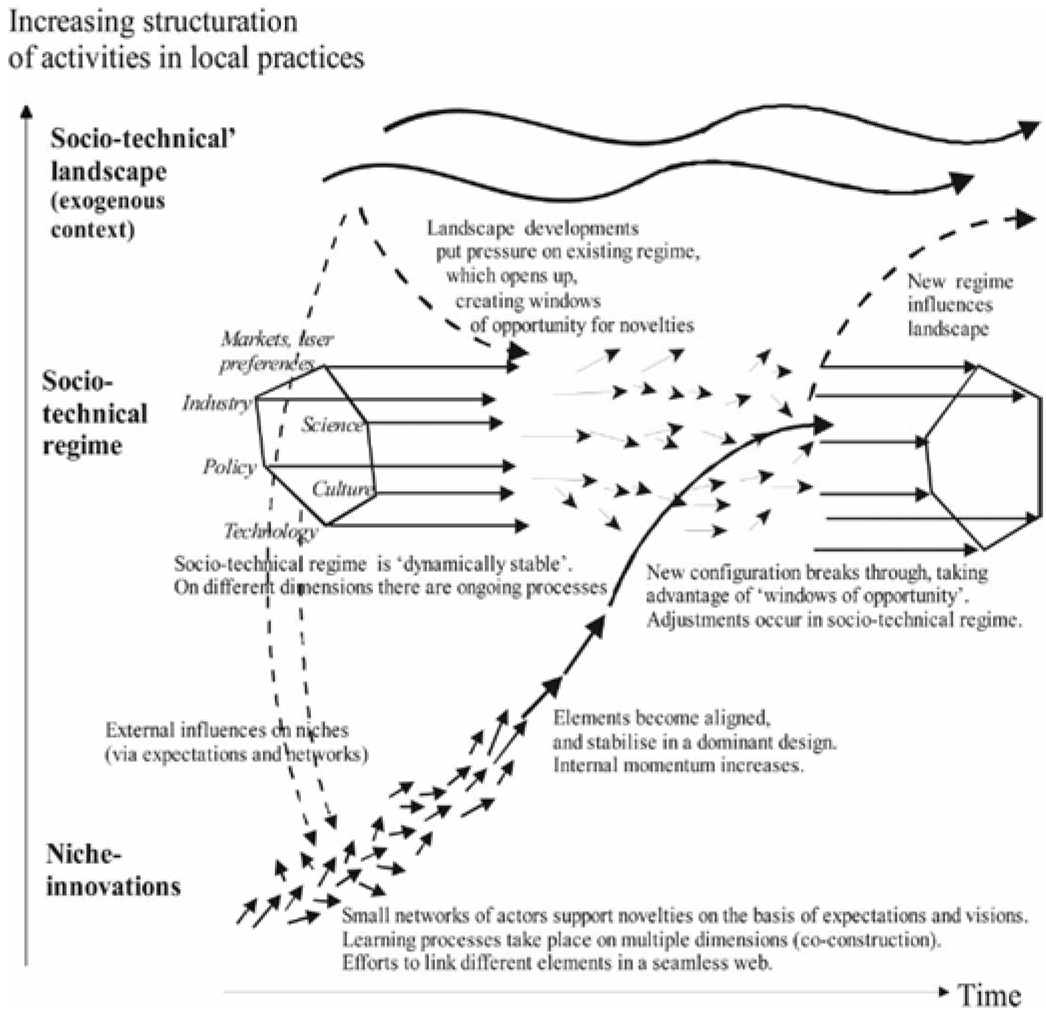

Figure 2d - Multi-Level dynamic between the three conceptual levels (Geels, 2002)

As stated above, promises and expectations are particularly strong when they are connected to societal problems for which existing technologies cannot provide the solution. Hoogma (2005) identifies three other important characteristics for the strength of the expectations which are the robustness, quality, and specificity. The more an expectation is shared, the more robust it is. Quality of expectation can be shown by demonstrating the advantages, getting expert support, getting endorsement from important actors, and testing expectations in experiments. Finally the clearer it is which steps have to be taken in the development of the technology to reach the expectations, the more specific the expectation is. In my thesis I will pay close attention to these three characteristics.

2.1.4 Developments in competing technologies

Expectations for new projects are based on internal technical considerations and experiences from previous projects. But these expectations also take into account the wider world, e.g. regulations, market dynamics and competing technical trajectories. Product champions, when searching resources for new projects, sketch 'diffuse scenarios' about future worlds in which the innovation would work (Rip and Kemp 1998). So the formulation of (new) expectations in niche A is influenced by experiences in niche B. If experiences in niche B are negative, it becomes easier to formulate positive visions for niche A, and attract people and funding (Figure 12).

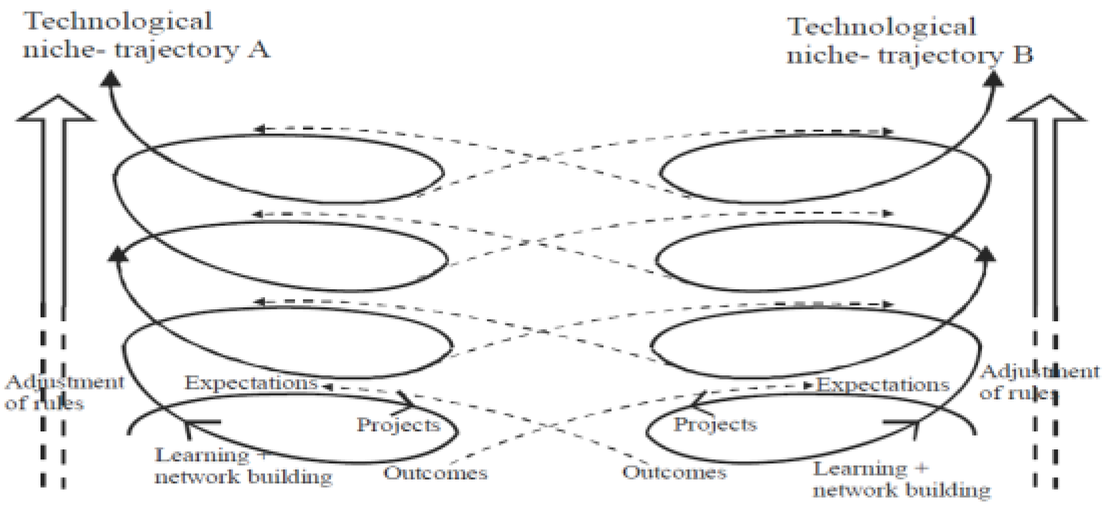

Figure 2e - Co-evolution mechanisms between competing niche trajectories (Rip and Kemp, 1998)

Van Lente and Bakker argue that technologies will compete in early phases of their development with alternatives on the basis of expectations and promises of future progress (2010). Because of this competition these promises will be carefully maintained.

2.2 Sociology of expectations

Expectations play an important role in the development of technologies as they stimulate, steer and coordinate action of actors (Bakker et al., 2011). The idea behind the importance of expectation in the development of technologies was examined by Van Lente (1993; 1998) and has been used in strategic niche management (Raven & Geels, 2006) as well that it has developed into a 'sociology of expectations' (Brown & Michael, 2003; Borup et al., 2006). In the strategic niche management literature expectations are important in providing direction for learning processes and development activities. Next to this the articulation of expectations is important in the generation of attention for the developments and for legitimating further protection of the niche. The 'sociology of expectations' takes a wider approach as they include a variety of approaches to expectation and the dynamics of expectation although the locus of the expectations studies lies in the science and technology studies (STS). They approach the topic from a variety of angles but the studies all emphasize the dynamics of expectations as a basic and important feature of modern science and technology (Borup et al., 2006). In order to understand the complexity of expectations, what role they can play in innovation journeys and in how they can be influenced, I will now turn to a number of insights of the sociology of expectations literature.

2.2.1 Van Lente's 'promise and requirements'-cycle

In this section I will draw heavily on insights of Harro Van Lente who made important insights into the role of expectations in technological development trajectories. He stated that the development of a technology is a social process and he studied the role of expectations in this process by looking at shared expectations in the form of statements. For him these expectations are the ones that play a role in interactions, while private expectations only become effective 'to the degree' that they are linked to shared expectations (Van Lente, 1993). 'Expectation statements are not in the head of actors, but are at the disposal of the audience'. An expectation does not have to be 'real' for the person that communicates the expectation. In sociological sense they are 'real' as soon as they have consequences for actions, when they are picked up by other actors. In other words, when a person states an expectations, it is not of importance whether the person really beliefs the expectation. Once it's 'out there' and sociologically and it does some work, whether positively or negatively, towards the fulfillment of the expectations, the expectation will be 'real'.

I will first present the original insight of Van Lente in which he identifies a cycle of promises and requirements in the development phase of a technology. Promises about the technology are according to Van Lente taken up in a shared agenda and in order to achieve these promises particular requirements are created. In order to meet these requirements a division of tasks is needed that guides the search processes in the niche. This is not the end of the process because when the promise has been fulfilled, new opportunities arise that bring with them new promises, and so the process begins again. This process will continue until the technology stabilises. On the other hand, it can happen that a promise is not (directly) fulfilled and a disappointment occurs with the result that the whole niche is endangered in its existence. Harro Van Lente has conceptualized this process in a 'promise-requirement' conversion-model (Van Lente, 1993).

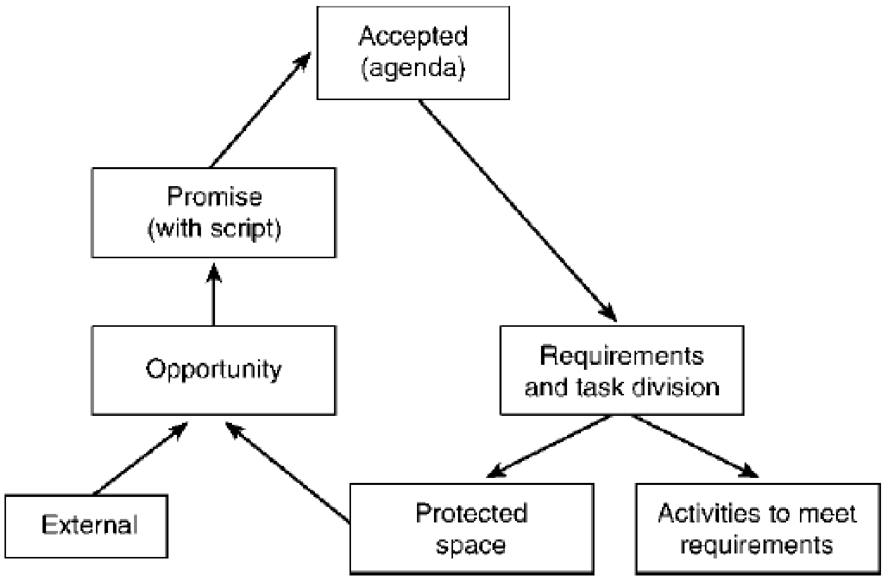

Figure 2f - Promise-requirement conversion-model (Van Lente, 1993)

2.2.2 Levels of expectations

Van Lente (1993) distinguished three types of expectations that are working on a different level and with a different function. The search process on the micro level is informed by expectations, these expectations on the micro-level Van Lente calls search-expectations. These show directions towards success, like what the requirements are, which methods and materials to use, and it indicates standards of evaluation. These are thus the expectations that are present in local test projects in which the technology is tested. On a higher level expectations exist that protect the search process. They indicate eventual successful outcomes of the project and by doing so they create space for the niche to develop further. These are broader in scope and are called niche-expectations. Niche-expectations provide reasons for actors to invest in this technology. These expectations are used by actors to protect the activities in the niche. They are used to generate attention by focusing on the future benefits of the technology for potential adopters. Even broader of scope are the scenario-expectations. These back up the niche-expectations and justify them. They provide further support for why there would be opportunities. Function is the difference between niche-expectations and scenario-expectations. Both are broad of scope but the niche-expectation explains why THIS project deserves support, while the scenario-expectations indicate that projects LIKE THIS ONE are worth the effort. This means that the scenario expectations are broad general expectations that justify why for example technology is worthwhile to invest resources in (Van Lente, 1993).

The three identified levels of expectations are comparable to other typologies used in STS literature on expectations. Ruef and Markard (2010) show that most authors distinguish between at least two levels of expectation: (i) specific micro expectations about improvements of the artifacts, and (ii) more generic meso expectations about the functionality of the technology. A third type of expectation is can be identified is the very broad socio-technical vision about future society, which includes social, political and economical aspects of the technology (Van Lente, 1993; van Merkerk and Van Lente, 2004). Other authors see external circumstances at work at the macro level (Geels and Raven, 2006).

The main point of Van Lente's insight for my thesis is that expectations in innovations trajectories do not occur as single entities but that they are embedded in a network of expectations that possibly have an influence on each other. Specific expectations about a technical possibility, of for example a particular material used in the Stirling engine of a micro-CHP boiler, relate to the more general functional promise of these Stirling micro-CHP boilers. These functional expectations on their turn relate to the even more general expectations about for example the expectation of the need for new alternative ways to produce and consume energy.

2.2.3 Dynamics of expectations

Various authors (among others; Konrad; van Lente; Rip; Borup; Brown) have convincingly argued that expectations dynamics have an impact on the behaviour of organizations. Since expectations are important for the development trajectory of innovations, actors deliberately contribute to the formation of collective expectations (Konrad et al., 2012). Van Lente and Rip (1998) for example showed that product champions try to mobilize public funding by communicating positive outlooks for the innovation while Musiolik and Markard (2011) showed that in order to improve the positive image of a technology actors strategically set up networks. Large numbers of actors thus interact and exchange expectations with the result that collective, shared expectations emerge. Actors contribute to the formation of collective, shared expectations by discourse activities in the form of press releases, conference presentations, publications, interviews, etc, or by innovation activities (Konrad, 2006).

Vertical dynamics of expectations

The typology of placing expectations on a micro, meso, and macro level is dangerous when this conceptualisation is seen this as a static framework. Rather the network of expectations operates as a dynamic environment, in which the expectations on the various levels are constantly changing, influencing activities, networks, other expectations, etcetera. Expectations mediate between various scales or levels of organization (vertical co-ordination (Borup et al., 2006)). A number of authors showed this vertical form of coordination. Konrad (2006) for example investigated the interplay between expectations on the level of an innovation field and on the micro-level of technological projects. An important insight was that technological projects are the places where technology dynamics and expectation dynamics are linked. She illustrates a dynamic between social or collective expectations and, more locally, specific expectations within ICT innovation communities. Geels and Raven (2006) analyzed the ups and downs in the development trajectory of biogas technology in which they address the interplay between local projects and a global niche level.

Another interesting aspect identified by Konrad (2006) and that can also be found in the Social Construction of Technology (SCOT) and SNM literature, is that it is often a matter of interpretation what conclusions can be drawn from local project outcomes. Specific circumstances, or context variables, are often blamed when problems occur with a project, and an expectation is stated that these will change in the near future with the result that the technology is not called into question. Repair work is thus done in order for the technological trajectory to continue without problems. Also it is shown that as long as collective expectations are high, they provide a protected space for the technology and outcomes will be interpreted favorably and the problem will be postponed. Once the collective expectations and the protected space collapse, the outcomes will be reevaluated (Konrad, 2006).

Horizontal dynamics of expectations

Besides the *vertical linking* of the micro, meso, and macro level of expectations, the linkage of expectations on the same co+nceptual level is also an important dynamic in the network of expectations surrounding a developing technology. This form of linking can be called *horizontal linking* and examples of this are competing and complementing niche expectations. Konrad and Budde (2009) conceptualize this by drawing an analogy with the Multi-Level Perspective and placing expectations on the niche, regime, and landscape level, and argue that expectations between as well as expectations on the same level have an impact on each other. They use the example of fuel cell-developments but the same can be applied to the micro-CHP boiler developments. Raven and Geels (2006) also highlight the expectations of competing technologies as an important external niche development.

Expectations can play an important role in the coordination of different actor communities and groups (horizontal co-ordination). These expectations about a technology and the future uncertainty that the technology can generate vary between the various groups in a technological community (Borup et. al, 2006). As the meaning of the technology varies among groups (Bijker, 1995), this interpretative flexibility causes different actor groups to react differently to the technology development. Brown and Michael (2003) point out that this different reaction to the development often is caused from the lack of access to the full information on which the expectations are based which results in uncertainty. Bakker et. al, (2011) make a distinction between the reaction of enactors and selectors to the technology. Enactors are creators (or enactors) of the technology and they need to make clear why their technology is promising while communicating why competing technologies are less well equipped to fulfill the same function. They often fight for funding and other forms of support. Selectors on the other hand are actors that select the technologies according to their criteria. The variation and the selection of the technologies are connected though expectations in, what Bakker et al. call arenas of expectations. In these arenas, the enactors and selectors fight their battles.

Konrad et al. (2012) also show different responses of different actor groups in the field of fuel cells. In their article they take a closer look at how actors changed their strategies and activities to both hype and disappointment. So-called hype-disappointment cycles can often be observed when looking at the development of new technologies. New technologies receive attention when expectations about the promise of the new technologies are widely accepted. The tone of the promises and expectations become more and more enthusiastic and the new technology often receives increasing attention from the media. Because the expectations are so hyped and cannot be met, a disappointment phase often follows whereby the attention and expectations cool down suddenly (Van Lente, 1993; Brown, 2003). Konrad et al. (2012) identified three factors that had an impact on organizations sensitivity to expectations dynamics. The first is the strategic embedding of a new technology. This means that the stronger the development activities fit with the more general strategy of a firm, the more it is likely that the firm will continue to invest resources in the development of the technology even when facing disappointments. The second variable is the dependency on other actors or dependency on external legitimacy. The more this is the case, for example with stock-exchanged listed organizations compared to firms led by an owner-manager, the more sensitive they are for disappointments. The third variable they identify is the type of organization. Depending on the role in the innovation process, different organizations will response differently to hype and disappointment. Research institutes for example reacted much more slowly than industry actors did.

2.2.4 Conclusion

The point of previous section is that the global niche expectations in the Stirling micro-CHP boiler niche relate to expectations on the regime and landscape level as well as to expectations in niches connected to the micro-CHP boiler niche, these can be competing niches but also complementing niches. The expectations are vertically linked to the regime and landscape level and the local niche level, and they are horizontally linked to the competing and complementing technologies. Geels and Raven (2006) have visualized these relations in the following figure.

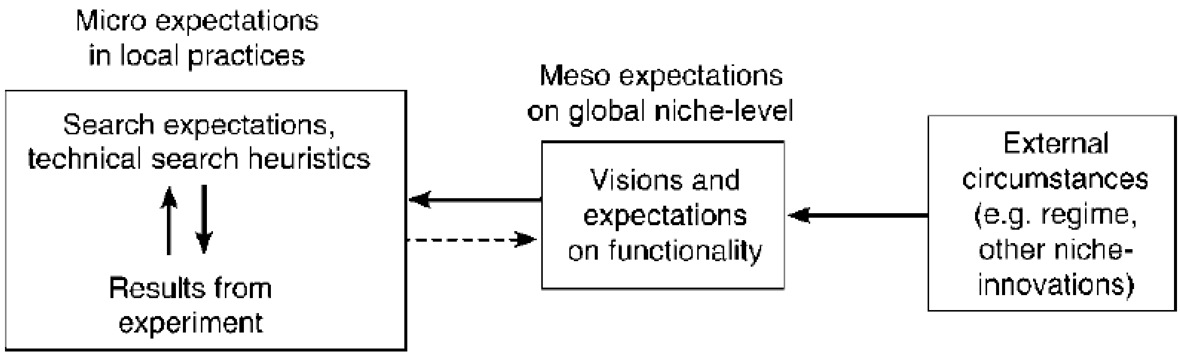

Figure 2g - Relationships between levels of expectations (Raven, 2005)

In their 2006 study they conclude that for the developments in the Dutch biogas innovation journey, the internal niche interactions are not sufficient to explain the change in meso expectations on the global niche level. For a complete picture, external circumstances need to be included in the analysis. In my thesis I will try to replicate the findings about the internal niche interactions for the Dutch Stirling micro-CHP boiler development journey and look what role external circumstances play in the development of expectations on the global niche-level. To do so I will look at the developments on the regime and landscape level as well as on competing and complementing niche developments.

Before presenting my method section, I will rephrase the central question that I want to answer in my thesis. The new central research question is as follows:

Which internal and external niche elements influence the global niche expectations in the development trajectory of the Stirling micro-Combined Heat and Power boiler in The Netherlands?

The research question can be split-up in three sub-questions:

i. *Which global niche expectations can be identified in the Stirling micro-CHP boiler niche?*
ii. *Which internal niche factors influence the global niche expectations in the Stirling micro-CHP boiler niche? And how do they influence the global niche expectations?*
iii. *Which external niche factors influence the global niche expectations in the Stirling micro-CHP boiler niche? And how do they influence the global niche expectations?*

Chapter 3 – Methodology

3.1 Data gathering

In order to find an answer to the sub-questions the core method of inquiry were 10 semi-structured interviews (see Appendix A) with diverse actors in the field. Before selecting which actors to interview, an actor-map was construed (see figure 4g) in which the actors were categorized by their function in the niche. The interviewees were chosen in a way that all the major actor groups were represented in the sample. Choosing a variety of actors also makes it possible to investigate the sensitivity of various types of actors to hype-and-disappointments in the field. The boiler manufacturers and the energy companies can be considered to be enactors while the installation, network, and housing companies can be considered selectors. Most interviewees were chosen after an exploration of the field and the rest were chosen after they were mentioned as being important in the first interviews, the so-called snowball method. Also important was the fact that Nuon, Alliander, Remeha, GasTerra, and Woonmensen were all involved in a local project called Smart City Apeldoorn. By choosing these actors, the effect of this local project could be examined for various actor groups.

