Towards large-scale implementation of cogeneration for a more sustainable energy supply of households in The Netherlands

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Abstract

The Netherlands are facing a large challenge in reaching the aims of the Kyoto protocol and the enforced European norms concerning air quality of urban areas. Moreover the newly formed cabinet of The Netherlands aims to become 'one of the most sustainable and most efficient energy providers in Europe'. Cogeneration is believed to have great potential to contribute to the ambitious goals and obligations of the Dutch government. The goal of this paper is to investigate whether cogeneration really has the potential to increase sustainability of energy provision in The Netherlands. It focuses on application of micro- and mini-cogeneration (capacity below 100 kWe) on a household scale. We will look at the efficiency of the cogeneration-systems and the different available technical cogeneration principles but also at their applicability and implementation.

We conclude that micro-cogeneration does best fit the current energy system but is not the most sustainable option. The micro-cogeneration units that are most ready for the market at this moment – based on Stirling engines – will not be able to fulfil the energy needs of Dutch households appropriately. This is due to the technology that is used as well as the capacity. A larger engine, mini-cogeneration and another technology like fuel cells, piston or gas engines will increase electrical efficiency and with that save fuel, reduce exhaustion and costs. We end with a number of recommendations to stimulate the implementation of this technology.
Keywords: cogeneration, appropriate scale and technology, households, sustainability, suggestions for stimulating implementation.

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1 Introduction

The Netherlands are facing a large challenge in reaching the aims of the Kyoto protocol and the enforced European norms concerning air quality of urban areas. Now Russia has signed the Kyoto protocol the Dutch government is obliged to reduce the national emission of CO_2 with 6% in the period 2008-2012 with 1990 as a reference year (Ministry of Housing [1]). Additionally The Netherlands have committed to reduce its NO_x exhaustion with 35% in the context of the National Emission Ceilings of the European Union compared to the year 2000. In this case at least 9% has to be accomplished in the domestic sector (Ministry of Housing [2]). Moreover the newly formed cabinet of The Netherlands aims to become ‘one of the most sustainable and most efficient energy providers in Europe’. In 2003 17% of all energy in The Netherlands was used for power generation for households according to CBS [3].

1.1 Energy saving in households

Almost 25% of all CO_2 reductions should be accomplished in the built environment (de Werk and Kamp [4]). These reductions should be reached by decreasing energy demand (about 1.5% per year), increasing sustainable energy generation (up to 10% in 2020) and deploying cogeneration (Ministry of Economic Affairs [5] and CDA et al [6]). Especially at the electricity demand side the challenge is enormous as the demand of electricity has grown by 20% since 1985 (Energiened [7]). The main reasons for this growth are the growing number of households, growing number of electrical devices and increasing electricity use to heat tap water (Novem [8]).

1.2 Cogeneration as successor for the high efficiency boiler

High efficiency boilers have largely contributed to the reduction of gas use in households (it almost halved in the last 30 years from 3000 to 1700 m^3 according to Novem [8]). The boiler is a mature technology of which efficiency can hardly be improved. Next to that, the market is satisfied so profits are minimized. Therefore, the market is looking for a worthy alternative.

These reasons plus the fact that the main challenge for households lies in increasing sustainability of electricity supply – as stated above – have put cogeneration in the picture. Cogeneration combines generation of heat and power, preventing heat to be wasted and thus increasing sustainability. This technology has a theoretical efficiency of 100% of which 10 to 70% is electrical power and 25-90% heat depending on the cogeneration principle used (ECN [9]).

Cogeneration can be divided in micro-, mini- and macro-cogeneration. Micro has an electricity generation capacity up to 5 kWe, mini ranges from 5 to 100 kWe and macro has a capacity of more than 100 kWe (SenterNovem [10]). As this paper regards replacement of high-efficiency boilers and electricity supply of households, we will just look at micro and mini applications. (Micro-cogeneration systems have about the same measures as high-efficiency boilers.)

Theoretically cogeneration on a household scale should be able to contribute to the goals of the government as it has a lot of advantages compared to separated generation of electricity by power plants and heat by households:

- Its process is highly efficient because it combines the generation of heat and power bringing total energy-efficiency to almost 100% whereas conventional power plants only have an average efficiency rate of 42%.
- It uses a cleaner fuel than conventional power plants (gas instead of coal).
- It makes households less dependent of central power supply.
- The heat produced can be used on the spot and does not have to be transported a few hundred meters (as it should in case of district heating).
- Because of its high efficiency, micro-cogeneration saves primary energy use and reduces NO_x, SO_x and CO_x exhaustion.
- Generating one's own electricity is more interesting in economic terms than generating one's own heat as electricity is more expensive than gas. So making electricity out of gas could be profitable.