Table 3a shows the overview of the interviewed actors. Next to these semi-structured interviews, I held informal discussions, which lasted around half an hour, with three actors which provided me with context of the field. These three actors were a PHD-student in the field of micro-CHP, Jan Willem Zweerink, an employee of Agentschap.nl, Ben Paulussen, an employee of a governmental agency responsible for subsidies, and the chairman of the foundation 'Slim met gas' Jeroen Wouts.

Actor	**Name**
Remeha	Hans Vermeulen
GasTerra	Frans Hazen
Nuon	Rene Engels
Eneco	Louke Wijntje
Gaes	Henry Berends
Woonmensen	Huub Kamp
Kiwa-Gastec	Rob van Kaam Erik Franssen
CE Delft	Kevin Jansen
Alliander	Pieter van Ackeren
Energy Matters	Paul Hellings

Table 3a - Overview interviewees

All interviews except the interview with Eneco were done face-to-face, the interview with Eneco as an exception was a phone interview. I was allowed to tape all of the interviews except the interview with Nuon. The reason for this interviewee to refuse to be taped was that Remeha had demanded confidentiality from all the actors involved about the outcomes of the test projects. This was the reason that the interviewee was not comfortable for me to tape our conversation. Other interviewees that also signed this clause simply did not provide me with detailed information about the projects, these mainly included questions about strategies and outcomes of local projects.

As a number of interviewees indicated that they would like to stay anonymous I have chosen to anonymized all the names of the interviewees. Real names, functions, and dates of interviews are presented in Appendix C, which is included in a separate document. Also in this document, full transcriptions of the interviews can be found, as well as descriptions of the local test projects in Appendix D.

As a way to control the data gathered in the interviews I used secondary sources like websites, conference presentations, and vision documents. These data sources gave me a good overview of the quality of the data from the interviews. The nature of global niche expectations, they are shared and articulated, allowed me to find out a number of the expectations mentioned in the interviews in these sources. Some if these findings also formed a base for interview questions.

3.2 Analysis

The interviews were all transcribed and entered into the program Atlas.ti. This program was used to code the transcribed interviews so that an analysis of the interviews could be performed. I used the results of the literary study as a basis for my coding. Each element identified by the literature as having a possible impact on the global niche expectations formed a code. Next to this the global niche expectations themselves of course also formed a code. Starting from this base I coded my interviews and with the results a map could be drawn in which the elements influencing the global niche expectations could be identified.

I used the program Atlas.ti to crosscheck the results of the interviews by entering the data found in websites, vision documents, conference papers/presentations, etc. in the program and coding it in the same way as the primary data. The results of these secondary data analyses were now compared to the primary data in order to identify interesting similarities and anomalies. After coding the interviews, I checked and compared the results with the data found in the study of the field in order to see whether there were elements found that were different from the ones I expected to find.

An example of my analysis is the usage of the code '*Global niche expectations*'. When all the interviews were coded, it became clear that four expectations were shared among a wide variety of actors and these I have presented in section 5.2. When I then combined the code '*Global niche expectations*' with for example the code *'Competitive technologies'*, five competitive technologies were identified and I have presented these in section 6.2.2. In the same way, I have combined the other possible influential factors and the result of this analysis can be found chapter 6.

Chapter 4 – The niche of micro-CHP boilers

The concept of combined heat and power (CHP), or the co-generation of heat and electricity, is known for a long time now. The usage of excess heat from power plants for heating purposes in the last decades has been used successfully numerous times in the industry. Micro-combined heat and power (micro-CHP) is the term for the small scale generation of electricity which applications can predominantly be found in households in the form of a boiler that uses its excess heat to generate a small amount of electricity. In this chapter I will first explain how this process of co-generation of heat and electricity takes place and which alternative methods exist for this co-generation on domestic scale. Next I will present which actors are involved in the micro-CHP boiler niche.

4.1 Micro-CHP concept

Micro-combined heat and power (micro-CHP) is the term for the domestic small scale generation of heat and electricity. At the moment the traditional method of generating electricity and heat is to generate electricity in a big power plant and generate heat in a boiler at home. In the past year a technology was introduced on the Dutch market that could replace this method, a micro-CHP boiler. It is a technology that allows users to generate heat and electricity on a domestic scale. It is a new generation condensing gas boiler (a boiler that uses condensing techniques to increase heat efficiency) that besides heat also generates electricity which can directly be used by the user or delivered back to the electricity grid. In the latter case the users thus become a producer on the electricity market.

By generating heat and electricity in a micro-CHP boiler, a lot of energy van be saved that would otherwise get lost by heat dumping in the air and rivers or by transport losses. An example of this principle is shown in figure 4a.

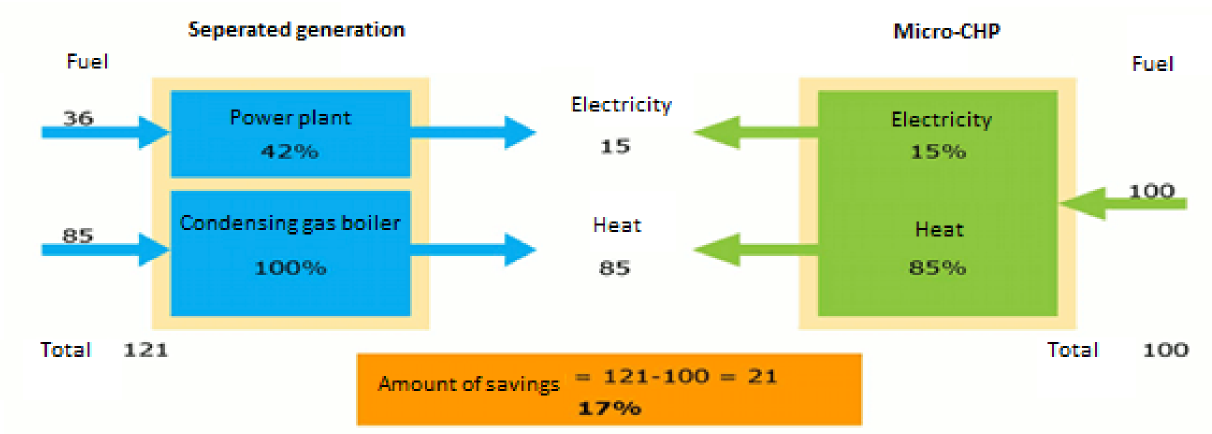

Figure 4a - Example of the potential amount of energy saved

A conceptual drawing of co-generation of heat and electrivity on a domestic scale is shown in figure 4b.

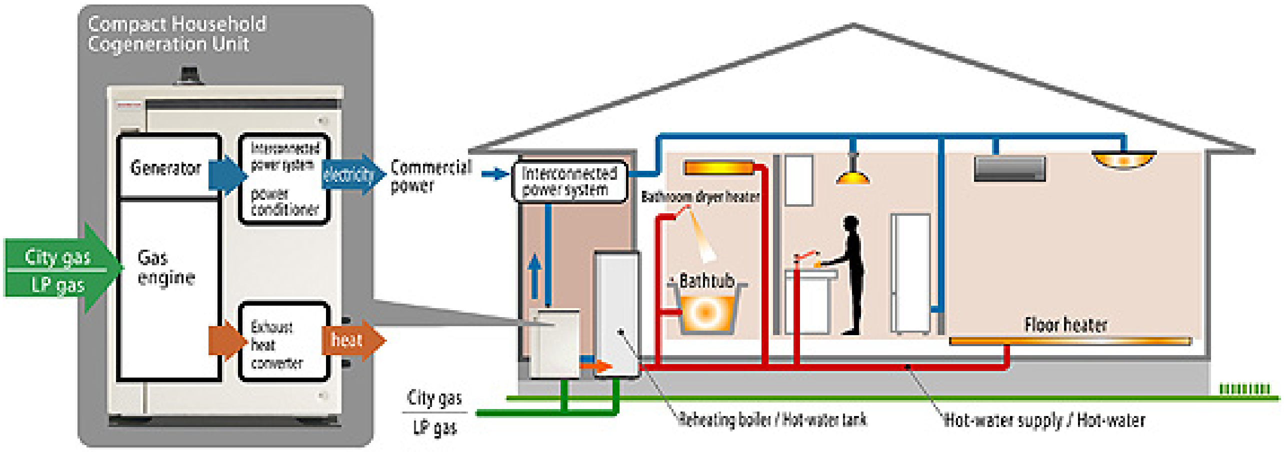

Figure 4b - Example of a solo micro-CHP boiler with an added reheating boiler for hot water supply

As I will show later, there are a number of alternative ways to co-generate heat and electricity on a domestic scale but for now it enough to know that the first generation micro-CHP boiler are heat driven systems that run on natural gas and are connected to the electricity grid. This connection to the grid is necessary since the system only delivers electricity when heat is needed in the household; for the other moments that electricity is needed, back-up electricity is provided by the grid. This connection to the grid also makes it possible to export the surplus of electricity back to the grid.

4.1.1 Various types of micro-CHP technologies

Micro-CHP is the umbrella term for a number of technologies that generate heat and electricity on a household level. Various alternative solutions to co-generate heat and electricity have been and are being developed; the figure 4c below gives an overview of these alternative solutions. The difference between the various technologies is the way in which electricity is produced from the various fuels. Three groups of technology are distinguished:

- External combustion (heat is transferred to another medium)
- Internal combustion (the combustion process directly results in a motion)
- Fuel cell (energy is chemically transferred)

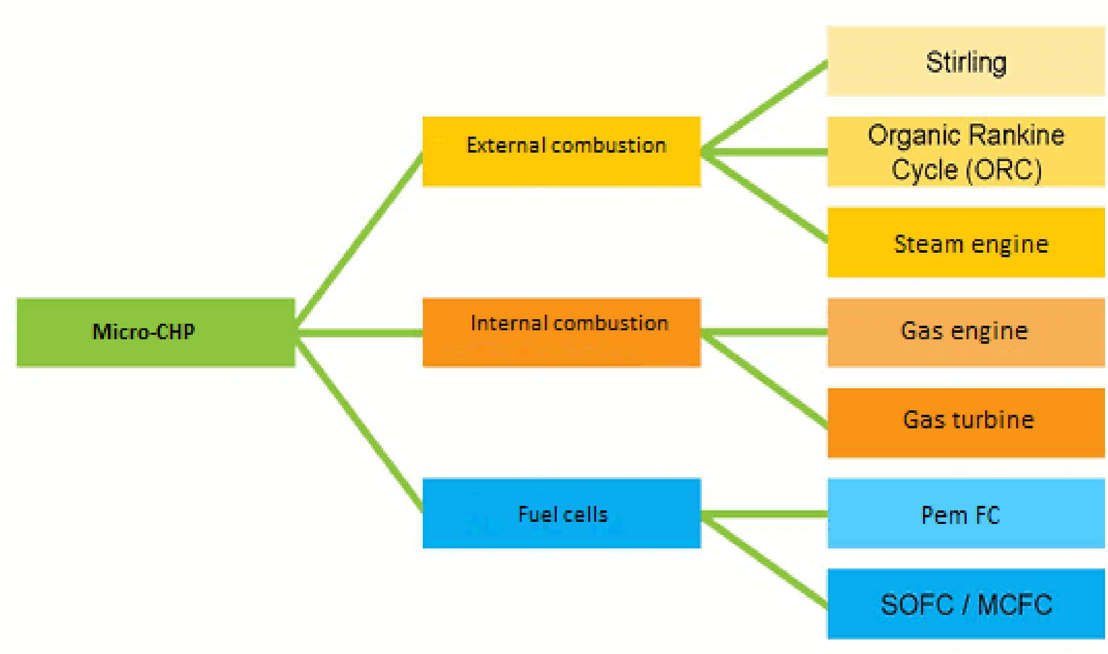

Figure 4c - Overview of various micro-CHP technologies (Werkgroep Decentrale Gastoepassingen, Smart Power Foundation, and Werkgroep micro-wkk Cogen Nederland, 2010)

Although all these technologies can potentially be used in micro-CHP units, the most competing technologies are the micro-CHP boilers based on the Stirling engine, the internal combustion gas engine (ICE) and the fuel cell. Research and development activities in the Netherlands have focused mostly on the development of the Stirling engine and on a much smaller scale on units driven by fuel cells. The Stirling engine based micro-CHP unit is the first technology that has entered the Dutch market. The micro-CHP units based on the Stirling engine have a high heat/power ratio, which means that it has a low electrical efficiency and a relatively high heat production for a particular capacity, with the result that they are best suited for houses that have a high heat demand. Fuel cell based micro-CHP units have a significantly higher electrical efficiency and they are therefore more suited for houses with a lower heat demand such as smaller houses and well isolated houses. As newly build houses are typically well isolated as this is the cheapest way to save energy, this technology seems to be the most promising technology in the longer term. Table 4a shows the result of a consultation among micro-CHP developers about the efficiencies for the three most competitive technologies for 2010 and 2020. η_e is the electrical efficiency while $\eta_{overall}$ stands for the overall efficiency; the heat efficiency η_w is then $\eta_{overall}$ - η_e. Although testing on units with fuel cells have been occurring on a smalls scale, it is still in the early stages of development and the interviewed actors all have mentioned that they expect that the technology will not be commercially ready for a long time.

	2010			2020		
	Stirling	ICE	Fuel cell	Stirling	ICE	Fuel cell
η_e * (range) (ow)	14% (12-20)	20% (18-25)	35% (30-40)	25% (20-30)	25% (20-30)	40% (35-45)
$\eta_{overall}$ * (ow)	105%	95%	85%	105%	105%	95%
P_e	1	1	1	1	1	1
P_{th}	6,1	3,8	1,4	4,9	3,0	1,4
	Available	Demo phase	Demo phase	Available	Available	Available
* Expected stationary efficiencies						

Table 4a – Expected efficiencies of the three most competitive micro-CHP technologies (Werkgroep Decentrale Gastoepassingen, Smart Power Foundation, and Werkgroep micro-wkk Cogen Nederland, 2010).

What can also be learned from the previous paragraph is that the fuel cell based micro-CHP boilers have properties that are very good for a future energy system in which micro-CHP boilers play an important role in the generation of electricity. While Stirling based micro-CHP units are driven by heat demand, fuel cell based micro-CHP boilers have such a low heat/power ratio that it is driven by the electricity demand. This set-up makes it an ideal device for a so-called virtual power plant that connects many de-central energy generating technologies to the grid and in which demand and supply is intelligently coordinated in order to create one big 'virtual power plant'.

In the first orientation of the field diverse parties identified the Stirling based micro-CHP boiler as the technology that has the most potential to be developed into a marketable product and most R&D activities in the Netherlands have focused on the development of this boiler with the result that since last year the boiler is commercially available. As figure 4e shows it is believed that Stirling micro-CHP boilers will dominate the market until at least 2030. I will therefore focus my research activities on the development of this type of micro-CHP boiler. In the next section I will present how a basic Stirling micro-CHP boiler works, which types of Stirling engines there are and what the benefit and disadvantages of each type are.

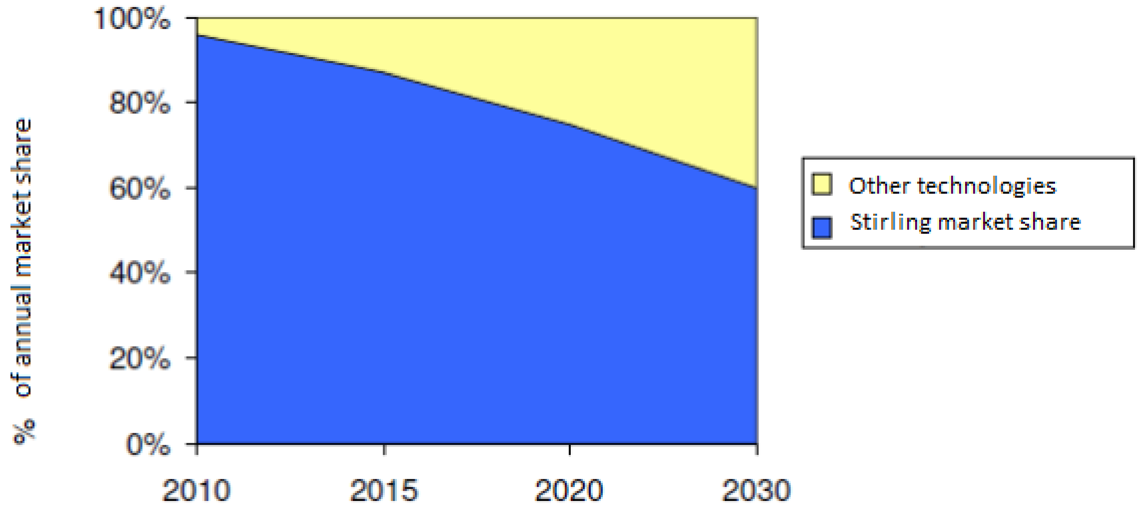

Figure 4e: Annual share of Stirling micro-CHP boiler in the micro-CHP market (De Jong, 2008)

4.2 Stirling engine based micro-CHP boiler

The Stirling engine has already been developed in 1816 by sir Robert Stirling as a low-pressure safe alternative for the high-pressure steam engines but it has not been used a lot over the past two centuries since his invention was not needed anymore after the invention of the steel that improved safety of steam engines dramatically. There was a small market for the Stirling engines in places where a reliable energy source of low to medium size was required. Although not very efficient since they ran on lower temperatures, they could be operated by anyone who was capable of managing fires. During the early years of the 20th century the role of the Stirling engine as a reliable motor for domestic use was taken over by electric motor and small internal combustion engines. In the 1940's the Dutch company Philips decided to build a Stirling engine of 200W to power radios in places where electricity was unavailable. They started production in 1951 but it was soon clear that the production of the small Stirling engines was not cost effective and they stopped the production. They did however continue to develop experimental engines for a variety of applications but were only successful with the development of the 'reversed Stirling engine' cryocooler. However they did patent a number of developments which they licensed to other companies and a lot of these formed the basis for later developments in this field.

As a result of the successful use of large scale co-generation of heat and power, towards the end of the 1990's a number of parties started seriously to look at the possibilities of building a domestic device that could co-generating heat and power. The technology of the Stirling engine seemed ideal for this purpose and in the early 2000's three different types of Stirling engine based micro-CHP boilers had been developed that were ready for the first field tests. The first being developed by Whisper Tech Ltd, a New Zealand based company that used Stirling engines in their power generators in ships in which they used seawater to cool the engine. When this turned out to be a success in 1998, in the following year they began to build their engines into a boiler for domestic use. Instead of cooling the engine with seawater, they used the heat of the boiler for domestic purposes. In 2006 Whisper Tech Ltd. was taken over by the Swiss energy company Meridian Energy. The second Stirling engine was developed by STC/Infinia and build in a boiler by Enatec, a collaboration of the Dutch energy company Eneco, the Dutch boiler manufacturer Atag, and the Dutch research institute ECN, and the third being developed by Sunpower, a USA based company, in 2001 bought by British Gas and renamed Microgen, later in 2007 they were bought by a wide partnership of boiler manufacturers of whom Rehema and Viessmann were the most prominent. The name changed again, this time to Microgen Engine Company (MEC). The three mentioned engines all use a different technology which all have their up and down sides, as I will discuss in a moment but I will first explain the general concept of the Stirling engine.

4.2.1 Stirling engine

A Stirling engine is an external combustion engine that uses an external heat source to expand a working fluid driving a piston engine. In its simplest form the Stirling engine comprises of a *cylinder*, *regenerator*, *piston* and *displacer* as shown in figure 4e. Fuel is burned continuously outside the engine to maintain one end of the cylinder at high temperature while the opposite end is cooled by circulating water around it. Power is derived from the pressure fluctuations acting on the working piston, as a fixed volume of working gas (air, hydrogen or helium) (sealed within the engine) is alternately heated and cooled, forcing it back and forth between the two temperature zones via the regenerator. The regenerator thus works as a pre-cooler and a pre-heater of the gas. The working gas is moved by the displacer, which is 90 degrees in advance of the working piston. The sinusoidal waveform of the power output results in low vibration and noise levels. Thermal efficiency is enhanced by the regenerator, a heavy matrix of fine wires that acts as a repository for heat extracted from the working gas during the cooling pass to be returned on the heating pass. The system is cooled by water which is thus heated by this process. The piston moves a crank shaft or a linear alternator to generate electricity.

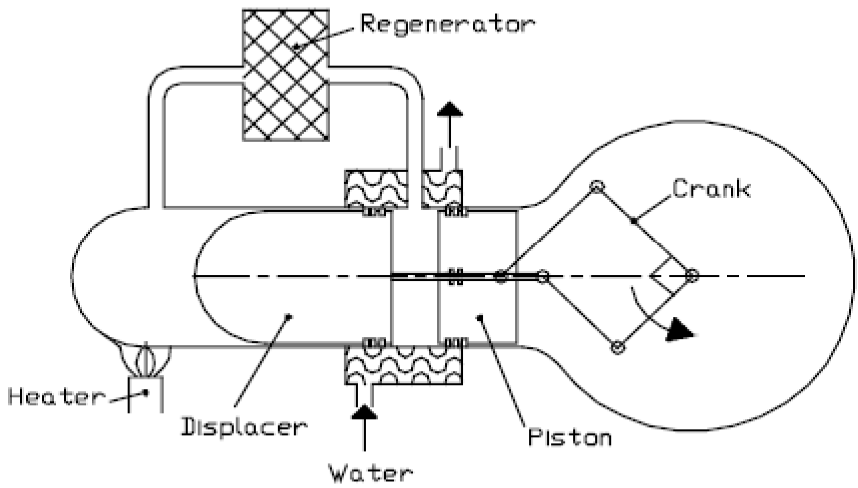

Figure 4f - Example of a kinematic Stirling engine (Harrison, 2002)

4.2.2 Kinematic versus Free-piston

A general benefit of a Stirling engine is that it can achieve a high efficiency, due to the limited number of moving parts it has a relatively low maintenance, and it has the flexibility to use a variety of fuels although in all the Stirling micro-CHP boilers natural gas is at the moment the fuel of choice. In the future however use of biogas or a mix that includes hydrogen gas is possible. However there are also a number of disadvantages of the Stirling technology and one of the most important one is that it uses expensive parts due to the fact that these part need to be heat and pressure proved. An example is that the materials and the assembly of the high temperature heat exchangers make up for 40% of the total costs of the unit. Another disadvantage is that high efficiency numbers of the boiler can only be achieved when the boiler is used for a long time. The efficiency drops dramatically when the engine needs to start-and-stop a lot of times. The activities of the user thus have a large impact on the efficiency.

There are two major design philosophies at work in the Stirling micro-CHP boiler field, called the kinematic engine and the free-piston engine, which both deal with the benefits and disadvantages in their own way. These two philosophies have to do with the way the mechanical energy of the movement of the piston is transformed into electricity. Whisper Tech Ltd. uses the kinematic engine for their boiler and their solution uses a crankshaft to transform the linear movement of the piston into a circular movement which is used to generate electricity. The Microgen and the Enatec unit both use the free-piston engine which uses a linear alternator to generate electricity. As said, both have their up and downsides. The solution of Whisper Tech Ltd. has a relatively low efficiency but is much cheaper than the two alternatives. It uses four cylinders in their Stirling engine and it thus has some mechanical complexity but it uses very pragmatic solutions for their problems and therefore the production cost per unit is relatively low. The free-piston engine on the other hand is very elegant in terms of engineering but in both designs great technical challenges needed to be overcome and these challenges have postponed the route to the market introduction. Compared to the kinematic engine, the free-piston engine practically has no moving parts and it operates on a higher temperature with the result that the efficiency is higher but also the complexity, and the cost of materials.

4.2.3 Solo versus combi

One characteristic that is important is a differentiation between a solo-boiler and a combi-boiler. The solo-boiler only provides heat for the central heating system. It always needs an added device to generate hot tap water. This most commonly comes in the form of a boiler which is basically a hot water tank which can provide hot water rapidly. The result of this is that a lot of space is needed for the hot water tank. A combi-boiler delivers both domestic hot water and heat for space heating from one unit. The condensing combi-boiler has become the standard boiler for most Dutch households with a penetration of 76% in 2010. When compared a penetration of 15% for the solo boiler one can understand that most efforts are focused to find a replacement for the combi-boiler (de Jong et al., 2006).

The market for condensing combi-boilers has been developed since the early 1980’s and since then it has developed into a strong regime including a strong maintenance and supplier network, a technology that has been perfected over the years, users that have accepted the technology and are familiar with the way the technology works, and with an industrial quality standard for its efficiency. The replacement market for boilers is very large with around 350.000 and 400.000 boilers a year so the potential market for micro-CHP boilers is very large. Proponents of the introduction of the micro-CHP boiler in the Netherlands have envisioned that this new boiler could be a direct replacement of the old wall mounted combi-boiler since most boilers in the Netherlands are of this type. The result of this vision is that Stirling micro-CHP boilers needed to be developed in a way that they would be a ‘fit’ to the old situation. This meant that they first of all needed to be wall mounted and that they have to be relatively small without the use of a large hot water tank.

The benefit of a solo-boiler with respect to the micro-CHP case is that it can store heat in the hot water tank and that they therefore are more flexible in its operating hours therefore also making it an interesting option to use in a future virtual power plant. A virtual power plant is an electricity grid in which a number of de-central energy generating devices that are able to store energy in buffers are connected to each other. These devices are controlled externally by the demand of energy elsewhere in the grid. A combi Stirling micro-CHP boiler is not suitable for this since there is no buffer in which to store excess heat.

4.3 Actor network

I will first describe which actors are involved in the micro-CHP niche. I will identify and describe the relevant social groups and the actors involved in these groups. I will also describe various relations between actors and actor groups.

In advance of the interviews, a field study was executed in order to identify the most relevant social groups. A selection of this group of stakeholders was approached for an interview. As a check, during the interviews the stakeholders were asked to describe their present and past position in the micro-CHP field. They were also asked to identify other stakeholders in the field and to elaborate on their roles. With the help of this information and the field research done in advance of the interviews, a categorization of the stakeholders could be made so that each stakeholder could be placed in one of the following categories: Energy suppliers, micro-CHP manufacturers, intermediaries/lobby groups, installers, grid operators, government, consumers, society, and research. Figure 4g shows an actor map (a multi-actor network) in which the various stakeholders are placed into categories. In the next section I will identify on the most interesting actors in each of these categories and elaborate on the role they play in the development of the niche.

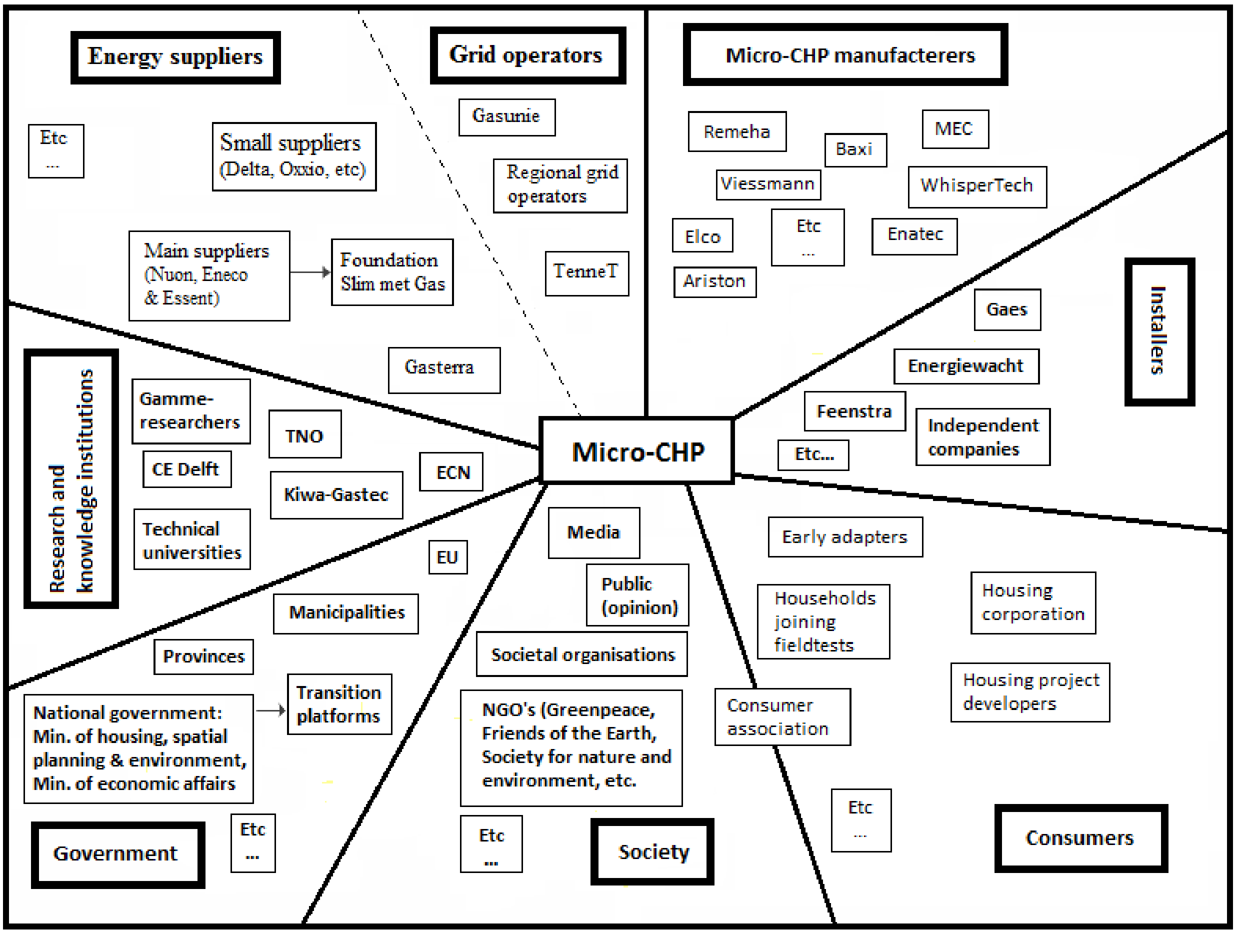

Figure 4g: Multi-actor map of micro-CHP field (Adaptation from Feenstra, 2008)

4.3.1 Energy suppliers

When discussing the Dutch energy market I first have to make a division between an electricity segment and a gas segment. In The Netherlands natural gas is by far most important source of heat. More than 90% of all houses and buildings are connected to the natural gas grid and heat is primarily produced by the burning of natural gas. Since the micro-CHP boiler produces heat as well as electricity, energy suppliers that deliver gas and/or electricity are interesting actors to include in the social network. In The Netherlands there are three main energy suppliers, Nuon, Essent and Eneco, and a number of smaller ones of which Delta is the biggest one but its size is still nowhere near the three big ones. These three all supply electricity as well as gas. These big companies all found their roots in the privatization gulf in the 90's. Regional energy companies were privatized after which they merged with each other to form big corporations. Of these three, Essent and Nuon have been taken over in 2009 by RWE and Vattenfall respectively.

GasTerra is a gas supplier and trader company owned for 50% by Shell and ExxonMobil (both 25%) and for 50% by the state. It used to be a part of the Dutch gas company Gasunie but in 2005 the company split up with a part that controls the transport of gas, Gasunie Transport Service (GTS), and a part that is in charge of the trade and supply of gas to customers, Gasunie Trade & Supply, nowadays called GasTerra. In the rest of this thesis I will refer to this actor as GasTerra. Its task as a semi-governmental organization is to trade gas as efficiently as possible. Their goal is to make the most of the available gas reserves in the Netherlands. This is also the main reason why GasTerra has supported the development of the micro-CHP-boiler in the Netherlands, it makes it possible to use the available gas more efficiently than the use of natural gas in the current configuration. Next to this it is much more lucrative to sell natural gas to domestic clients although a lot of the profits made on the gas market return to the Dutch treasury.

In 2006 GasTerra, Essent, Eneco, and Nuon together formed a temporary association 'Slim met Gas' (Smart with Gas) with the goal to 'stimulate the use of efficient and relative clean natural gas technology'. This association had as the primary focus the development of micro-CHP. At the establishment of the association, they identified a number of possible legal, technical, and economic bottlenecks that would hinder a smooth market introduction and they tried to find a solution for these problems.

When Frans Hazen [GasTerra] approached Eneco in 2005 they already had done a successful field test with 9 units. Before Frans Hazen [GasTerra] approached Eneco they already had tried to start a collaboration with their colleagues of Essent and Nuon but this apparently did not result in a collaboration. After Frans Hazen [GasTerra] approached Eneco, Eneco received the right contacts and a collaboration was suggested and accepted. In 2007 'Slim Met Gas' was founded which predominantly supported field tests with Stirling micro-CHP-boilers. Eneco continued with the testing of its ENATEC boiler (although not solely with ENATEC's) while Essent and Nuon predominantly tested with Remeha's boiler. Nuon and Essent took a different approach than Eneco, they primarily worked with the use of housing corporations while Eneco worked with single users. The reason for Eneco to use single users was that they would have very motivated users as test subjects while in the tests with Nuon and Essent the users were more or less forced to accept the micro-CHP-boiler.

Interested in micro-CHP development because ….

Actors in this group all have an interest in new technologies that have an impact on the field of energy generation although sometimes with diverse motivations, they all benefit from knowledge of new applications in the field. For the energy companies the micro-CHP-boiler is interesting since the boiler can generate electricity de-centrally thus having the potential making the user a producer. The relationship of the energy companies with the end-user of gas and electricity potentially changes and it also has the potential to change the 'profit-generating model' of the energy companies. When micro-CHP-boilers are installed in big numbers this can have an impact on their business since they are obliged by law to buy the electricity that micro-CHP-boiler users would deliver back to the grid.

Energy companies are involved in a wide range of activities in the energy system and therefore constantly will need to invest in information about these activities in order to stay informed and to be able to make the right decision at the right times. Knowledge is the most important for the energy companies and networking companies and this is the main reason why they invest in the local test projects. The group is important for the niche since they invest a lot in test-projects in the development phase of the technological-niche and they have major marketing budgets which can be used to promote the technology in the marketing-niche phase.

4.3.2 Grid controllers

Before 2011 the energy suppliers and grid controllers could be placed in the same category because the grid controllers used to belong to the energy suppliers but due to a 'split up law' (that became active 01-01-2011 and was created under EU pressure) the companies had to split up. This was done because since the grid controllers controlled a physically fixated grid, they had the possibility to favor their own energy supplier. By splitting the companies into a supplier and a controller the government tried to create a more open market place.

There is a division between the regional and the national grid controllers. The national grid controllers are 100% state owned. For electricity this controller is called TenneT and it controls the high voltage net (110 kV or higher). For gas this controller is called Gasunie Transport Services (GTS) and its main responsibility is the building and maintenance of the national gas transport system. Next to the national grid there are regional grid controllers that own and maintain the net in a particular region, in the case of electricity this is a low voltage net. There are 8 regional grid controllers for electricity and 11 for gas. The municipalities in The Netherlands decide which grid controller will be active in their municipality but as you can see in the figure 4h, only a few dominate the market. After the split up law the three biggest grid controllers dominate. Enexis was part of Essent, Alliander was part of Nuon, and Stedin was part of Eneco.

Figure 4h; Regional grid controllers

Interested in micro-CHP development because ….

Traditionally the network transports electricity from a production site, like a large power plant, to the user. When a large number of micro-CHP-boilers are connected the grid gains a new function and that is to transport energy from the user/producer back to the grid. This new function is also present with the excess amount of power produced in PV-solar panels, or decentralized small wind mills. In order to know whether the grid can still reliably transport power with the same quality, the grid controllers participated in field tests. The problem for the grid controller with micro-CHP is twofold. 1) There is a safety issue. When the grid is down and the micro-CHP units are still pumping energy back into the system, there cannot be any work done on the grid. Therefore the micro-CHP units should have a failsafe for these situations. 2) The second is whether or not the grid can handle the strained that the micro-CHP units will put on the grid. Various tests were done to test this such as the 'Weiland test' in 2006 and the 'Smart City Apeldoorn project' started in 2009.

4.3.3 Micro-CHP manufacturers

Producers of Stirling micro-CHP boilers can be divided into a group of traditional boiler manufacturers like Remeha and Viessmann and a group of producers that had no experience in the field of heat boilers like for example Whisper Tech Ltd. Typically the group of traditional boiler manufacturers do not build the engine themselves but they buy it from a dedicated Stirling engine manufacturer. There were two competing free-piston Stirling engine designs, the Microgen-engine and the Infinia-engine, that are build in micro-CHP boilers of various actors. The Microgen-engine was originally developed by the BG group in the U.K. and it is used by a number of boiler manufactures such as Remeha, Baxi, Viessmann, Vaillant, and KV Navien. The Infinia-engine is built in Japan by the boiler manufacturer Rinnai and used in boilers of Ariston (a brand of the MTS group), Bosch and Rinnai. The main proponent of the new boiler manufacturer, Whisper Tech Ltd., builds its own kinetic Stirling engine.

WhisperGen micro CHP boiler — Ariston micro-CHP boiler with Infinia-engine — Remeha micro-CHP boiler with Microgen-engine

Figure 4i: Three Stirling micro-CHP boilers

The group of Stirling micro-CHP-boiler producers is very important in the developing niche since they obviously build the machine around which the niche is being developed. Actors in this group have invested in the R&D of the new technology and they are responsible for the price setting of their machines which is of vital importance for the success of the technology. Also design decisions that are taken by these actors directly influence the applicability in the Dutch situation.

In 2006 an association 'Smart Power Foundation' has been set up between the various actors including Remeha, Baxi, Elco, Vailliant, Whispergen, MEC, Elco, and GasTerra. The mission of this association was: 'to increase the market opportunities for the application of mini- and micro-CHP and to promote the micro-CHP boiler as a possible successor of the condensing gas boiler'.

Interested in micro-CHP development because ….

The group of traditional boiler manufacturers perceives the micro-CHP-bioler as a new type of product that increases their boiler-portfolio while for the new group the micro-CHP-boiler is the main product in their portfolio.

4.3.4 Installation companies

The installers are very important for the success of the micro-CHP boilers. The boilers are not just simple heat generators but a high-tech machine with an engine that has to be fine-tuned at the homes of clients. If this is done incorrectly then the whole micro-CHP-boiler will not work efficiently and is thus missing the goal. This is also the reason why Remeha has training days on which installers get to know how the installation exactly works. When they finish this training they get a certificate to show that they are licensed to install micro-CHP boilers.

Besides the more advanced machinery, the unit is also much heavier than the old one so that the workers need an electrical stair climber to bring the boiler to the top floor. In the old situation one worker could install the condensing gas boiler but in the new situation two workers are needed. Another reason why the installation branch is so important is that they are the ones that deal with the customers. The installation companies are the link between the producer and the end-user of the product. They are important in the sense that they are able to inform potential customers about the micro-CHP-technology. Remeha does not really come in touch with the people that are going to use the micro-CHP boiler. They sell boilers to the installation companies who sell them to customers.

One more interesting thing to mention is that energy suppliers often have a national network of installation specialists that will act under the banner of that supplier. There is a lot of money to be made on the servicecontracts that come with the boilers. Part of Eneco is Metapart, Tempus, and GSU, Nuon has Feenstra, and Essent has Delta, Geas, Energiewacht, Kemkens, and Volta. Although these installation companies have an important part of the market in the Netherlands, most installation companies are independent from the big energy companies and since the energy companies use their own installation companies for the local test projects, the training program of Remeha is more important for these companies than for the installation companies connected to the energy companies.

Interested in micro-CHP development because ….

The micro-CHP boiler is one of the many appliances in their portfolio to install. Since the Stirling micro-CHP boiler has a condensing gas boiler and a Stirling engine integrated in the device, the installation companies are not worried that the boiler require less maintenance. They have direct contacts with the user and they sign service contracts with clients for annual maintenance. So not only the installation of the boilers is important, the market for service contracts is at least as important for them. A small example, at the moment the cost for servicing a boiler is slightly below 100 euro annually. With a life span of 15 plus years and a cost of the boiler of around 1500 euro one can easily see that the service contract market is almost as big as the boiler market itself.

The knowledge of the installation companies is of importance. When they do not have the knowledge and means to install the micro-CHP-boilers then this is a clear barrier for the successful introduction of this technology in the Netherlands.

4.3.5 Consumers / potential adopters

Within the potential adopters two actor groups are of importance, the housing associations and the individual end consumer. These associations are important because they are ideal to kick start the production of a lot of boilers. When an association can be convinced that the micro-CHP boiler is a better option than the normal condensing gas boiler, potentially a huge number of boilers can be sold at once. When the boilers perform well this is then for other associations a sign that the technology is reliable and interesting to take a further look at. Nuon and Essent have adopted this strategy and they chose to include housing corporations at big local test projects. Eneco on the other hand has opted for a different strategy and they choose to execute tests at individual actors in order to keep the support for the technology high since often early adaptors choose to participate in tests and these individuals tend to be rather flexible when dealing with new technologies.

The branch organization of the housing corporations Aedes also plays a role in plans to install large number of micro-CHP boilers in the Netherlands. During the third national micro-WKK congress in 2009 the minister that was responsible for environmental issues challenged the market parties involved in the micro-CHP niche to install 100.000 micro-CHP units, starting with the installation of 10.000 units. Aedes was one of the parties that supported this idea and together with a number of other actors a support group, HRe-in-versnelling, was formed to achieve this challenge. Plans were made which started with 5 fore-runners in Aedes, later others would follow. Unfortunately this didn't work out since when the boilers would be installed, the subsidy was dropped and the housing corporations that would participate in the tests, withdrew.

Other possibly important actors are the housing project developers since with use of micro-CHP boilers the developer can conform to the demand of the government (new since January) that newly build homes should have a an EPC (Energy Performance Coefficient) of 0.6. It is not the only option the developer has but micro-CHP is now one of the options.

Interested in micro-CHP development because ….

Well, for the housing project developers this is quite clear. They are forced by law to search for options to make their houses more energy efficient. For individual actors this is also quite clear, this is not because they want to save a lot of money because in that case they know that it is better to wait for a while so that the prices drop and the quality improves. No, it probably has more to do with being interested in new technologies. [not so strong, revise] For the housing corporations this is a rather interesting question. When interviewing 'De Woonmensen' the interviewee stated that they were the frontrunners of the housing corporations and they were always looking for possibilities to use new technologies. Apparently early adapters can also e found in organizations.