The main question of this paper is whether cogeneration really has the potential to increase sustainability of power supply of households in The Netherlands and if so which technology and which scale will be most suitable.

2 Cogeneration: sorts, sizes and dynamics of the market

In this chapter, we will briefly describe the various technical options for micro-cogeneration. We will look into technical aspects, efficiency, sustainability, the scope of applications and the dynamics of the market.

2.1 The sustainability potential of cogeneration in general

There are two important reasons why electricity generation with micro-cogeneration is very interesting especially from a sustainability point of view. Firstly, because it uses a cleaner and more efficient fuel than conventional power plants it could reduce CO_2-emissions with at least 1.0 to 2.7 tons per year per household. Secondly, ECN [9] states that it can reduce primary energy demand with 32% because it has a 20% higher exergetic efficiency than high efficiency boilers as next to heat it produces electricity which has about a five times higher exergetic value.

2.2 Five cogeneration principles to supply households with energy

The most well known technologies for cogeneration in The Netherlands are the ones based on the gas turbine and the Stirling engine. More recent technologies are based on fuel cells and the Organic Ranking Cycle (ORC). Below we will compare these technologies in terms of efficiency, contribution to sustainable development and readiness for the market. Because we have only limited space available, we will keep this comparison very short. For a more elaborate text and references, see De Werk and Kamp [4]. When interpreting the tables take notice of the following:

- The data presented for the Stirling engine in the first table are based on only one system that is on the market right now, the SOLO, a system with an adjustable power range of 2-7.5 kWe and 8-22 kWh. Total price is 25.000 Euro.
- Table 2 only deals with micro- and mini-cogeneration (max. 100 kWe) because this paper deals with cogeneration on (multiple-)household level so efficiency rates may differ from table 1 which includes macro-cogeneration.
- Because the ORC-turbine is quite a new technology and no fossil fuels are used not much information can be found about efficiencies. As far as data are present in Onovwiona [11] they fit the data in the table.
- The range of gas turbines differs from the usual cogeneration categories. Micro gas turbines have a range up to 500 kWe starting at 25 kWe, mini gas turbines have a range from 500-2000 kWe. Usually micro-scale is maximized at 5 kWe. Theoretical values of a 1 kWe gas turbine are calculated by ECN which expects electrical efficiency of 18-25%, total efficiency 85-97% and NOx emission of 20-80 g/GJ.

Table 1: Characteristics of different cogeneration principles concerning the full range of capacity: micro, meso and macro.

	Piston	Stirling	Gas	Fuel Cell	ORC
€/kWe	450-1360	3300	360 -1140	800-2700	n/a
Power range (kWe)	1-2000	1-500	28-2000	1-10.000	2-500
Total efficiency (%)	80-95	100	60-80	85-90	100
Niches/fields	Transport	Aerospace Marine	Industry	Transport	Horticulture
Commercially available	Yes	No (but available)	Yes	No	Yes
Partial load (eff/exh)**	-/-	0/0	-/--	++/0	0/0
In-house applicability	No	Yes	No	Yes	No
Fuel	All	All	Gas	H_2-richgas	All/bio-fuel

Explanation of table: With ‘partial load’ is meant whether the technology is suitable to use for partial load. ‘eff’ stands for efficiency gain (++) or loss (-/--) and ‘exh’ stands for increase of exhaustion (-/--) or no remarkable difference (0).

When taking tables 1 and 2 into account and focusing on micro-cogeneration we can conclude the following for the separate technologies:

- **The Stirling engine** is the easiest way as it is already in the demonstration phase and relatively a lot of companies are working on further development of the engine. It also has the lowest electrical efficiency and most exhaustion, but the highest total efficiency (almost 100%). As this engine is relatively silent it is the only currently available technology that could fit in households. As long as it exhausts NO_x, SO_x and CO_x the system cannot be considered sustainable even though it performs better than conventional systems. So if it is implemented on a large scale, in the future it should be running on a different fuel or replaced by another type of cogeneration system that is more sustainable. It would be even better if the system is designed modular so the engine can be replaced by a more sustainable one.

Table 2: Overview of technological sustainability potential of different micro and mini-cogeneration technologies.