4.3.6 Governmental agencies

This social group consists of diverse actors on the various governmental levels, from the European Union to local municipalities. Investments are made on each level to support local projects. The 'connecting elements' between these levels are the various clime agreements that were made. On global (national) level the members of the European Union have agreed to speak with one voice in the Kyoto climate negotiations with the result that an emission cut of greenhouse gases with an amount of 8% compared to the level of greenhouse gases in 1990 was agreed upon for the whole EU-zone. When the Kyoto protocol was signed, agreements were made between members of the EU on the amount of emissions cut per country, for the Netherlands this amount was 6%. An additional climate agreement was made within the European Union that commit the members to reduce the amount of emission gases in 2020 with 20% compared to the emission levels in 1990.

The Dutch government formulated a plan in 2001 to facilitate the transition of the fossil based energy system into a sustainable system in thirty to fifty years (Nationaal Milieubeleidsplan 4, 2001). This plan eventually led in 2004 to the definition of a number of transition paths which would lead to public-private cooperation on a number of areas. The defined areas, or platforms as they were called, are:

- Green raw materials
- Sustainable mobility
- Chain efficiency
- New gas
- Sustainable electricity facility
- Build environment
- Local energy initiatives

Various workgroups were formed in each platform and in the platform 'new gas', the workgroup 'decentral gas applications' was formed. In this workgroup various public and private actors worked together to achieve the goals set by this transition path which is mainly to increase the efficiency of gas conversion in the build environment. Members of the workgroup were ECN, Enatec, Essent, Delta, GasTerra, Microgen, Nuon, Remeha, Rendo, SenterNovem, Smart Power Foundation, Vaillant, Whisper Tech Ltd. This workgroup has formed a vision towards the use of micro-CHP until 2030. I will present these visions in chapter 5.

On the national level the government has a number of tools at its disposal to support the development of new technologies. In the case of micro-CHP the government has decided in 2008 to provide a subsidy of €4000.- for each micro-CHP boiler. In juli 2011 the new minister of Economic affairs, Agriculture, and Innovation, stated that the program had the goal to help start up the market before the end of 2011 so that no subsidies were needed after 2011. However he stated that the subsidies have not helped to make the expectations come true. The necessary and by the sector predicted cost reductions because of learning effects and economies of scale have almost not occurred. He has not had enough confidence to continue to subsidize the micro-CHP boilers. From 17 February 2012 the program has been cancelled.

On the national level the legal issue of the feed-in of electricity back to the grid was settled and a tariff was agreed upon. The energy companies now have the obligation to buy back the electricity at market conform prices. Also the legal issue of attaching an electricity producing unit was settled in a way that it is allowed to attach a unit that generates a maximum of 1 kWh to the grid via a normal plug-socket.

While the Dutch government supported programs at the national level, provinces created their own climate programs in order to help to achieve the climate goals. These programs are for example important for permits for projects and for the coordination of projects that stretch over the borders of the municipalities. Provinces on their turn worked together with municipalities that have their own climate ambitions.

A special actor to mention here is Agentschap.nl. This actor was until last year called SenterNovem and it is a department of the Ministry of Economic Affairs, Agriculture, and Innovation. The department executes policies that deal with Energy and Climate, Innovation, and Environment. Under the Agentschap.nl a number of transition platforms fall in which a number of committees were active that studied the various elements of the energy transition. They looked for example at de-central gas solutions in the building environment, in which micro-CHP would be located.

Interested in micro-CHP development because ….

The use of micro-CHP boilers is for the various parties a possibility to contribute to a solution for the climate problems and to honor previously made climate agreements. What is also interesting is that expectation existed that micro-CHP would make more efficient use of the available natural gas reserve which was a motive to support developments in the micro-CHP field. The result of this more efficient use is that The Netherland will become less dependent on external energy suppliers as well as that, since fossil fuels will become more and more expensive due to its finite nature, prices will rise and the government will receive more money.

4.3.7 Research and knowledge institutions

A number of actors can be mentioned here but arguably one of the most important is ECN (Energyresearch Centre the Nederlands). This is the largest Dutch research center in the field of energy. Their mission is to develop high-quality knowledge and technology for a sustainable energy society and also to bring this to the market place. An example is the Stirling engine they developed in cooperation with Eneco.

The composition of this group is very varied. Kiwa-Gastec is for example an actor that independently tests the efficiency of various gas appliances and they also help organizations with the certification of their product. Also important to mention here is the Council of Accreditation. This is an independent foundation originally founded by the ministry of Economic Affairs that objectively assesses the quality of products and services on various fields of activity and which can acknowledge particular quality marks for these products and services. This Council of Accreditation controls the procedures that Kiwa-Gastec uses.

Consultancy agencies also fall into this category. Agencies like CE Delft and Energy Matters are being hired by for example commissions of the former SenterNovem to report to them. Other actors in this category are the universities. In the University of Twente for example research is being done on Smart Grids and how micro-CHP can support this grid.

Interested in micro-CHP development because ….

New technologies are for knowledge institutes very interesting since a field of research lies is opened up with their introduction. When, as for example is in the case of micro-CHP, parties are interested in the possible future application of the technology then funds will be freed and knowledge institutes are very good at locating these funds. They are thus not primarily interested in the development of the technology per se, but they are very interested in being hired to investigate the technology in all its aspects.

4.3.8 Societal agents

Like the previous group this actors group is very diverse. Consumer organizations that actively protect the right of consumers, as well as environmental organizations can be counted as a part of this group. The media play an important role in the communication between various actors and actor groups. They play an essential role in the dispersion of expectations.

Examples of actors in this group are NGO's like Greenpeace, Society for nature and environment, Friends for nature, etc. These NGO's use another societal actor, the press, to spread their thoughts on new technologies like micro-CHP and therefore can influence another actor, the public (opinion) which on its turn can influence policy by the government. The public is also able to vote with their Euro whether they support the new technology or not, although this is at the beginning of the development process off course not really an issue.

Another societal actor is the foundation Energy Performance License. This is an independent organization that develops and promotes certifications for energy efficient and clean devices. These certifications can be used to compare for example the new micro-CHP boilers to the existing condensing gas boilers. The earlier mentioned Kiwa-Gastec is the organization that test and certifies the devices.

Interested in micro-CHP development because ….

A wide variety of reasons but there is often a link with a protecting of some societal interest. An example is the environmentalists that have mixed feelings with the micro-CHP technology based on the Stirling engine since this is a boiler that works more effective than the old one, which is positive, but it still runs on fossil fuel and is propagated by actors in the fossil fuel regimes, which makes the technology for them very doubtful.

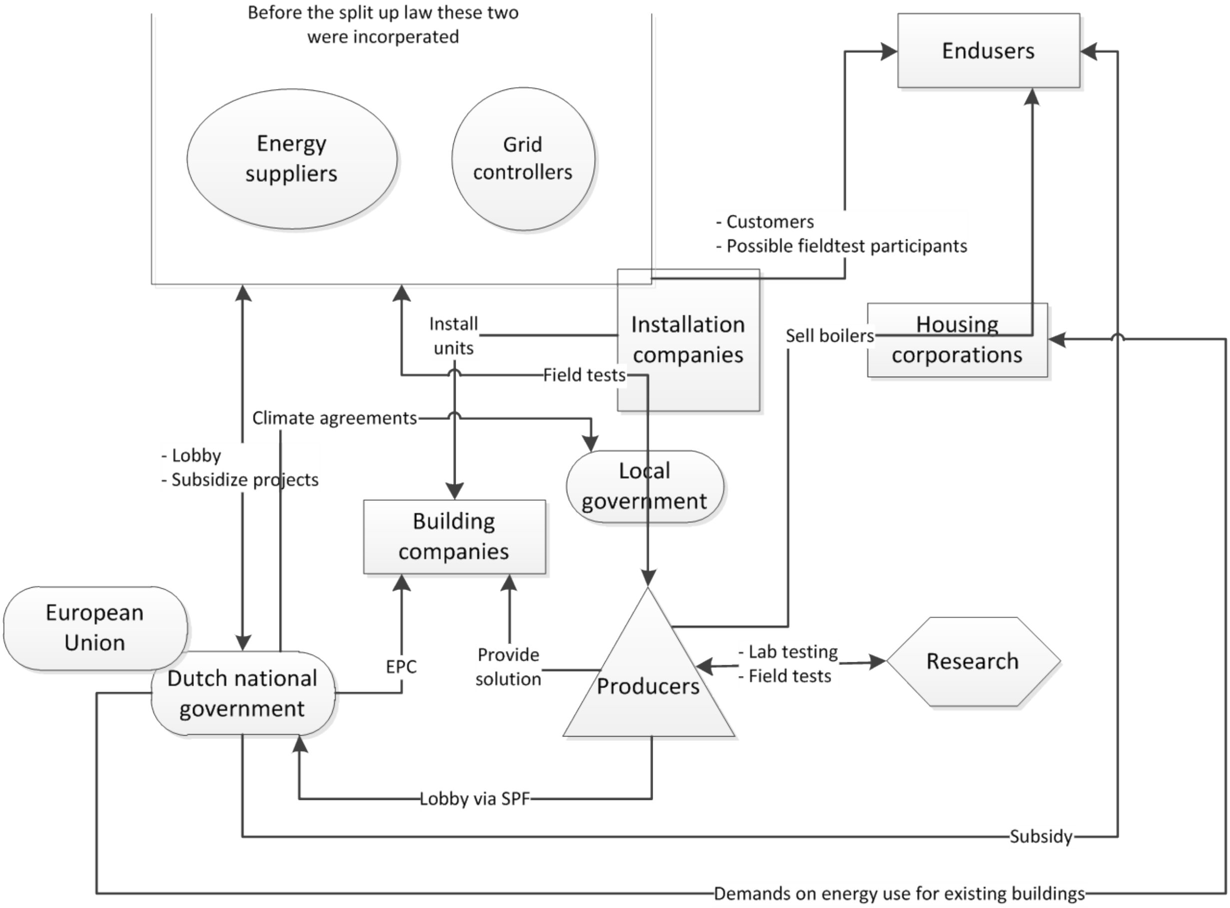

Figure 4j: Overview of relations between actor groups

4.4 Stirling micro-CHP boiler niche's relation to its connected regimes

Two regimes can be identified as being very closely connected to the niche; these are the heat regime and the electricity regime. The energy companies sell gas and electricity to consumers and they are the dominant actors in these two regimes. Also important in the heat regime are the boiler manufacturers that sell devices to consumers to transform gas into heat. As shown above, the actors that dominate the two regimes are also the dominant actors in the Stirling micro-CHP boiler niche. Most of the resources that are used in the niche originate from the regimes with the main actors from both regimes investing heavily in the niche.

What is interesting here is that while often radical system changing novel technologies are developed by a small network of actors that are outsiders to the regime, the Stirling micro-CHP boiler is being developed by regime actors from the heat regime and supported by actors in the energy regime. For the boiler manufacturers this can be explained by the fact that they see other de-central energy generating technologies as a threat to their business and their reaction was to invest in the development of a new device that would increase their portfolio in order to reduce the threat.

For the energy companies this is a different story. The initial vision with which they were attracted to invest resources in the Stirling micro-CHP boiler niche was that the new boiler would be more efficient than the old boiler, that it would be a direct replacement technology for the old boiler, and that the new boiler would be able to compete on price with the old boiler. These expectations however do not explain why the energy companies should invest in the novel technology. The answer can be found elsewhere in the various activities of the energy companies at the time when the energy companies got involved in the niche. At that time the networking companies were a part of the energy companies and because the amount of de-central energy generating devices has increased in the last few decades, they were forced to invest in research into the effects of these devices on the grid. The expectation that the de-centralization of the energy supply that has increased in the last past decades will continue in the future is important in the decision of the energy companies to invest in research into the effects of this new technology. A second expectation that is linked with the previous expectation is the possibility of using the Stirling micro-CHP boiler in a future Smart Grid. Although the Smart Grid is not expected to be a reality soon, the networking companies need to make sure that the future grid can handle the loads generated by the de-central energy generating devices.

4.5 Overview of projects

I will present a number of projects in which I have a special interest and which I will later reflect on or which are important for the general overview of the field. All the test are located in the Netherlands accept for the first proof-of-principle test which took place in England and which marks the start of the field testing in the Stirling micro-CHP boiler niche. Table 4b presents an overview of the various test projects, beginning with the first proof-of-principle test. In chapter 6.1 I will discuss how these projects have contributed to the expectations about Stirling micro-CHP in the Netherlands. In Appendix D an elaborate description of the tests projects is presented.

Project	Period	Actors involved	Description
Proof-of-principle test Whisper Tech Ltd.	2000-2002	Whisper Tech Ltd.	Fieldtest in the UK with 20 boilers with kinetic four-piston Stirling engines
Demo tests Whisper Tech Ltd.	2000-2002	GasTerra	50 WhisperGen WG800 systems underwent demo tests at sites in a number of countries. In the Netherlands GasTerra tested this boiler in order to see whether it was a viable option for the replacement of the condensing gas boiler
Proof-of-principle test Enatec	2002-2004	Enatec – Eneco, Atag, ECN	Fieldtest with 9 boilers with free-piston Stirling engines
Whispergen 1	2006-2007	GasTerra, Stichting Natuur en Milieu, Energycompanies, Cogen, Smart Power System	50 WhisperGen Mk4's were placed mainly in houses of employee's of energy companies. Subsidy has been received via the UKR (unique opportunity regulation)
Paddock trial	2006-2007	GasTerra, Grid controllers, Eneco, Kiwa Gastec	48 WhisperGen Mk5's are installed in a hall and connected via one transformer in order to test the stability of the low-voltage grid
Remeha 1	2007	Slim met Gas, Remeha	8 FPSE micro-CHP wall-mounted boilers from Remeha were installed in houses with a heat demand of 1600 m^3 natural gas / year
Remeha 2	2007-2009	Slim met Gas, Remeha	100 FPSE micro-CHP wall-mounted boilers from Remeha were installed mainly in houses of employee's of energy companies.
Smart Power City Apeldoorn	2009-2012	Slim met Gas (especially Nuon), Rehema, Alliander, ECN, housing corporation Woonmensen, Feenstra installation company, municipality Apeldoorn, Exendis, Imtech, KEMA, Eaton	173 FPSE micro-CHP wall-mounted boilers from Remeha were installed in a single district in Apeldoorn in order to primarily test the real life quality and stability of the grid
Duurzaam Ameland	2009 - 2012	Slim met Gas (especially Eneco and GasTerra), municipality Ameland, Ariston	100 micro-CHP wall-mounted boilers from Ariston have been installed on the island of Ameland. The goal of the test was to demonstrate that the Ariston boiler functions well, that it delivers comfort, and that it actually saves energy.
Maaspoort 's-Hertogenbosch	2009 – 2012	Slim met Gas (especially Essent), Remeha, Enexis, housing corporation Zayaz, municipality 's-Hertogenbosch	10 FPSE micro-CHP wall-mounted boilers from Remeha were installed in a district in 's-Hertogenbosch together with a number of other small scale energy technologies in order to see whether the interactions between these different systems works well.

Table 4b: Overview test projects

Chapter 5 – Expectations in the Stirling micro-CHP boiler niche

At the start of niches the structure of a local and a global niche level is not very clear, expectations that exist at this stage are unstable, not detailed, and crude. They are important to find initial support and in order to receive resources. Since at this early stage of the development there is not a community that can share expectations, global niche expectations do not exist at this early stage. In later stages of the development the global niche expectations are shared by various members of the community and in this chapter I will present the expectations that are mentioned by multiple interviewees which represent various groups in the Stirling micro-CHP boiler community. In chapter 6 I will explicitly discuss the changes of the expectation within my period of investigation.

I will start by presenting the landscape expectations, or macro expectations, that support the developments in the niche. In chapter 6 I will refer back to these expectations in order to show which role they play in protecting niche activities and stimulating the niche developments. Next I will present the global niche expectations that are shared among the various actors in the niche; Geels and Raven call these meso expectations. Finally I will present the micro expectations that deal with specific problems on the local level and which are to be dealt with in test projects. These micro expectations are linked to the global niche expectations in a way that when promises about the technology are shared these create particular requirements which can be fulfilled by search processes on the micro level of the niche.

5.1 Landscape expectations

Since the energy crisis's of the 1970's and the interest of the impact of human actions on our environment so-called 'green-energy efficient-technologies' have become more and more popular. Proponents of these 'green-energy efficient-technologies' have used expectations strategically in order to build a discourse around the negative impact of the use of 'environmentally damaging technologies'. This discourse uses taken-for-granted expectations as a basis for their case. One of the most important of these taken-for-granted expectations is the widely shared expectation that *human activity is responsible for greenhouse effects and negative climate change in general*. For a number of new 'green-energy efficient-technologies' developed since the 1970's this expectation forms the basis of convincing actors to invest resources into the new 'green' technologies. Another widely shared expectation that has become prominent in the discourse around new energy efficient technologies is the expectation that *fossil fuel sources are not limitless*. In other words, we will eventually run out of fossil fuels and when that happens we need to generate energy in an alternative way. These expectations, coupled with the expectation that *the demand for energy will continue to rise in the future*, often formed the basis for support for new technologies that could be a part of the solution for these problems.

As mentioned in chapter 4.6, actors on various governmental levels, from the European Union to local municipalities, have accepted these expectations and have devised policies in order to deal with these problems. Since in the 1990's the energy companies were controlled by the government, these companies were forced to invest in green-energy efficient-technologies. For example for GasTerra these three expectations were all important when they developed the condensing gas boiler in the late 1970's, a boiler that since then has become the standard in most Dutch households. They wanted to develop an efficient boiler in order to make the most use of the available natural gas reserve in the Netherlands. At the end of the 1990's they started to look whether another step in the development could be made with this boiler in order to make even more efficient use of the available natural gas (Frans Hazen [GasTerra], personal communication, October, 2010). For societal actors like Greenpeace and Friends of the earth, the expectation that human activity is responsible for negative climate change is central in the motivation for their activities.

5.2 Regime expectations

Next to the landscape expectations there are also expectations that can be located on the regime level. These expectations are less stable than the landscape expectations but they are more stable than the niche expectations. The regime expectations have links to both the landscape expectations and the niche expectations. The two most important regime expectations I have mentioned already in section 4.4 of which the first one is the expectations that *the increasing use of de-central energy generating technologies will continue in the future*. The second regime expectation is that *Smart Grids will be an important part of the energy grid of the future*. Such a Smart Grid controls the energy generating power of many de-centralized devices thereby creating a 'Virtual Power Plant'.

The two regime expectations are connected to the landscape expectation that *human activity is responsible for greenhouse effects and negative climate change in general*. This is because de-central generation of energy is believed to be more efficient than the central generation of electricity as well as that Smart Grids are perceived to be helpful in creating a grid that will have a very efficient energy management.

5.3 Global niche expectations

There are a number of expectations that are shared within the Stirling micro-CHP boiler niche. From the interviews four global niche expectations were identified which were shared over a wide range of actors. These identified shared expectations are:

- *Generating heat and electricity with Stirling micro-CHP boilers is more efficient than generating heat with a condensing boiler and electricity with a traditional power plant*
- *Stirling micro-CHP boiler is the direct replacement of the condensing gas boiler in existing buildings*
- *Stirling micro-CHP boilers will be able to compete on price with the condensing gas boiler*
- *The German market is a more interesting market for the Stirling micro-CHP boiler than the Dutch market*

In the remainder of this subsection I will elaborate on these expectations.

5.3.1 Generating heat and electricity with Stirling micro-CHP boilers is more efficient than generating heat with a condensing gas boiler and electricity in a conventional power plant.

An important expectation in the niche is the expectation that generating electricity and heat with a Stirling micro-CHP boiler is more efficient than the conventional combination of generating electricity from a power plant and heat from the boiler at home. Theoretically this expectation makes perfect sense. The heat loss from the central plant does not occur so it is more efficient to generate heat and electricity on the site where the energy is used, which is in the houses of consumers. This principle of cogenerating of heat and power plays an important role in the energy sector in the Netherlands, around 40% of the total amount of electricity in the Netherlands is produced in a combined heat and power station (Cogen Nederland, n.d.). A lot of knowledge is present in the Netherlands about cogeneration and when this principle of cogeneration was suggested to be applied on a domestic scale, this seemed intuitively like a system that could work. Kevin Jansen of CE Delft mentioned:

"… it [the use of a Stirling micro-CHP boiler] is a lot more efficient than burning gas in a big gas power plant. In that case you still lose 40% and with the Stirling micro-CHP boiler you only lose what comes out of the chimney, which is 2-3%."

Various early laboratory tests and field tests showed that it was more efficient than the old configuration (van der Woude et al., 2004; van der Laag and Ruijg, 2002). Frans Hazen of GasTerra also mentioned about their early experiences:

"… we tried out several technologies and when you do that than in the end the technology that has the most potential will surface. In this case it was the free piston Stirling engine. After a year of testing we came to the conclusion that it was indeed possible to efficiently produce heat and electricity in your own house, and better than the old configuration."

In order to emphasize this and to make a clear distinction between the old condensing gas boiler and the Stirling micro-CHP boiler, a quality mark was introduced in 2008 that showed that the boiler was indeed more efficient. The old condensing gas boiler had a quality mark HR107, which means that it has an efficiency of 107% for central heating and warm tap water. When Stirling micro CHP boilers have efficiencies of at least 125% they receive the quality mark 'HRe-boiler'. The 'e' in the quality mark stands for electricity; it is thus a condensing gas boiler (in Dutch this boiler is called a HR-boiler) that besides heat thus also produces electricity. The quality mark was developed in collaboration with the foundation 'Slim met Gas', which includes the energy companies, and the Smart Power Foundation, which includes the various manufacturers and it is acknowledged by the Council of Accreditation.

5.3.2 Stirling micro-CHP boiler is the direct successor of the condensing gas boiler in existing buildings.

Especially early in the development trajectory the expectation was communicated that the boiler was a plug-and-play device that could directly replace the condensing gas boiler without any problems. Hans Vermeulen [Remeha] mentioned:

"… the expectation that the condensing gas boiler can 1-on-1 be replaced by the Stirling micro-CHP boiler was really believed. It is off course an ideal replacement market, plug-and-play. You take the old boiler off, and you put the new one in place of the old boiler."

Manufacturers in the Smart Power Foundation presented a scenario in 2006 in which they projected that in 2020 1.6 million micro-CHP boilers would be installed (Hendriks, 2006). As a basis for this scenario the development of the condensing gas boiler over the last 20 years was taken. In figure 5a, scenario 1 presents the expectation of the Smart Power Foundation about the installed numbers of micro-CHP boilers. The workgroup 'de-central gas applications' added a second scenario in order to present the effects of a slower market development. In this scenario the payback period of 5 year cannot be reached for small households in which the heat demand is relatively low (De Jong, 2008). In the first scenario 4.1 million micro-CHP boilers will be installed by 2030, in the second, more conservative, scenario 2.2 million micro-CHP boilers will be installed by 2030**.** The expectation that micro-CHP boiler is the direct successor of the condensing gas boiler was thus widely carried over actors in the niche and since until 2015 most micro-CHP boilers are based on Stirling engines, the expectations that the Stirling micro-CHP boiler is the direct successor of the condensing gas boiler was also widely shared within the niche.

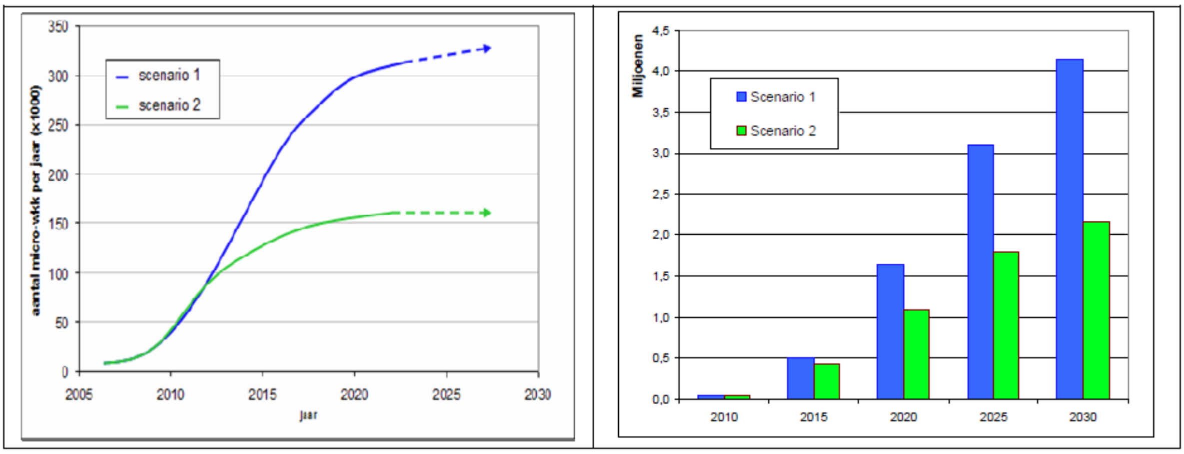

Figure 5a: two market scenarios for micro-CHP in the Netherlands (De Jong, 2006)

As said above, in these scenarios the first generation of micro-CHP boilers are the Stirling based micro-CHP boilers which are driven by heat demand and which are thus primarily suited for houses in which a large amount of heat is needed. Since newly built houses are well isolated and the heat demand is fairly low, the Stirling micro-CHP boiler is envisioned as being used in older, less well isolated houses (De Jong, 2008). When the Stirling micro-CHP boiler initially was developed there were few alternatives to a new generation of local heating solutions in these existing buildings as Kevin Jansen [CE Delft, Senior Consultant] mentioned:

“... there are 5 million gas boilers in the Netherlands for which a solution had to be found. And for newly built houses you can invent anything you want but for existing buildings this was very difficult…. ”

A number of de-central energy generating solutions have been developed in the last decade and these new alternatives have caused the expectations that Stirling micro-CHP boiler is the successor for the condensing gas boiler in existing buildings to decrease in strength as I will show in chapter 6.?. Even the main proponents of the technology, GasTerra, Remeha , and Energy Matters, indicated that the expectations about the wide dispersion of Stirling micro-CHP boilers had to be adapted. As Kevin Jansen of CE Delft mentioned:

“… the Stirling micro-CHP boiler is now just one of the options as a heat solution.”

As I will show in the next subsection various actors indicated that decreased expectations about the economic competitiveness of the Stirling micro-CHP boilers were important in their expectation about the possible success of the Stirling micro-CHP boiler as the successor of the condensing gas boiler.

5.3.3 Stirling micro-CHP boiler is able to compete on price with the condensing gas boiler

The expectation that the boiler is economically attractive for end-users was communicated by both the manufacturers in the Smart Power Foundation (Hendriks, 2006), by the energy companies in the foundation 'Slim met Gas' and by the workgroup 'de-central gas applications' (De Jong, 2006). Interviews with the actors in these groups, Frans Hazen [GasTerra], Rene Engels [Nuon], Louke Wijntje [Eneco], Kevin Jansen [CE Delft], and Paul Hellings [Energy Matters] confirm that these actors held these expectations.

In order to reach the numbers presented in the scenarios above it was important that the boilers would have a maximum payback period of 5 years. In order to achieve this, the cost price had to be at most 1.500 euro more than the condensing gas boiler which means that the selling price of the Stirling micro-CHP boiler needs to be around 3.000 euro. The expectation of the Smart Power Foundation in 2006 was that in 2014 the price of the micro-CHP boiler would have a selling price of around 3.000 euro, which is 1.500 euro more than the condensing gas boiler (De Jong, 2006). The manufacturers believed that after the commercial introduction in 2009/2010, the micro-CHP boiler would soon drop in price because of the economies of scale of mass production. In order to achieve this within 5 years the market introduction price was expected to be around 6000 euro (De Jong, 2008).

The expectation that generating energy with the Stirling micro-CHP boiler is more efficient than generating energy in the old configuration is connected to this expectation. The fact that less gas is used for the same amount of energy means that the generated energy is also cheaper than energy generated in the old configuration. The effect for users of Stirling micro-CHP boilers is that they do not have to buy electricity from the grid and even have the possibility to return electricity to the grid. Since per kilowatt-hour gas is cheaper than electricity (mainly due to the fact that energy tax is 6 times higher on electricity than on gas (E129.-/MWh vs. E19.-/MWh) this means that the user will save money compared to the old configuration. The expectation communicated by for example the SPF is that the total energy costs will be reduced by 20%, which for an average household means a saving of 300.- a 400.- annually. With these numbers, the 300.- a 400.- savings annually and the market price of 3000.-, the expectation was that the Stirling micro-CHP boiler will compared to the condensing gas boiler have a return-on-investment of 3 – 7 years. This means that the price difference with the Stirling micro-CHP boiler, which is around 1500.-, will be earned back in 3 – 7 years, with a life expectancy of 15 years.

When the market introduction price was announced, the expectation that the Stirling micro-CHP boiler could economically compete with the condensing gas boiler without subsidy was negatively influenced. When the subsidy of 4000 euro stopped, this expectation was even more damaged. The expectation that the Stirling micro-CHP boiler could successfully penetrate the condensing gas regime in the short term was no longer believed. This global niche expectation thus has disappeared. As Frans Hazen [GasTerra] clearly stated:

"Remeha has communicated in the Smart Power Foundation that the market introduction price would be between 6.000 and 6.250 euro. And what do they do? They set a price of 10.000. Well, the ministry of Economic Affairs was pretty irritated about that. We always communicated, also as the working group Decentral energy solutions, that the market introduction price would lay between

6.000 and 6.500. And after a few years this would drop to an amount of 3.000-3.500 due to the economy of scale. And what happens now? The market introduction price is 10.000 euro. So the ministry of Economic Affairs said to me: 'my god Hans, we don't believe in it any more. These high prices are not suitable for the Netherlands'."

As I will show in the next chapter, all other interviewees also mention this introduction price as detrimental to the expectations about the economic competitiveness. The low price of the condensing gas boiler in the Netherlands is also stated as being a difficult element in the success of the Stirling micro-CHP boiler in the Netherlands. As Rene Engels [Nuon] mentioned:

"… including installation, the costs have reduced well below 2000.-, you cannot compete against this…"

Even Hans Vermeulen of the Remeha, the main proponent of the Stirling micro-CHP boiler, mentioned:

"…when the boiler remains at such a high price it will be become difficult for the Stirling micro-CHP boiler to become a success in the Netherlands. The difference between the price of the condensing gas boiler and the Stirling micro-CHP boiler is just too high at the moment."

5.3.4 The German market is a more interesting market for the Stirling micro-CHP boiler than the Dutch market

There is thus a large consensus in the niche that with the current price setting it will be impossible for the Stirling micro-CHP boiler to economically compete with the condensing gas boiler. In Germany on the other hand this price difference is considerably smaller since the condensing gas boilers are more expensive than in the Netherlands. This makes Germany a more interesting market for the manufactures of Stirling micro-CHP boilers (personal communication Frans Hazen [GasTerra], Kevin Jansen [CE Delft], Cor Sagel [Agentschap.nl], Rene Engels [Nuon] , Hans Vermeulen [Remeha], Henry Berends [Gaes], Paul Hellings [Energy Matters]). Hans Vermeulen [Remeha] mentioned that the demand in Germany is at the moment much bigger than the demand in the Netherlands. This was not the case when the Stirling micro-CHP boiler was developed by them. He stated that in the beginning the strategy was to focus on the Dutch market and to see what happens with the German market but that this has turned around. Now the German market is the primary market for Remeha and the development of the Dutch market for Stirling micro-CHP boiler has slowed down almost to a stop. He mentioned that the most likely way for the Stirling micro-CHP boiler to become a success in the Netherlands is when the price will drop though developments made in the Germany market.

Not only the price difference between the condensing gas boiler and the Stirling micro-CHP boiler is important in making the German market a more attractive market for the Stirling micro-CHP boiler. First of all the German market is of course much larger than the Dutch market. Next to this in Germany the boiler is often not installed in the attic like in the Netherlands but in the basement or in a separate boiler room (personal communication Frans Hazen [GasTerra], Hans Vermeulen [Remeha]). A number of benefits are attached to this arrangement. The first is that noise is less of an issue when the boiler is not located next to the bedroom of the users. The second is that installation of the boiler becomes easier since the boilers are not located at the top of the house. The third is that often there is room to install a large hot water tank next to the Stirling micro-CHP boiler which makes the boiler more efficient. This is because when more heat is demanded than can be delivered by the Stirling engine, this heat can be taken from the hot water tank. In the Dutch configuration with a combi Stirling-micro-CHP boiler, when more heat is demanded than can be delivered by the Stirling engine, the normal gas engine has to deliver this heat which decreases the total efficiency of the Stirling micro-CHP boiler. Hans Vermeulen [Remeha] stated that in Germany only 10% of the sold Stirling micro-CHP boilers are combi-boilers (personal communication Hans Vermeulen [Remeha]).

5.3 Micro level expectations

Besides the global niche expectations on the meso level of the niche, a number of expectations existed that focused on local problems. They were identified by actors as problems that needed to be addressed in order for the technology to become successful. Van Lente (1993) called these search expectations and located these at the micro level of the niche; they are expectations about the requirements of the technology. These were thus the expectations that were present in local projects in which the technology was tested.

In 2006 various research institutes (University of Utrecht, ECN, Ecofys) produced a report for the ministry of economic affairs in which they stated that the success of the micro-CHP was dependent on the price of the boiler and the size and weight of the boiler (Londo, 2006). When the foundation 'Slim met Gas' in 2006 was started they formulated a number of issues that had to be addressed in order for the Stirling micro-CHP boiler to become successful in the Netherlands. These included issues with:

- *The noise of the boiler*
- *The weight of the boiler*
- *The reliability of the boiler*
- *The purchase price and the payback time*
- *The usability of the boiler*

The various interviewees also mentioned that finding a solution for these five problems is critical in the success of the Stirling micro-CHP boiler.

Noise problems

The problem of the noise of the Stirling micro-CHP boiler is caused by the Stirling engine that vibrates at 50Hz and this can causes an irritating humming noise. From the start of the niche this was indicated as a problem that needed to be addresses in order for the Stirling micro-CHP boiler to stand a chance of becoming successful in the Netherlands. This problem is for the Dutch market more important than for the markets in for example Japan and Germany because in the Dutch setting the boiler is often installed next to or above bedrooms, while in Japan it is installed outside the houses and in Germany it is often installed in dedicated boiler rooms or basements.

Weight problems

In the Netherlands it is common that the boilers are installed on the top floor of houses. It was also clear from the beginning that the weight of the boiler, +/- 140 kilograms, is a problem for the installers. Comparing with the condensing gas boiler, which weight approximately 25 kilograms, this was a big difference. Although new methods were developed in order to address this problem the weight of the boiler still causes problems for installation companies.

Reliability problems

The condensing gas boiler is a very reliable device and in order for the Stirling micro-CHP to stand a chance in competition with the condensing gas boiler, it also needs to be a very reliable device with low maintenance costs. Since the boiler is a new technology, the improvement of the reliability was thus an obvious problem that needed to be addressed. As I will discuss later, the first boilers were hand-build prototypes of which some in early tests broke down and had to be replaced. Although later tests showed the reliability of the device, some actors remain skeptical about whether the Stirling engine is capable of functioning for 15 years without major problems.

Purchase price and payback time

In order for the Stirling micro-CHP boiler to be able to compete on price with the condensing gas boiler it needed to have a reasonable payback time. In order to achieve this, two things were important; the price and the amount of savings. The price was envisioned to drop to about 1.500 euro above the price of the condensing gas boiler so that combined with the amount of savings a payback time of around 5 years could be achievable. As mentioned, the price setting was much higher than expected and the expectation of the payback time is subsequently much longer than 5 years.

Usability problems

The condensing gas boiler uses a simple thermostat in order for the user to control the central heating system. Since the technique of the generating heat the Stirling engine is based on a completely different principle than the condensing gas boiler, the use of the thermostat is also different. The boiler needs to start up slowly and needs to reduce the start-stops to a minimum in order to maximize the potential of the boiler. This is a problem that is addressed partially by the development of a user-friendly interface, but in order to completely fix this problem the users have to change their behavior with regards to the use of the control system.

5.4 Changed expectations

Figure 5b presents the identified early landscape, global niche, and micro expectations. The graph in figure 5c represents the expectations late in the niche; it shows which expectations are new, which have changed, or which have completely disappeared.

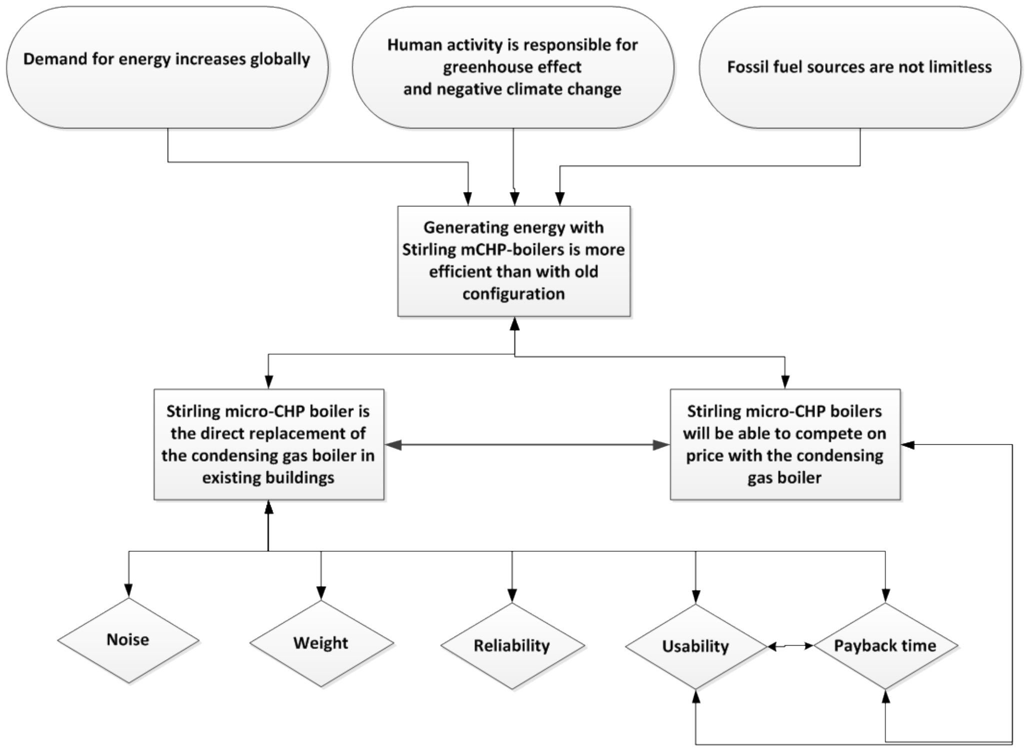

Figure 5b - Graph representing early niche expectations

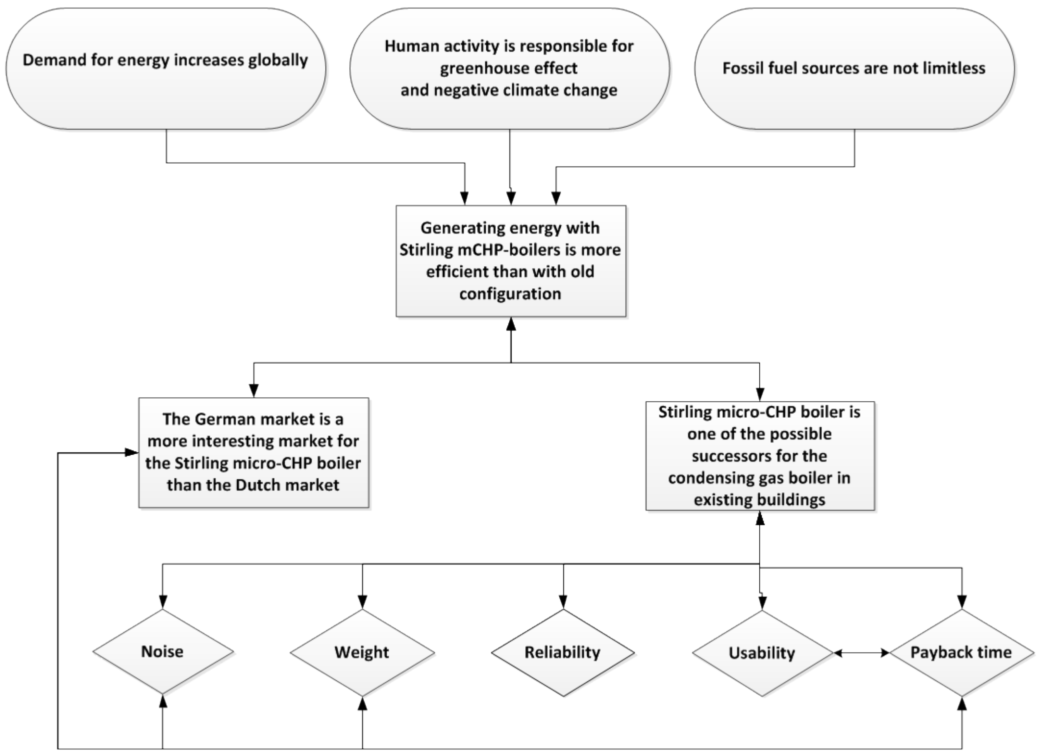

Figure 5c - Graph representing present niche expectations

The three landscape expectations did not change. They still cause disruptions in the socio-technical energy regime of which new technologies can take profit. They provide chances for renewable energy sources and technologies that generate energy more efficiently.

The expectation that generating energy with the Stirling micro-CHP boiler is more efficient than generating heat and electricity with the help of a traditional power plant and a condensing boiler has not changed either. The theory made claims that were proven in laboratories and later in field tests, although the first tests with the Whispergen boilers did not show the full potential of the Stirling micro-CHP boiler as I will show in chapter 6.

The expectation that the Stirling micro-CHP boiler would be able to compete on price with the condensing gas boiler has been influenced in a number of ways. At first, after the first tests it was apparent that the choice of location was of paramount importance with respect to the return-on-investment. The second influence was the use of the thermostat. When not properly used, the Stirling micro-CHP boiler would never be able to compete on price. These two were thus specifications of the expectation. Then there two negative influences on this expectation, the price setting by Remeha and the fact that the subsidy stopped. After these two influences the interest in the boiler dropped considerably and Remeha switched their attention to the German market on which Viessmann already launched a Stirling micro-CHP boiler.