	Scale	Efficiency (%) Heat	Electr.	Total	Emission NO_x (g/GJ)	Readiness Market
Stirling	Mini	80-90	10-25	90-100	n/a	-
	Micro	75-90	8-25	90-100	8	0
Piston	Mini	50-60	25-35	85-95	< 140	++
	Micro	70-75	20-25	90-95	80-110	+
Gasturbine	Mini	40-60	20-43	60-80	40-60	++
	Micro	50-60	23-33	60-80	10-20	++
Fuel cells	Mini	25-50	30-70	85-90	< 1	0
	Micro	45-70	35-45	85-100	< 1	-

Legend for readiness for market introduction (readiness market):
- Not ready but technology is under development or market is not really interested
0 Technology not ready, but research is done or demonstration projects are running
\+ Technology on the market but not commercially or in The Netherlands
++ Technology commercially available in The Netherlands

- **The piston engine** does not seem to be interesting for the Dutch energy market (yet) because is has to be used at full power constantly to prevent too much exhaustion and reduction of efficiency. Only one micro-system is available on the Dutch market that is far too powerful for a single household. Next to that most developments take place on mini-scale because of the use of the engine in the transport sector with the consequence that noise and vibration is not dealt with. Furthermore, the system is very noisy so it is not applicable inside households.
- **The gas turbine** has high efficiencies but is not available on the market on a micro-scale (<5 kWe). Though not suitable for micro-application as they are too noisy gas turbines could be interesting on a large scale as for example LNG or biogas can be used to fuel the engine and electrical efficiency is relatively high.
- **The ORC-turbine** is available on a micro-scale but usually the fuel that it uses is not available on a large scale (yet) (bio-fuels, fat of slaughter, manure, wood, etc.) especially not in the vicinity of houses. Although it is not interesting for single households, it is for example for farmers and horticulture as their waste can be turned into energy (and material loops can be closed). The ORC-turbine is usually most suited for application on the

site where the fuel is produced to avoid long distance transportation of the fuel. Next to that most fuels that can be used are not common so licenses are needed for delivery and installation of a turbine especially in living-areas.

- **Fuel cells** theoretically are the best option for cogeneration even though their total efficiency is not 100 %, their electrical efficiency rises up to 45%. They are not ready for market introduction as fuel cells only last for two years and they are too big and too expensive. So if we do want to get towards a micro-cogeneration infrastructure right now we will have to do it with another technology.

In general it seems the Stirling engine has gained most attention of the market, even though it is the least efficient in generating electricity and it generates most emissions. More interesting technologies like the piston engine or the fuel cell get attention because of their use in other fields, mainly transport. The consequence is that the engines do not get smaller than mini-scale which means development mainly deals with the problems in those sectors like efficiency and exhaustion leaving noise, vibration and downscaling out of consideration.

3 Applicability of cogeneration on a household scale

This last chapter deals with the question whether cogeneration is really suitable for a household scale or if it could better be implemented on a larger scale like for example in Germany is done in 'Mehrfamilienwohnungen' (multiple family housing). We will deal with the question in which way cogeneration will gain most profit, economically as well as environmentally and whether the system really is suitable for The Netherlands.

3.1 Economical feasibility of micro-cogeneration

High efficiency boilers are currently half the price of micro-cogeneration systems, partly because of economies of scale, partly because they are less complex. Because high efficiency boilers have a higher efficiency rate on heat (almost 100% whereas the Stirling engine has about 80%) the difference in price should be earned by the production of electricity. An advantage in this is that electricity from the grid is more expensive than gas, so the more electricity can be home-made from gas, the more profit is generated. Profit can even be raised if overproduction of electricity can be sold to the grid.

This means that the higher the electrical efficiency is, the more feasible cogeneration systems get. Next to that total primary fuel consumption will reduce as exergetic efficiency rises when electrical efficiency rises (because electricity has a higher exergetic value than heat). Feasibility can be further improved if working hours are increased to generate more electricity.