The price setting of boilers in Germany is higher than in the Netherlands and the payback time of the boiler would therefore be lower in Germany than in the Netherlands. Next to this the German market is in terms of potential customers of course much higher than in the Netherlands. Another important aspect of the more positive outlook for Stirling micro-CHP boiler in Germany is the configuration of German houses and the location of the boilers. The boiler is often located in a dedicated boiler room of in basements while in the Netherlands the vast majority of the boilers are located in the attic and close to the sleeping rooms. The weight of the boiler is thus in the Dutch setting much more problematic for the installation companies than in the German setting while the noise of the boiler is also more problematic in the Dutch setting than in the German setting. These elements caused a new global niche expectation to appear in the niche which was not favorable for the development of Stirling micro-CHP boilers in the Netherlands. This expectation is the following: *Germany is a more interesting market for Stirling micro-CHP boiler manufacturers than the Netherlands.*

From early field tests on it was quite clear that the expectation that the Stirling micro-CHP boiler was a simple direct plug-and-play replacement technology for the condensing gas boiler was wrong, the expectation has been specified. The Stirling micro-CHP boiler can only be installed in houses with a sturdy staircase, and can only work properly in a house in which the resonance of the boiler does not occur and in which the boiler is used in a manner that eliminates constant start-stops. It has also become clear that with the development of new alternative technologies to generate energy de-centrally, the Stirling micro-CHP boiler is not the only possible successor of the condensing gas boiler.

Chapter 6 – Internal and external niche factors

In this chapter I will answer the second and third research question which can be combined to form the following question:

Which internal and external niche factors influence the global niche expectations? And how do they influence the global niche expectations?

In order to do so I will look at the internal niche interactions via the outcomes of local projects and the external niche influences via developments in complementary and competing technologies and developments in regimes. The information in this chapter is predominantly taken from the interviews (for interview schedule see Appendix A).

6.1 Outcomes of local projects

As mentioned in chapter 5.3, finding a solution for five problems was identified as being pivotal for the success of the Stirling micro-CHP boilers in the Netherlands. These five problems were issues with:

- *The noise of the boiler*
- *The weight of the boiler*
- *The reliability of the boiler*
- *The purchase price and the payback time*
- *The usability of the boiler*

As I have visualized in figure 5b and figure 5c, each of these problems are connected to one or more global niche expectations. I will use these problems in order to discuss the impact of outcomes of local projects on the global niche expectations identified in chapter five.

6.1.1 The noise problem

The problem of the noise of the boiler is connected to the expectation that the Stirling micro-CHP boiler is the direct successor of the condensing gas boiler in existing building. In order for the new technology to provide the same comfort as the condensing gas boiler the problem of the noise of the device needed to be addressed. All interviewees regarded the noise problem as an essential problem for the success of the technology and at the start of the niche in laboratory tests this problem was already identified (personal communication Frans Hazen [GasTerra], Hans Vermeulen [Remeha], Rene Engels [Nuon], Henry Berends [Gaes], Paul Hellings [Energy Matters], Louke Wijntje [Eneco]).

As the first tests were done with early prototypes, the problem of noise became clear but the general consensus of the manufactures in the field was that the noise problem would be solved when later models would be introduced. Louke Wijntje [Eneco] mentions about the noise in the proof-of-principle test of Enatec in 2002: ".. the first field test participants were used to a device that they would not hear and this was a very negative experience for them because the whole day an irritating humming sound could be heard." In the report about this test the claim was made that the noise problem would be solved by modifications in the insulation of engine and the further fixation of the panels of the casing (Intermediate results of the Enatec micro cogeneration system field trials, van der Woude et al, 2004, Enatec micro-cogen B.V.). However Louke Wijntje [Eneco] claimed that in

2009 when the latest test of a boiler with an Enatec engine was done, the boiler still made more noise than they wanted. The most annoying problem according to her was the unpredictability of the problem:

"… in some houses you could, as a matter of speech, sleep under the boiler without problems while in other houses exactly the same boiler could be in an awkward frequency which would results in a terrible noise. This was not only the case with our own Enatec boiler, we also tested Baxi boilers with the same result while in a laboratory setting, this device performed relatively silently [….] a combination of factors play a role in deciding whether it is a configuration that works, or not."

Also other proponents of the technology like the energy companies choose this route. When the corporation 'Slim met Gas' was founded they did not highlight that the problem of the noise would be overly problematic. It was a problem that could and would be addressed in the future and in meanwhile the user would accept this problem. As Rene Engels of Nuon mentions: "An example is the noise of the machine. If we in the beginning had emphasized this problem then this would have not have been very smart. But we decided the costumer would accept this or that the problem would be managed in the future".

Other actors did find the noise to be problematic. When for example in 2006 Henry Berends of the installation company Gaes watched a boiler of Microgen in a laboratory setting, he was told that: "… it is now heavy and big, and makes a lot of noise, but in the near future we will make it lighter, smaller, and we will reduce the noise significantly." But when in 2007, as part of the Rehema 2 test (see Appendix D), he received a number of boilers, he was very disappointed when he discovered that they were heavier and noisier than the prototype in 2006. He would test 25 boilers but after installing only 2, he stopped the test to send the boilers back to Remeha with the agreement that they would provide new boilers when new improved engines were available. His expectations about the Stirling micro-CHP boilers of Remeha, envisioned to be THE successor of the condensing gas boiler, were negatively adjusted. He, as well as Frans Hazen [GasTerra], also mentions that other actors in the installation sector shared this sentiment about the noise of the new boiler.

Huub Kamp of the housing corporation De Woonmensen, one of the main actors in the Smart Power City Apeldoorn project, mentions that in 2009 after installing just one unit, noise problems appeared and the project was put on hold for a couple of months so that Remeha could tackle the problem. Since it was clearly communicated that these were still not finished products, although the Smart City Apeldoorn project was postponed for several months due to the sound problems, this was not interpreted by the actors involved as being problematic. As Pieter van Ackeren of Liander mentions: "…off course there are some growing pains, and noise was one of them, but for the rest it was a normal consumer product that needed to develop itself a bit more." Rene Engels of Nuon also mentions that a beta product is used in the Smart Power City Apeldoorn project. This product is in constant development towards from the commercially product available in the future, but it is not there yet.

The speed in which the problem of noise was addressed was for Henry Berends [Gaes] also an indication that the developments were not going fast enough. This was also mentioned by Frans Hazen [GasTerra] who stated that the manufactures have taken up this problem too late in the development process with the effect that the noise of the boiler remained a problem for a long time and still is a problem according to most actors.

Conclusion

The general expectations of actors in the field have been affected in that the idea that Stirling micro-CHP boilers can be noisy has rooted itself in the field. As a result it contributed to the change of the expectation that Stirling micro-CHP boiler is a plug-and-play replacement technology for the condensing gas boiler. It was clear that the new boiler would not fit in every house; the boiler could for example not be installed on thin walls. The broad expectation about the Stirling micro-CHP boiler being THE replacement technology for the condensing gas boiler thus changed into a more specific expectation that the Stirling micro-CHP boiler would only successfully function in a house in which it could be installed on a sturdy wall and in a house in which the vibrations of the boiler would not be in an awkward frequency resulting in a loud noise. The expectations that the Stirling micro-CHP boiler is THE replacement technology for the condensing gas boiler changed into the expectations that the Stirling micro-CHP boiler is one of the possible successors of the condensing gas boilers.

Since in Germany boilers are often installed in separate boiler rooms or in basements, the problem of noise is not so urgent the German market. The noise problems for the niche in the Netherlands helped to give rise to a new global niche expectation which is that the German market could be a more interesting market for the Stilling micro-CHP boiler than he Dutch market.

It is interesting to see that while Louke Wijntje [Eneco], Rene Engels [Nuon] and Henry Berends [Gaes] all had a negative experience with the noise, their interpretations are different. Louke Wijntje and Rene Engels continue with the expectation that the problem of noise will be fixed in the future while Henry Berends is much more skeptical. Hans Overdiep [GasTerra] also mentions that various other installation companies also share this skepticism. A possible explanation can be provided by the enactor-selector difference. The selector is further away from the place where knowledge about the product is gathered and the uncertainty of this actor group is higher. This can lead to a more negative image of the development.

6.1.2 Weight problems

As the noise of the Stirling micro-CHP boiler formed a problem for the user of the boiler, the weight of the boiler caused problems for the installation companies. As the installation companies installed a total of 100 boilers in the first large scale field test that started in 2007 it became clear that the weight of the product would become a problem for the Dutch setting. While the floor mounted models of Whisper Tech Ltd. in earlier test projects were located at ground floor level, the wall mounted boilers of Remeha that were specifically designed for the Dutch market had to be carried to the top-floor of the houses of the test subjects. The Stirling micro-CHP boilers weighs more than 150 kilo and this was thus a problem for the installation companies.

Interesting is that the problem of the weight was the main reason why in the corporation 'Slim met Gas' Nuon and Essent chose to not use the Stirling micro-CHP boiler of Ariston. As Louke Wijntje [Eneco] mentions about the choice between Ariston boiler which had an Enatec engine integrated in it, and a Remeha boiler with a Microgen engine:

"… but because the boiler was in the first place build into an existing model of Ariston, which was a floor mounted model with an integrated boiler, which caused its measurements to be 1.80m high, 60 cm wide and 60 cm deep, Nuon and Essent said that they did not thought it was suitable to the Dutch market. Because it was so heavy (plus 200 kilos) and big it was not possible to transport this boiler to the top floor which is tricky since in the Netherlands most households the condensing gas boiler is of course located in the attic. For this big, heavy boiler one had to look hard for households that could place the boiler in the garage, or side-kitchen.”

Eneco agreed with this and decided to test the Ariston boilers themselves outside the corporation ‘Slim met Gas’ which resulted at the end of 2009 with the start of two projects from which the results are yet to be revealed.

As I have mentioned in section 6.1.1, Henry Berends of Gaes had seen the boiler of Remeha in 2006 in a laboratory setting and he was promised that the boilers that would become available in the field tests would be lighter. When the boilers arrived in 2007 it appeared that the boilers actually were heavier than the prototypes which, in combination with the noise problems, caused their expectations to drop. He formulates the problem as follows:

“In comparison, the modern condensing gas boiler weighs between 25 and 50 kilo’s and they are installed by a maximum of two installers. At the moment I use for transportation of the new 150-plus kilo heavy Stirling micro-CHP boiler at least three men and I have to be careful with this because, according to the safety, health and welfare service, each person is only allowed to lift 25 kilos. For these heavy boilers I thus need, if you stretch this to 30 kilo, at least 5 men, which is of course impossible.”

He mentions that they are using tools like stairclimbers, sleds, lifts, and lifting straps, in order to find ways to transport the boiler to the topfloor without the need for all this manpower and although this works in a number of cases, it became clear that the boiler could not be installed in every house.

According to Hans Vermeulen [Remeha] the weight of the Stirling engine alone is already 60 kilo’s so the weight is not expected to drop in the near future. When the problems for the installation sector became apparent in the first tests, Remeha also changed the expectation about in which houses the Stirling micro-CHP boiler could be installed. Now they first assess the situation and when a house has a very weak staircase to the attic or a very small staircase, they will not consider delivering a boiler to that customer.

Conclusion

As in the case of the problem of the noise, the problem with the weight contributed to the change of the expectation that Stirling micro-CHP boiler is a plug-and-play replacement technology for the condensing gas boiler. The boilers could not be installed in houses which have a very small entrance to the attic were the old condensing boiler is located. It is also not possible to carry the 150 kilo heavy boiler up very weak staircases. The broad expectations that the Stirling micro-CHP boiler is THE replacement technology for the condensing gas boiler had to be changed into a more specific expectation. The weight problems also contributed to the change of this expectation into the global niche expectation that that the Stirling micro-CHP boiler is one of the possible successors of the condensing gas boilers.

As I mentioned in the conclusion of 6.1.1, in Germany boilers are often installed in separate boiler rooms or in basements. This makes the weight problem not so urgent in the German market and these weight problems thus contributed to the rise of the new global niche expectation that the

German market could be a more interesting market for the Stilling micro-CHP boiler than he Dutch market.

Just like with the noise problem, Henry Berends of the installation company Gaes was much more negative about this problem than for example the chairman of ‘Slim met Gas’ Jeroen Wouts. The latter one explained that in his house the stair climber worked perfectly.

6.1.3 Reliability problems

The sensitivity to failures of the Stirling micro-CHP boiler is linked to the expectation that it could successfully replace the condensing gas boiler. Although the first boilers were prototypes and this was also communicated to the involved actors, the breaking down of the first boilers still had an effect on the expectations for some actors that as a result became more skeptical. Kevin Jansen of CE Delft mentions about these initial tests:

“…. during the Remeha 1 test with 8 Stirling micro-CHP boilers, there were on almost a weekly basis failures with the boilers. In the Remeha 2 test a year later which included 100 boilers, the engines that were used were a bit more advanced and more reliable although they were still assembled by hand. There is still a risk in this and regularly units had to be replaced because a production error occurred when the engines were fabricated. But this is normal when new products are used in tests and these tests are used to improve the product.”

Although it was time and again mentioned to the participants that the tested boiler were alpha and beta products that were certainly not yet ready for the market, like for example Huub Kamp [De Woonmensen] mentioned above about the products in the Smart Power City Apeldoorn test, the installation companies were skeptical about the reliability of the products. Frans Hazen [GasTerra] mentions that they looked very skeptical towards the tests and a number of stories appeared in the installation world which mentioned the problems with the sound and which mentions that a lot of Stirling micro-CHP boilers broke down after a year. Johnny Meulendijk [Gaes] confirms this image as he states: “…. the chance that these boilers break down within 15 years is very high because they are just not reliable enough.”

Frans Hazen [GasTerra] also confirms the problems with the perception of the installation companies about the reliability of the boiler. He adds as a possible source of problems for this perception that the factory in which the Microgen engine was initially produced, moved from Japan to China and this caused a number of problems with the quality of the engines. As a result, the first boilers for the Smart Power Apeldoorn Project had reliability issued and were too noisy. As a result the project was postponed for a number of months

Conclusion

The expectations that the Stirling micro-CHP boiler is the successor of the condensing gas boiler has not changed because of the reliability problems. Most actors see these problems as a normal part of the development process of a new technology which start out with alpha products not ready for market introduction which continue to improve as the niche progresses. However not all actors share these thoughts as actors in the installation sector see this problem together with the noise problems and the weight problems as a sign that the technology of the Stirling micro-CHP boiler is not THE successor for the condensing gas boiler.

While the global niche expectations may not have been influenced by the reliability problems, the problems did have an impact on the delay in particular projects. This delay on its turn had an impact on the realization of the number of Stirling micro-CHP boilers that were expected to be installed as communicated in the market scenario of the Smart Power Foundation. The result is that the scenario about the number of installed Striling micro-CHP boilers had to be changed a number of times. This had the effect that particular promises that were communicated in the beginning of the niche were not fulfilled and, as I will later in chapter 6.3 further explain; this had an impact on the expectations of a number of actors about the overall future success of the Stirling micro-CHP boiler in the Netherlands.

Again Henry Berends of the installation company Gaes was very skeptical about the reliability. Other selectors, like Huub Kamp [De Woonmensen] and Peter Pos [Liander] much more followed the rationale of the boiler manufacturers and energy companies who highlight that the tested products were prototypes and that it is normal that reliability problems existed. It looks like that among the selectors, the installation company is much more skeptical about the technology than the networking company and the housing corporation. A possible explanation is that the stakes for the installation companies are higher than for the housing corporation and the networking company. The installation and maintenance of the condensing gas boiler is very important for the installation companies and when a direct competitor of this device enters the market, the installation companies will automatically be very sensitive to any faults, mistakes, malfunctions, etc.

6.1.4 Purchase price and payback time

The first tests disappointed somewhat on the level of savings. This was caused by two elements, the choice of the test-locations and the use of the thermostat. Both caused the amount of savings to disappoint. The result of this was again a realization that it is not a simple replacement technology. The expectation that the Stirling micro-CHP boiler would save money was not per se affected but the expectation about the amount of these savings was affected. It became clear that the size of the test-locations was of major importance in the amount of energy and money one could save.

Hans Vermeulen [Remeha] mentions that they had learned from their mistakes in the Remeha 2 test in which a number of very small households only achieved savings in the amount of 100 euro annually. Reasonable savings could only be made from a gas use of above 1.600 m^3. Unfortunately the preparations for the next big field test, the Smart Power City Apeldoorn test, were already underway and when the housing corporation De Woonmensen chose a neighborhood in which to test the boilers this was not yet communicated to them. Huub Kamp [De Woonmensen] mentions:

"… Remeha communicated to us that the chosen houses did not have the optimum heat demand for the Stirling micro-CHP boiler, a bigger house would be more suited. And when we received the number from the big houses they were good, around 300 à 400 euro annually per house was possible. If the price becomes more interesting than we would be happy to see whether we can use them in our older bigger houses."

Pieter van Ackeren of Liander also mentions about the Smart City Power Apeldoorn project that: "… for provinces, municipalities, and housing corporations it became pretty clear that the gas demand should be above 1.500-1.600 m^3 in order to make the Stirling micro-CHP boiler economically attractive." Paul Hellings [Energy Matters] also states that it became clear after the first tests that not every house of the housing corporations will be suited for the first stages after the market introduction. A big part of the housing corporation market needed to be written off in the market introduction scenario.

Louke Wijntje [Eneco] mentioned that in Germany the houses are in general a bit bigger and the heat demand is also higher which gives the Stirling micro-CHP boiler more chance to achieve a relatively high amount of annual savings. As Frans Hazen [GasTerra] states that the prices of condensing heat boilers in Germany are much higher than in the Netherlands, the payback time will be lower and is therefore more attractive for consumers. Next to this, both Louke Wijntje [Eneco] and Frans Hazen [GasTerra] mention that in the Netherlands the market is big for small combi-boilers. While in Germany the location of the boiler in the basement or in a separate boiler room makes it possible to install a large water tank which makes it possible to use the Stirling micro-CHP boiler more flexible and thus achieve a higher efficiency.

Next to the size of the houses that were important for the amount of savings, the way the user controls the behavior of the boiler with the thermostat is very important for the amount of savings and thus for the payback time. I will come back to this in chapter 6.5.

Conclusion

The expectation that the Stirling micro-CHP boiler could compete on price with the condensing gas boiler was not damaged by the results of the tests. Although the amount of annual savings was not as high as expected, it was certainly was not that far off. The first tests showed a level of annual savings of around 300 euro, which, when the initially expected additional cost of 1.500 euro compared to the condensing gas boiler were taken into account, would result in a payback time of around 5 – 6 years. This expectation took a bit hit when the commercial price was announced. This price was around 10.000 euro and the annual amount of savings was just too low in order for the new boiler to compete on price with the old boiler.

The local project outcomes did influence the expectation that the Stirling micro-CHP-boiler was THE de-central energy generating technology of the future. The outcomes made it clear that a one-on-one replacement with the condensing gas boiler was not as straightforward as thought in the beginning. The efficiency problems were of such a nature that it became clear that the market of the Stirling micro-CHP boiler was not as large as thought initially. Houses with a gas usage of below 1600 cubic meters of gas will not provide enough electricity to justify the use of the Stirling micro-CHP boiler. The realization that for a large amount of houses the payback time of 5 years could not be achieved contributed to rise of the expectations that the German market is a more interesting market for the Stirling micro-CHP boiler.

6.1.5 Usability

The problem with the usability has two dimensions which are linked to each other. These first one is the amount of savings that can be achieved by the boiler and the second one is the amount of comfort or discomfort that the user perceives when using the boiler. Both are linked to the control of the boiler which is quite different than the control of the condensing gas boiler.

An important lesson from the field tests was the importance of the control of the device and the used thermostat (personal communication Frans Hazen [GasTerra], Louke Wijntje [Eneco], Hans

Vermeulen [Remeha], Huub Kamp [De Woonmensen], Kevin Jansen [CE Delft]). The amount of savings that the Stirling micro-CHP boiler could achieve is very dependent on the behavior of the user. He or she has to use the thermostat in a different way than with the standard condensing gas boiler. The control of the installation has to be focused on achieving the highest amount of working hours for the Stirling engine. The Stirling micro-CHP boiler works best when the temperature is slowly increased and decreased. Users that are not used to this and often change the temperature on the thermostat they will decrease the efficiency of the boiler. When the user uses the Stirling micro-CHP boiler in the same way as the condensing gas boiler, than the second burner in the Stirling micro-CHP boiler is used, which is basically a small condensing which is used when the heat demand is too high for the Stirling engine. The problem here is of course that gas is used without generating electricity thus reducing the efficiency of the device. The Stirling micro-CHP boiler works best when the temperature is slowly increased and decreased. Contance Heijnen [Eneco] mentions that a big problem was that: "… the users that participated in the field tests were told that the Stirling micro-CHP boiler would be a one-on-one replacement technology for the condensing gas boiler." Although when the boilers were installed the participants were instructed on the best way to use the device some people just wanted to use the Stirling micro-CHP boiler as they were using their old boiler.

Next to the reduced amount of savings that could occur for using the device just like the old condensing boiler, the field tests showed a second problem with the control of the device and that is the acceptance of the user for the thermostat. Due to a contract with Siemens, the same thermostat was used in the various field tests of 'Slim met Gas'. The user interface of this thermostat was perceived to be too technical and too complicated and a lot of users were put off by this (personal communication Frans Hazen [GasTerra], Louke Wijntje [Eneco], Hans Vermeulen [Remeha], Huub Kamp [De Woonmensen], Kevin Jansen [CE Delft]). Huub Kamp mentions about the use of these thermostats in the Smart Power City Apeldoorn test:

"… the thermostat that comes with the Stirling micro-CHP boiler is just a very complicated device. Participants really had to make a study about how to use this and when it is not used on a daily basis, than you really needed the instruction manual to change the settings. It is definitely not like a traditional Honeywell thermostat with a round turning nub. It is fairly complicated and they are now trying to make a bit simpler which is general more accessible. That is what they learned from this field test."

Hans Vermeulen [Rehema] also confirms this and he mentions that since the Smart Power City Apeldoorn project they have developed a new thermostat called the I-Sense which is a thermostat that is easier to operate and which shows clearly the amount of savings achieved.

Conclusion

The Stirling micro-CHP boiler has to be controlled in a different way than the condensing gas boiler and the local projects showed that when the user keeps using the boiler in the same way than the amount of savings cannot be achieved. This can be achieved by first of all informing the users about the general workings of the Stirling micro-CHP engine and why it needs start up slowly so that they understand the do and don't of this new device. Secondly the user has to be helped and stimulated by providing him or her with a thermostat in which the controls are easy and the information they need to maximize the workings of the Stirling engine is provided.

The expectations that the Stirling micro-CHP boiler is a 1-on-1 replacement technology had to be changed because this was clearly not the case in terms of the use of the device. Louke Wijntje [Eneco] admits that the promoters of the Stirling micro-CHP boiler have made a mistake by promoting the device as just a new type of condensing gas boiler. When users do not like the workings of new device because they want instant heat delivered to the central heating system than this device is not for them. The expectations that it is THE direct replacement technology for the condensing gas boiler thus had to be nuanced into the expectations that it is one of the possible successors of the condensing gas boiler.

6.1.6 Positive outcomes of the local tests projects

Next to negative outcomes, the projects also yielded positive outcomes. As mentioned in chapter 5, early field and proof-of-principle tests resulted in the global niche expectation that generating heat and electricity with Stirling micro-CHP boilers is more efficient than generating heat with a condensing gas boiler and electricity in a conventional power plant. In addition, the expected amount of savings of around 300 a 400 euro was achieved, resulting in the global niche expectations that the Stirling micro-CHP boiler would be able to compete with the condensing gas boiler. According to Frans Hazen of GasTerra, the Whispergen 1 test was essential in the development of the niche since as the results of this test was positive, the energy companies Nuon and Essent became more involved in the niche and the expectations about the success of the Stirling micro-CHP boiler were strengthened. He stated:

“... I think the most important test was in 2005 when we started to place the first Whispergen’s to convince the energy companies. We have paid for the majority of costs and then the energy companies could see whether they liked it. They could test the boiler in real life…[….] We did this to convince them and also their sales organizations, their installation companies.”

After this test the energy companies together with GasTerra formed the foundation ‘Slim met Gas’ and the niche developments really took off.

The Remeha 2 test was an important test for the experiences of the users and a survey held under the users showed that many users perceived the micro-CHP boiler as a regular condensing gas boiler that also generated electricity. According to the survey the micro-CHP boiler is associated with something that is already familiar; users do not appear to experience the mico-CHP boiler as an alienating technology and are not suspicious about it. Information regarding savings was also collected (Bijkerk, 2009). Huub Kamp of De Woonmensen mentioned this test as being important for them to decide to cooperate with Remeha in the Smart City Apeldoorn test:

“… the Remeha tests showed that the new boiler is more efficient and that it looks like a normal device. We could not exactly calculate the risk for us but we decided to go for it since the previous tests did yield positive results.”

Apparently the Remeha 2 test confirmed the expectation of De Woonmensen that the device was more efficient than the conventional gas boiler and they decided to join the network and participate in the Smart City Apeldoorn test.

Conclusion

In order to strengthen the network, proponents of the Stirling micro-CHP boile used the positive outcomes of the local tests. This can both be seen in the Whispergen 1 test as Nuon and Essent became more involved in the niche, and in the Remeha 2 test, which convinced De Woonmensen to join the network.

6.2 Influence of developments of competing and complementing technologies on the global niche expectations about Stirling micro-CHP boilers.

The niche of Stirling micro-CHP boilers is connected to various other niches in which technologies are being developed that provide similar functionalities as the Stirling micro-CHP boiler. Developments in these niches can have an effect on the expectations about Stirling micro-CHP boiler. Negative experiences about a competitive technology can have a positive effect on the expectations and promises for Stirling micro-CHP boilers. On the other hand when a competitive technology experiences a breakthrough, this can have an immediate negative effect on the expectations about the future progress of the Stirling micro-CHP niche. Next to competitive technologies, also materials and technologies are being developed that are able to complement the Stirling micro-CHP boiler. Developments in these can have a positive effect on the expectations and promises for the Stirling micro-CHP boiler niche.

Both developments are external niche developments which can impact the expectations in the niche from outside the niche. Both possible influences can be conceptualized as being horizontally linked to the global niche level of the niche.

6.2.1 Complementing technologies

Developments in complementing technologies that were mentioned by the interviewees included the development of a new thermostat and the development of a smart energy meter.

New thermostat

In the local projects it became clear that the thermostat that was used in the tests did not meet the demands of the users. It was seen as a bottleneck for the comfort of the user and it needed to be improved in order for the user to accept the Stirling micro-CHP boiler. In the 'Slim met Gas' tests, the boiler was controlled by an operating system build by Siemens and they also provided the thermostats. Remeha, in an attempt to find a solution for the 'ogre' of a thermostat, as one of the interviewees named the thermostat, reprogrammed the linkage between the boiler and the thermostat. The boiler is still controlled by the Siemens operating system but the boiler can now communicate with the thermostat via an open communication protocol called OpenTherm which was developed by Honeywell in 1996. This protocol is a company independent system between modulating heating devices and thermostats and it can be freely used by any company that is a part of the OpenTherm association which includes all the major players in the heating industry. The result of this is that the boiler of company A can communicate with thermostats from company B. Every manufacturer now has the possibility to develop a thermostat that can control the Stirling micro-CHP boiler. An example of this a new type of thermostat is the iSense, developed by Remeha, which has to make it much easier to operate the boiler for the user. All the current tests still use the old Siemens thermostat so whether or not it increases user satisfaction is at the moment not known.

Figure 6a; The Isense thermostat of Remeha

The development of this thermostat did not change the global niche expectations but without the development of this technology, the expectations about the Stirling micro-CHP boiler would drop considerably since it is vital for the efficient working of the boiler. It has become a part of the Stirling micro-CHP boiler system.

Smart energy meter

A smart energy meter is an energy meter with build in information and communication technology that is able to send information to the energy companies. A smart meter is not primarily needed for the use of Stirling micro-CHP boiler but it does provide possibilities for Smart Grids to be developed and Stirling micro-CHP boilers are one of the possible de-central energy generating technologies that could be incorporated in a Smart Grid. The meter is needed in order to measure the amount of electricity that is flowing back into the grid and the amount of electricity needed on every location. Only when this information is generated the control of the flow of electricity becomes an option.

The development of the smart energy meter did not change the global niche expectations about Stirling micro-CHP boilers. With the development of the smart energy meter the general expectations about the connection of de-central energy generating technologies into a smart grid remained intact.

Conclusion

The development of the new thermostat could be the solution for the functional problem of the usability although tests with the new thermostat take place at this moment so no claims can be made at this moment. Further expectations did not change because of these developments but they ensured that the expectations were not influenced in a negative way. For example the development of the smart meter ensured that the regime expectation of smart grids remained intact.

6.2.2 Competing technologies

Developments in competing technologies that were mentioned by the interviewees included:

- Fuel cell micro-CHP boilers
- Internal combustion engines
- Hybrid heat pump
- Solar-PV
- Condensing gas boiler

Fuel cell micro-CHP boilers

Fuel cell technologies are according to all interviewees interesting but not feasible in the near future so it is now not a realistic competitor for Stirling micro-CHP boilers. But when this technology, first in the form of the gas driven fuel cell Stirling micro-CHP boiler, further develops it will become an interesting option since the electricity efficiency of a fuel cell based micro-CHP boiler is much higher than a Stirling based micro-CHP boiler which makes it also interesting for situations with a low heat demand. The benefit of fuel cell Stirling micro-CHP boilers is primarily that is has a very good heat/electricity-ratio compared to the Stirling micro-CHP boiler. The fuel cell-based Stirling micro-CHP boiler is not driven by heat-demand but rather by electricity-demand. This makes this boiler very suitable in houses that have very good insulation, or in future smart grids.

Although Louke Wijntje of Eneco also does not see the fuel cell micro-CHP boilers commercially available for a number of years, she does state that the development of the fuel cell technology has gone faster than expected. This in combination with the high price setting, the cancellation of the subsidy, and the slow development of the Stirling micro-CHP field, has shifted the vision of Eneco towards fuel cell micro-CHP. As she mentions in the interview:

“... one thing has been an issue, I think. And that is that we have always said, first there was the improved efficiency gas boiler than the condensing gas boiler which is even more efficient, then the Stirling micro-CHP and after that we will probably go to the fuel cell technology. But the development of the Stirling micro-CHP boiler takes a long time and because you see that the fuel cell development has gone much faster than everybody had thought, I notice that in our company voices appear that state that are critical about the Stirling micro-CHP boiler and that want to wait until the fuel cell micro-CHP boiler has been developed.”

Internal combustion engine
The micro-CHP boiler based on an internal combustion engine is very popular in Japan (personal communication Frans Hazen [GasTerra]). Vaillant in collaboration with Honda have developed a variant on this boiler for the German market which has resulted in a reliable device which is a large competitor for Remeha’s Stirling micro-CHP boiler on the German market as Hans Vermeulen of Remeha mentions: “… for the German market this works well but since it is a system solution with a warm water tank attached to it, this is unsuited for the Dutch market because it is not a plug-and-play solution.” Developments in this technology showed that the internal combustion engine was indeed too large, too heavy, and too noisy for the Dutch market.

Heat pumps
Although not an electricity generating device, the hybrid heat pump is fierce competitor for the Stirling micro-CHP boiler, especially in existing buildings which is the area in which the major benefits of a Stirling micro-CHP boiler come into play (personal communication Kevin Jansen [CE Delft], Frans Hazen [GasTerra], Louke Wijntje [Eneco], Henry Berends [Gaes]). The hybrid heat pump is an air-water heat pump in combination with a condensing gas boiler. The heat pump transfers heat from the air outside to a heating circuit and a tank of domestic hot water. When the outside temperature is too cold than the efficiency and capacity of the heat pump becomes too low and the condensing gas boiler does the work. When housing corporations make decisions to try out new technologies, the hybrid heat pump becomes an interesting option because it is cheaper than the Stirling micro-CHP boiler. The hybrid heat pump has come into play because the development of the Stirling micro-CHP boiler has been delayed a number of times. The Stirling micro-CHP boiler has the advantage that it also generates electricity but because the price is simply too high, the hybrid heat pump has become a interesting alternative for housing corporations that want to experiment with new sustainable technologies. Frans Hazen [GasTerra] mentions:

"… it is a serious competitor. Yes, and this should not have been the case if the Stirling micro-CHP boiler had been given a price that was acceptable. But now they are a competitor without question because the housing corporations tell me that the manufacturers can deliver something else which is also fun for less money."

The expectation that Stirling micro-CHP was THE decentral energy generating technology has been changed to that it is one of the options. This is because the development of the boiler has been delayed a number of times. So that technologies like the hybrid heat pump also became options. Although this technology also its own problems: mainly weight and the usability. And off course this is only for heat generation and not for electricity generation.

Solar-PV

Solar-PV generates electricity with the help a photovoltaic reaction to sunlight. The price of solar panels has been reduced in the last 10 years while the price of energy has risen dramatically. As a consequence the payback time of the solar panels is almost cut in half and with rising energy prices these figures will become better of course. Hans Vermeulen of Remeha confirms that in combination with a condensing gas boiler solar-PV can also be seen as a competitor for the Stirling micro-CHP boiler. Louke Wijntje of Eneco and Kevin Jansen of CE Delft also mention that Stirling micro-CHP boiler is just one of the many possible options you can use and that solar-PV in combination with the traditional condensing gas boiler is indeed a competitor.

Condensing gas boiler

This is a rather interesting one since this is more a regime-technology. The development that is interest here is that the price of the boiler which has dropped significantly since the introduction of the boiler in 1981. Especially in the last five years these prices have dropped dramatically (Personal communication Frans Hazen [GasTerra]). These developments have an influence on the calculated pay-back time of the Stirling micro-CHP boiler because in the models the calculations take as a base the price of the condensing gas boilers. So the expectation stated in the beginning of the development process that the new boiler would save money for the user is not so clear-cut.

Conclusion

Although it was mentioned by an actor that the developments in the fuel cell-field have gone faster than was expected, the developments in this field have not directly had an impact on the global niche expectations about the Stirling micro-CHP boiler. The expectation that the fuel cell based micro-CHP boiler will not be available for a number of years and that the Stirling micro-CHP boiler is the micro-CHP boiler for the moment is strong and shared among many actors. Developments of another micro-CHP boiler, one based on an internal combustion engine had the effect that it confirmed that the Stirling micro-CHP engine was the better option for the Dutch market. It was lighter, more quite, and smaller than the micro-CHP boiler based on an internal combustion engine.

The development of the hybrid heat pump did change the expectation of a number of housing corporations that Stirling micro-CHP boiler is the de-central energy generating device of the future and also that it is the direct replacement for the condensing gas boiler. For them the technology of Stirling micro-CHP is simply too expensive.

Due to price developments in the last 10 years, solar-PV has become a competitor for the Stirling micro-CHP boiler. Also due to price developments in the last few years, it has become more difficult for the Stirling micro-CHP boiler to compete with this boiler the condensing gas boiler. A condensing gas boiler can already be bought nowadays for between 1.000 and 1.500 euro.

6.3 Regime developments

The interviewees mentioned a number of developments in the regimes surrounding the Stirling micro-CHP boiler niche that had an impact on the expectations in the niche. The most important ones were:

- *Big corporations invest in Stirling micro-CHP boiler development trajectory*
- *Microgen is sold by British Gas and bought by several boiler manufacturers*
- *Remeha takes over Baxi*
- *Price setting Remeha*
- *Government provides and stops subsidy*

Big corporations invest in Stirling micro-CHP boiler development trajectory

Support of major regime actors added credibility to the niche. GasTerra and Eneco already invested funds into the development trajectory and when Nuon and Essent joined them in forming the foundation 'Slim met Gas' in 2006, the technology had the support of all the main energy companies in the Netherlands. GasTerra, Nuon, Essent, and Eneco invested millions in the development trajectory in return for knowledge about the technology that they could communicate (personal communication Frans Hazen [GasTerra]). Hans Vermeulen [Remeha] about the importance for the niche:

"… and that actors like GasTerra, Nuon, Liander, etc. were supportive of the new technology, that was really needed, you simply needed these companies to participate in the development process. These are the most important actors in the Netherland; they are the actors with whom you have to cooperate in order to develop the technology. They also have to assist in promoting the technology."

Boiler companies like Remeha decided to invest in the new technology. In the same year as the foundation 'Slim met Gas', the Smart Power Foundation was founded which is a lobby association in which the boiler manufacturers Baxi, Elco Rendamax, Microgen, Remeha, Vaillant en Whispergen collaborate. GasTerra is also a member of this foundation and they were the initiators of this foundation (personal communication Frans Hazen [GasTerra]). The mission of this foundation is to increase opportunities for commercial success for the application of mini- and micro-CHP.

The most important actors in the niche now were involved in the niche as Kevin Jansen [Ce Delft] mentions: "The most important actors are the energy retailers and the boiler manufacturers. These energy retailers together make up 90% of the Dutch energy market." The result of this was that the network was strengthened and the expectations about the future success of the Stirling micro-CHP boiler were strengthened. Frans Hazen [GasTerra] mentions about the expectations in the early days of 'Slim met Gas':

“…we were very enthusiastic. When such big parties are involved that invest of money in the development of the boiler, and we are talking about a huge sum of money, than everybody has confidence in it.”

Microgen is sold by British Gas and bought by several boiler manufacturers

Stirling-engine manufacturer Microgen was ahead of the competition when in 2006 the British Gas-group decided to sell Microgen in order for them to focus on their primary activities. At this moment a signal was given to the field that British Gas did not believe in the technology. This was not per se true, but since Microgen was ahead of the competition this action was projected on the rest of the Stirling-engine field. Frans Hazen [GasTerra] mentions:

“The expectations were severely negatively influenced by this because everybody saw that Microgen was the furthest with the development of their Stirling micro-CHP boiler and when British Gas-group put Microgen up for sale, everybody thought that they were not happy with Microgen. As a consequence questions were asked about the technology. Questions like: ‘well, you state that it is an interesting technology, but we hear that there are sound and reliability problems and why would British Gas otherwise quit if it is not a good technology?’

It seems like the local problems of sound and reliability that were initially accepted as fixable, were reinterpreted as a consequence of the exit of British Gas. These expectations only returned when a collaboration of boiler manufactures in 2007 bought Microgen including their patented technology. The major boiler manufacturers apparently believed in the technology and they bought the patents of Microgen in order to continue with it, now calling the new company Microgen Engine Company (MEC). After this move, the positive expectations in the technology came back. Although the expectations returned, the development trajectory had encountered a delay of one to two years. Frans Hazen [GasTerra] about this: “.... and then all the expectations came back because you notice that the large boiler manufacterers, especially world players like Viessmann and Remeha, remained confident about the technology. They could have quite and choose another technology but they didn’t.”

When British Gas decided to sell Microgen, a big field test with 100 boilers that was planned for 2006/2007 had to be put on (temporarily) hold which according to Frans Hazen [GasTerra] strengthened the opinion that the Stirling micro-CHP boiler was not going to be a success. A subsidy for the test had already been given and when the boiler manufacturers bought Microgen, it was agreed that the subsidy could be used for a field test with a new boiler build by Remeha.

Remeha takes over Baxi

Baxi is a British boiler manufacturer that like Remeha had developed a wall-mounted Stirling micro-CHP boiler. They had developed it for the British market and this British market had a number of similarities to the Dutch market. Small houses with limited space and an existing gas infrastructure were the two most important ones. Baxi was the main competitor for Remeha in the Dutch market and it was expected by a number of actors that this competition was going to affect the price of the Stirling micro-CHP boiler. However, BDR Thermea, the owner of Remeha since 2004, bought Baxi in 2009 with the result that no more competition is expected from other wall-mounted Stirling micro-

CHP boilers. Henry Berends from Gaes about this: "… there was some competition because Baxi and Remeha were both active in the market. There was a tension between them and we expected that this would have an impact on the price setting. When Remeha took over Baxi this was of course the end of that story." Frans Hazen [GasTerra] adds to that: "… we were afraid that Remeha would gain a sort of monopoly and Baxi was seen by us as an actor that could give Remeha some opposition. When they were taken over we noticed that the price of the Baxi is higher than that of Remeha, while before the take-over it was lower. Remeha thus does not want to give Baxi any room on the Dutch market"

The take-over from Baxi by Remeha has had an impact on the expectations that the Stirling micro-CHP boiler would be able to compete on price with the condensing gas boiler. It was clear after this take-over that Remeha would remain the dominant actor in the Netherlands and since no wall-mounted alternatives for the Remeha boiler existed, the market was dependent on the price that Remeha set which I will discuss in the next subsection.

Price setting Remeha

As I already mentioned in chapter 5.3, all interviewees mention that the price for which Remeha put the boiler on the market negatively influenced the expectations about the future success of the Stirling micro-CHP boiler in the Netherlands. The price was set at 10.250 euro which was around 4.000 euro more than expected at the beginning of the development trajectory.

When the Smart Power Foundation was founded in 2005/2006 they sketched a scenario in which they stated the expected numbers of installed Stirling micro-CHP boilers would be around 38.000 in 2010 (Appendix B). The price of the boiler price was based on these market scenarios and when the expected number were actually realized, the price of the boiler would be around 6.000-6.500 euro when it entered the market (personal communication Louke Wijntje [Eneco] Frans Hazen [GasTerra]). As a result of the disappointing number of installed boilers between 2006 and 2007, a new scenario was presented by the Smart Power Foundation in 2008 in which they had changed this expectation to an expected number of installed Stirling micro-CHP boilers of 18.000 (Appendix B). As a result of these disappointing numbers, the price of the Stirling micro-CHP boiler did not drop as fast as expected (p.c. Louke Wijntje [Eneco]).

The members of the foundation 'Slim met Gas' have invested a lot in field tests with the expectation that the price would drop considerably so that, including subsidy, the Stirling micro-CHP boiler could compete on price with the condensing gas boiler. Rene Engels [Nuon], Louke Wijntje [Eneco] and Frans Hazen [GasTerra] all mention that they are disappointed about the high price of the device. Frans Hazen mentions about this;

"... the foundation is very irritated that Remeha comes with such a high price. We have of course in the beginning paid Remeha 20.000 euro for each device with the expectation that they would do their best for the Dutch market and you don't do that when you set the price so high. Then they had to make it 6.000-6.500 euro and the subsidy could also have dropped to 2000 euro. The first boilers could then have entered the market for around 4000-4.500 euro."

Several reasons are mentioned by diverse actors about why the price is set so high by Remeha. Louke Wijntje [Eneco] states that the amount of installed numbers is problematic for the price. The more units are produced, the lower the manufacturing costs due to economics of scale and because the expected numbers were not achieved, the expected price was also not achieved. Kevin Jansen of CE Delft and Erik Franssen of Kiwa-Gastec mention the possibility that Remeha is being very cautious to put a large number of boilers on the market because they are not 100% certain about the reliability of the unit. For this reasons they do not produce to capacity so when something goes wrong they have the possibility to repair it. A third possibility mentioned by a number of interviewees (Frans Hazen [GasTerra]; Rene Engels [Nuon]; Louke Wijntje [Eneco]; Paul Hellings [Energy Matters]) is that the Stirling micro-CHP boiler of Remeha can be marketed in Germany for 10.000 euro and that because of this Remeha will not sell the boiler for a lower price in the Netherlands.

Hans Vermeulen of Remeha confirms that the prices paid in Germany cannot be asked in the Netherlands and that they marketed the boiler in the high-end segment of the market, but he does not confirm that this is a strategic choice. He mentions:

"…. in Germany boilers are in general more expensive, for the same device we can ask a higher price. This means that we can sell our Stirling micro-CHP boiler more easily in Germany, there is more demand for it than in the Netherlands. To be honest, we initially wanted to come to a cost price reduction through the Dutch market but at these prices it is more realistic that the cost price reduction will come through large numbers we can achieve in Germany."

The installation companies are the link between Remeha and the end-consumer. Henry Berends of Gaes mentions that because the price is too high, nobody wants to buy a Stirling micro-CHP boiler. He mentions that they commercially just cannot market the boiler. According to him:

"… the amount of savings is quite okay, 300 euro annually. The problem is that they have marketed the Stirling micro-CHP boiler as a commercially attractive alternative to the condensing gas boiler, but this is just not achievable with a device that costs 8000 euro more than its competitor and that still has uncertainty with regards to the reliability."

Hans Vermeulen of Remeha confirms that the interest of consumers was initially high when the device was introduced at the end of 2010 but that this went away after six months. He mentions about the training they gave installation companies about the installation of the Stirling micro-CHP boiler: "… in the beginning it we could not handle the requests for trainings, there were a lot of installation companies that subscribed for the trainings. After 5-6 months the interest reduced significantly because the demand of end-users was not high, 10.000 euro is just a whole lot of money for a private person."

Government provides and stops subsidy

The price of the device and the subsidy that the government provided has a close relationship with each other. According to Cor Sagel of the Agenschap.nl in 2008, the lobby of the Smart Power Foundation, Slim met Gas and Energy Matters resulted in granting a subsidy of 10 million euro for the development of the Stirling micro-CHP boiler. The subsidy that was earlier granted in 2006 as support for the cancelled project of British Gas now became a part of this 10 million euro. According to Kevin Jansen [CE Delft] this did not go without problems:

"… talks with the ministry of economic affairs did not go well at the end of 2006 and the beginning of 2007. They were very skeptical about the Stirling micro-CHP boiler because there were of course claims and expectations made in the past and we still could not show a result for these claims. In the end due to a change of guard at the ministry of economic affairs we talked to a new civil servant who was not negative to our cause and we received the subsidy."

Although the subsidy was granted, it was part of the regulation 'Sustainable Heat' which was a regulation for consumer products which was not ideal for a product that was still in development. Louke Wijntje of Eneco about this:

"Off course we were happy that the subsidy was granted, but we were not so happy with the way it was implemented. As part of the regulation 'Sustainable heat ', which is a true consumer regulation and we did not understand this since the Stirling micro-CHP was not for sale at that moment. The only consumer participation at that moment was in prototyping pilot and being a part of that regulation meant that we had to receive autographs of every participant before we could receive the subsidy. But we could not do anything about it anymore except make good arrangements with Agentschap.nl, which we did. […] We kept worrying because we did not know how long this consumer regulation would exist. We made huge investments because when we ordered the devices we would order for example 100 devices. These were very expensive and if the regulation would stop at any moment, than that would be unwelcome. The signals we received were reassuring, they said 'don't worry, it will exist in the future, it will be alright.' So when last year the regulation suddenly came to an end, we were hit hard. We still had a number of boilers in our warehouses without an owner"

On the 17th of februari, 2011, the regulation 'Sustainable Heat' subsidy was stopped (Verhagen, 2011) leaving the energy companies with expensive boilers (the price had just been officially announced) in their warehouses and without subsidy available to sell them. According to Louke Wijntje this caused the expectations about the future success of Stirling micro-CHP boilers in the Netherlands to drop significantly.

The expectations of the housing corporations were also impacted by the high price and the cancellation of the subsidies. As this actor owns a total of 2.4 million houses with predominantly condensing gas boilers installed in it (Centaal Fonds Volkshuisvesting, n.d.), a number of proponents of the Stirling micro-CHP boiler saw this group as being very important in the early development of the technology since they have the capability to distribute many new devices in a very high pace. Nuon and Essent have focused their strategy on the housing corporations for this exact reason while Eneco have focused their efforts more on single users with the reasoning that they would be more motivated as test subjects (personal communication Louke Wijntje [Eneco]). In order to speed up the distribution of the Stirling micro-CHP boiler and with that to try to lower the price, plans were made with five housing corporations to install a total of 300 Stirling micro-CHP boilers in 2010 (Agentschap.nl, n.d.). Unfortunately in June 2011 it was announced that three of the five would not participate in the project due to the problems with subsidy and due to the unknown service costs and benefits for their tenants. One will probably go through with it if or once the subsidy uncertainties are resolved and the fifth could not say anything about their decision.

Conclusion

Activities and decisions of actors surrounding the Stirling micro-CHP boiler niche had an impact on the general expectations about the successfulness of Stirling micro-CHP boilers in the Dutch market. It had also an impact on the expectation that the Stirling micro-CHP boiler would be able to compete on price with the condensing gas boiler. The support of big corporations was a clear signal that they had positive expectations about the technology; as a result a strong network was created after the initial promises. After Microgen was put on sale by British Gas there was a period in which the expectations about the success of the Stirling micro-CHP boiler declined and this only returned after a number of boiler manufacturers bought Microgen and relaunched its activities. After a positive period the expectations declined again when Remeha launched its boiler for a price that was far beyond earlier expectations. Now that the German market looks like the primary objective for Remeha, these expectations declined even further, especially since the subsidies have stopped in the Netherlands.

Chapter 7 – Conclusions

In this final part of my thesis I will discuss the results of my research and draw conclusions. As a quick reminder, my research has tried provide an answer to the following problem statement:

Since developments within the niche are not the only possible influence on expectations about new technologies such as the Stirling micro-CHP boiler, for a complete analysis of these expectations the external niche developments should also be included in the analysis.

In this research project I have investigated what role internal niche developments as well as external niche developments play in shaping and changing the expectation about the technology of the Stirling micro-CHP boiler. My hypothesis was that next to internal niche developments, external niche developments would also play an important role in the development of the Stirling micro-CHP boiler global niche expectations.

7.1 Internal niche developments versus external niche developments

In chapter 2 I have identified a number of possible variables that could influence the global niche expectations which could be divided into internal niche developments, in the form of outcomes of local test projects, and external niche developments, in the form of developments in competing and complementing technologies, and developments in regimes. After introducing the field and the actors in the field, I have worked out these three variables in chapter 6.

7.1.1 Outcomes of local test projects

The outcomes of the local test projects both negatively and positively affected the global niche expectations. The most important positive outcome was with the Whispergen 1 test in which the energy companies were convinced that the boiler could become a success. Because of the positive interpretation of the outcomes, multiple strong actors now shared the niche expectations thus increasing the strength of these expectations, making them more robust. Other positive project outcomes included the technical workings of the Stirling engines, strengthening the expectation that the Stirling micro-CHP boiler was able to make sufficient savings in order for it to be economically competitive with the condensing gas boiler.

Outcomes of the test also had a negative impact on the global niche expectations. In chapter 5 I have identified two global niche expectations that were negatively influenced by the local project outcomes. These first was the expectation that the Stirling micro-CHP boiler is the direct successor of the condensing gas boiler in existing buildings. The second was the expectations that the Stirling micro-CHP boiler is able to compete on price with the condensing gas boiler. Local test outcomes showed that these expectations were not as simple as some proponents of the new technology would communicate them to be. Various tests showed problems with the noise, weight, reliability, usability, and the payback time, which all had an impact on the belief of actors in these general global niche expectations. The tests showed for example that the boiler would only save enough money when installed in houses of household that consume above 1.600 m^3 natural gas and only when the user makes correct use of the thermostat. The noise would be problematic in houses in which the vibrations of the boiler would result in an awkward frequency resulting in a loud noise. The weight was a problem since a Stirling micro-CHP boiler weighs 150-plus kilo and could therefore not be transported over small, light staircases. Because of these problems, the expectations became more specific. Instead of expecting that the Stirling micro-CHP boiler is a 1-on-1 replacement technology for the condensing gas boiler and that it would be economically competitive with the condensing gas boiler, it became apparent that for both expectations, the boiler would only work in specific situations.

A number of problems were specific for the Dutch setting. For example, noise, weight, and size were problematic due to the location of the boiler on the top floor of the houses close to the sleeping rooms while the payback time was problematic due to the low price of the condensing gas boiler in the Netherlands. These problems contributed to the formation of a new global niche expectation that Germany is a more interesting market for Stirling micro-CHP boiler than the Dutch market.

7.1.2 Developments in competing and complementing technologies

The development of competing technologies like the hybrid heat pump and the price-developments in the solar-PV field contributed to the change of the expectations that the Stirling micro-CHP boiler is the direct replacement technology of the condensing gas boiler. This expectation changed into the expectation that the Stirling micro-CHP boiler is only one of the possible successors of the condensing gas boiler. All interviewees see fuel cell technology as an interesting technology for the future although not the near future. However, one of the most important actors in the Dutch Stirling micro-CHP field, Eneco, mentions that the positive developments in the fuel cell field in combination with the problems occurring in the Stirling micro-CHP field shifted their attention away from the Stirling micro-CHP boiler technology.

Developments in complementing technologies did not have an impact on the global niche expectations. However, developments in complementing technologies, like a new thermostat and a smart power meter, contributed to the continuation of the global niche expectations about the future success of the technology.

7.1.3 Developments in regimes

Decisions and activities of actors in the energy regime had an impact on the expectations about the future success of the Stirling micro-CHP boiler, when for example the three large energy companies started to support the technology this send a strong signal about their belief in this technology. Initial promises of the technology about the economic competitiveness and about the ability to replace the condensing gas boiler were taken up in the agenda of these companies and a strong network was created around the technology. When on the other hand British Gas decided to sell Microgen, the leading Stirling-engine manufacturer, this sends a negative signal to the other parties in the niche and as a result, negative voices appeared. Actors in the field whose expectations were negatively influenced by the departure of British Gas out of the niche, pointed to the problems in the local project outcomes to vent their criticism. When large boiler manufacturers together bought Microgen this sends another signal to the field but this time a positive one. It showed that the major boiler manufacturers believed in the technology and the positive expectations returned. When Remeha announced its price at the end of 2010 the expectations took another negative turn since this price at 10.500 euro was much higher than was expected and the expectation that the Stirling micro-CHP boiler would be able to compete on price with the condensing gas boiler could not be taken seriously anymore. When at the beginning of 2011 the government announced to stop the subsidy of 4.000 euro for the Stirling micro-CHP boiler, this was the final nail in the coffin for the expectation about the economic competitiveness of the Stirling micro-CHP boiler. As this expectation was used to promote the technology, this had a devastating effect on the expectations in the niche for the success of the technology in the Netherlands. Instead, the global niche expectation that the German market is a more interesting market for Stirling micro-CHP boiler than the Dutch market now is widely believed in the niche.

7.2 Conclusion

Interpretations of the local test projects are only partially able to explain the change in direction and content of the global niche expectations. Although the interpretations of the outcomes of the local test projects clearly had an impact on the global niche expectations, external niche developments have also heavily contributed to the changing and shaping of global niche expectations. The interaction between the internal and external niche developments appears to be very important in the development of the niche expectations and to exclude the external niche developments in the analysis of niche expectations would be to miss an important piece of the puzzle.

Chapter 8 – Discussion and reflection

In this chapter I will discuss the most interesting findings of my research project. I will see whether the results presented in chapter 6 match with findings in earlier researches and I will discuss any interesting differences and similarities. In the final part of this chapter I will reflect on my research, I will discuss any shortcomings in my study and how they can be improved in future studies.

8.1 Interpretations and explanation of results

I started my research with the idea to see whether the conclusions that Geels and Raven (2006) drew about the influence of internal and external niche developments on niche expectations could be replicated in the field of the Stirling micro-CHP boilers. Their conclusion was that too only look at internal niche developments would be insufficient to explain the niche expectation dynamics. In my research I have identified various up and downs in the expectations about the Dutch development of the Stirling micro-CHP boiler and I have concluded that these up and downswings of the expectations can only be partially explained by either niche internal dynamics or niche external developments.

In their model Geels and Raven use the niche development perspective to show the impact of the internal niche dynamic on expectations and developments in the niche. In this study this dynamic can also be spotted. Early positive project results were used to convince a number of major actors to join the network and to invest resources in the niche. The outcomes of the early test projects also give rise to learning processes about the amount of savings that could be achieved with the Stirling micro-CHP boiler. Later learning processes showed that the market for the Stirling micro-CHP boiler was smaller than expected and a specification of these expectations occurred.

At first, the expectations about the locations in which the Stirling micro-CHP boiler would be able to function successfully were thus very broad and fluid. Learning processes from test projects caused these expectations to become more specific. Van Lente (1993) describes this dynamic in a 'promise-requirement'-cycle in which expectations are at first very high but they become more and more specific as the technology develops. Other elements of this 'promise-requirement'-cycle can also be seen in my study. According to Van Lente protagonists formulate promises in order to attract attention from sponsors, which is the case when GasTerra convinces the energy companies. When these promises become accepted they are translated into an agenda for an emerging field, which happened in the case of foundation 'Slim met Gas' which formulated a number of possible barriers for success. The expectation is then translated into goals, specification, requirements and task divisions, for which projects are developed, this was exactly what happened in the case of 'Slim met Gas'. The foundation formulated, in collaboration with the Smart Power Foundation and Remeha, a road map towards market introduction in which they planned to execute a number of projects which would tackle the barriers.

Besides these internal niche expectations, I have shown that external niche developments play an important role in explaining the downswings in global niche expectations. When projects yielded negative results with respect to for example noise and weight problems, the expectations initially stayed high. Only when British gas decided to sell Microgen, this caused some actors to lower their expectations and as a result the earlier local test results were reinterpreted. Later the expectations returned as a result of the support of large boiler manufacturers like Remeha and Viessmann, and the result was that the problems of noise and the weight of the device apparently were again not seen as a deal breaker for the other actors in the field. Reinterpretation of local project outcomes as result of changing expectations is line with an expectation dynamic that Konrad (2006) has identified. She mentions that project results can be reinterpreted in the light of changed expectations. She states that collective expectations, which are taken-for-granted shared expectations that can be located on the global niche level, create protected spaces. When these expectations are weakened, local project outcomes can be reinterpreted.

What is further interesting is that the Stirling micro-CHP boiler was promoted as a non-radical technology by which I mean that is was promoted as working in the same way as the condensing gas boiler, being able to replace this boiler 1-on-1. This is the strength as well as the weakness of the technology. The strength is that it can use the success of the condensing gas boiler in order to convince actors to join the network. The weakness is that it will be 1-on-1 compared to the condensing gas boiler. It is promoted to work in the same manner as the condensing gas boiler and thus it can only differentiate on price. This was even seen by Cor Sagel of the Agentschap.nl as one of the greatest barriers for the Stirling micro-CHP boiler. As he mentions:

"…. The biggest problem is its invisibility. It tries to look like a condensing gas boiler, it is promoted as a condensing gas boiler, but it does not work like a condensing gas boiler. Therefore I think the biggest problem for the Stirling micro-CHP boiler is its invisibility."

Clearly, the proponents of the Stirling micro-CHP boiler have chosen to start the development of the new technology as close as possible to the old configuration. This means that the user environment as well as the technical form is at the beginning of the niche very close to the existing technology and the existing user environment. Hoogma (2000) describes this as a fit-stretch dynamic. Form and function of a new technology has a good fit with the technology in the existing regime and a good fit with the existing user environment. Most early experiments take place in this fit-fit environment. The Stirling micro-CHP boiler starts out as a plug-and-play technology that has a good fit with the condensing gas boiler regime. As results of the interpretations of the early experiments, a stretch dynamic takes place in which in the first place the user environment is stretched. The use of the thermostat is very different for the new technology and new thermostats have been developed to use with the new boiler. The user environment thus gets stretched because of project outcomes and as a result new technologies are being developed stretching the technical form of the design. This stretching of the form and function will probably continue in the future with new technologies being developed that will result in new functions. The vision of the future of micro-CHP is that users will one day own a fuel cell micro-CHP boiler with which they generate their own electricity as well as sell this electricity to the market thus making the, consumer-producers.

8.2 Hype-disappointment dynamic

In the empirical case that I have described, a number of elements come together to form a hype. The promise of the new technology had shown itself in early test projects. Proponents of the technology, like GasTerra, used these results to convince other actors to join the network. When the big energy corporations joined the network in 2005/2006, a strong lobby convinced the government to subsidize the boiler. New projects were started that included even more actors and positive messages about Stirling micro-CHP boilers started to appear in the media.

This hype did not last very long since in 2006 British Gas decided to sell its daughter Microgen, an important manufacturer of Stirling engines. The disposal of Microgen by BG had sent a negative signal to the field and since the Stirling engines were no longer in production by Microgen, test projects had to be put on hold. Actors in the field started to lose faith in the new technologies and it looked like the disappointment that had entered the niche would result in the termination of test projects which could ultimately result in the end of the niche.

However, the main boiler manufacturers bought Microgen and this had sent a positive signal to the other actors in the niche. Test projects were started up again and the niche continued. Outcomes of test projects caused the expectation to change and become more specific but it did not lead to negative expectations about the future of Stirling micro-CHP. When Remeha announced the market price for its Stirling micro-CHP boiler, this was much higher than it was expected. The result of the price setting was that a number of important actors in the niche lost faith in the technology including the energy companies and the government. The government has stopped its subsidy to the Stirling micro-CHP boiler and in combination with the high market price, this looks like the nail in the coffin for development of the Stirling micro-CHP boiler in the Netherlands.

What can be concluded is that an up-and-down hype-disappointment dynamic can be seen in the development trajectory of the Dutch Stirling micro-CHP boiler. When within a niche various elements converge and come together, a hype can arises. Within the development trajectory disappointments also occur and they have the possibility to have a high impact on the niche since the trajectory is not yet very stable. When a number of disappointments come together, the negative impact on the niche can have a high impact on the niche with, as the most negative result, the possibility that the niche can cease to exist.

8.3 Limitations of my research project and suggestions for further research

The main problem I encountered during this research project was the limitation on information about the local project outcomes. I initially focused my efforts on the project of Smart Power City Apeldoorn but it became clear that Remeha obligated the participants to remain silent on the project outcomes. All actors that participated in this project had to sign a confidentiality clause, which was also the case with other projects in which Remeha was the main actor. This made it very difficult for me to pursue my initial research direction in which I wanted to focus on the interpretation of project outcomes and as a result, I had to to widen my research question. It might be fruitful to return in the future to this research direction when Remeha is confident enough to provide information about these projects.

Due to the limited scope of this research project, I was only able to interview a small number of actors in the field. Although they represented the various actor groups well, in future research projects it would be interesting to also interview actors like the non-users of the technology such as boiler manufacturers that did not participate in the development trajectory and the housing corporations that decided not to participate in tests. Other interesting actors to interview are the ministry of economic affairs, non-governmental organizations like Greenpeace, and smaller energy companies like Delta and Oxxio.

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Appendix A - Interview schedule

1) Introduction – What is the position and function of the interviewee?

2) Micro-CHP activities

In what (kind of) micro-CHP activities is the actor involved?
Which specific goals did the actor have with these activities?

3) Micro-CHP strategy

Why does the actor participate in the development trajectory of micro-CHP?
How does the strategy with respect to micro-CHP match with the general goals of the company?
How did the actor come to this strategy?
How does the actor assess the activities?
Which expectations did the actor have before participating in the niche activities?
What are your current expectations?
What are the possible barriers? And the opportunities?
What are the biggest rival technologies for micro-CHP?
How do you assess these competing technologies?

4) Dynamics of expectations within the micro-CHP niche

How have the expectations evolved?
What was the main reason?
What was the effect of the change in expectations?
What is the current sentiment in the niche?
Are there overarching visions that you use to orientate yourself?

5) Attitude towards discourse and information

How does the actor communicate?
Actively or passively?
How do you inform yourself?
How do you 'market' your activities?
Does PR play an important role?

6) Meta innovation history of the micro-CHP field

How is the sector organized?
What is the position of the actor in the system?
How does the actor perceive other roles?
Which changes has the actor perceived in the sector?
Which actors/networks/institutes will have an important impact on micro-CHP's future? And why?

Appendix B – Smart Power Foundation scenarios

Zichtjaar	Aantal geplaatste toestellen (x1000)	
	Scenario 1	Scenario 2
2010	38	38
2015	498	425
2020	1638	1085
2030	4140	2159

Figure Ba: Number of sold micro-CHP devices per period according to the two penetration scenarios in 2006 (De Jong, 2006)

Periode	Aantal verkochte toestellen (x1000)	
	Scenario 1	Scenario 2
Nu-2010	18.000	18.000
2010 - 2015	340.000	309.000
2015 - 2020	1.000.000	609.500
2020 - 2030	2.980.000	1.498.400

Figure Bb: Number of sold micro-CHP devices per period according to the two penetration scenarios in 2008 (De Jong, 2008)