ECN [12] states that unfortunately in practice cogeneration systems have to be designed on the amount of heat demanded to prevent thermal energy to be wasted. If not all the heat is used the efficiency and total reduction of emissions are reduced, making the system less attractive. Next to that, usually electricity and heat demand do not take place at the same time. This means another device is needed to supply extra heat at times of peak demand. Such devices are a boiler or a peak burner. A boiler (for heat storage) can improve feasibility of the system as it enables more electricity production. But a peak burner will reduce feasibility because it only burns natural gas without producing electricity (reducing total exergetic efficiency). Additionally there are more problems with production and storage of heat which make it impossible for micro-cogeneration units to run at full-load all day because in that case way too much heat is produced that will be wasted (De Werk and Kamp [4]):

1. Boilers do have a maximum capacity of water storage. Next to that there are two main peaks in hot water use (in the morning and evening) whereas during the day usually not that much hot water is used.
2. Houses are better insulated nowadays which means that less heat is needed for room heating.
3. In summer less heat is needed because houses are warmed by the sun.

In short: a system is needed that produces as little heat as possible, has a very high electrical efficiency and still has an efficiency that approaches 100%. So the heat that is produced should be needed.

3.2 Micro- versus mini-cogeneration

Micro-cogeneration is not the most appropriate way to deal with energy demand on a household scale as electrical efficiency of mini-cogeneration is much higher. Next to that the only technology that is about ready for market introduction is the Stirling engine except for the price which is two times higher than a high-efficiency boiler. As it has a very poor efficiency rate and produces very much heat it is only feasible for badly insulated houses to replace conventional boilers.

At this moment micro-cogeneration does not suit new-estate, only fuel cell base systems could be suitable for single households as the heat demand is really low because of very good insulation. So if efficiency rates will not rise mini-cogeneration will be more suitable for use on household level because they have a far higher electrical efficiency. Not only because the engine can be larger, but also because a more efficient technology can be used. Next to that energy can be shared easier and heat storage media will be cheaper (as the costs can be spread over multiple households instead of just one).

In this case infrastructure is also needed to distribute the electricity and heat but energy buffers will probably not be necessary as the infrastructure that combines the households will serve as a buffer. Such an electricity grid will be necessary on the short term anyway because one micro-cogeneration unit is not able to fulfil all electricity needs of a single household without spilling heat.

3.3 Current situation of implementation of cogeneration on a household scale in The Netherlands

What became clear from the above is that cogeneration has a large potential to reduce exhaustion, depletion of fossil fuel even the current not-so-efficient micro-systems can already reduce primary fuel consumption with 14%. Unfortunately the Dutch market does not seem to be ready for large-scale implementation of cogeneration on household scale:

1. The (national) government does not support micro-cogeneration. But it does have means to do so financially as well as advisory or legally even though so far no changes in legislation are due in favor of micro-cogeneration.
2. Besides there is a lot of uncertainty about policy-development regarding (environmental) taxes, subsidies and the possibility of connecting micro-cogeneration units. One of the results is that investors do not have enough long-term certainty to secure large investments in sustainable technologies (in contrary to Germany) (ECN [13]).
3. At the moment there does not seem to be a large interest in micro-cogeneration on the demand-side of the market as it is not proven to be commercially attractive. Property developers and fitters mainly think of heat pumps as a commercial option to increase sustainability of energy production on a household scale.
4. Overproduction of electricity is not attractive as the return rate now is about 4 cents and the costs of getting electricity from the grid are 17 cents. This means that the return rates should become higher or the electricity meter should just go back when individuals produce too much electricity for their own use (as is the case with solar power already). To prevent losses and improve attractiveness of micro-cogeneration return rates should be at least the same as home-production rates (ECN [12]).

3.4 Implementation of cogeneration, what can we learn from the past

Macro-cogeneration was already introduced in the 60's in The Netherlands; it only became a success in the 80's when the government started to intervene. She started to actively promote cogeneration by deploying knowledge intermediaries, adaptation of legislation, introduction of payback tariffs, etc. From this De Werk and Kamp [4] derive that the role (and actions) of the government could be crucial in the success of micro-cogeneration.

Next to that we see that, besides some very energy-intensive companies, no special niche market was created but existing electricity users formed the main market switching from central generation to private electricity generation to fulfil their own needs. This means that as long as the capacity of a cogeneration system fits the demands of the user (it should fulfil electricity and heat demand of a household, should be affordable and investments should be paid back by electricity generation) it could really work.

Another important reason for the success of cogeneration can be found in the availability and price of other energy sources as experiments with nuclear power failed and Chernobyl occurred, the oil crises took place and natural gas reserves were considered to be finite. So if for example consumer prices will rise or central power generation pollutes too much, micro-cogeneration will get a better chance.

4 Conclusion

To increase sustainability and (economical) feasibility of cogeneration units the electricity efficiency should be as high as possible. The higher the electrical efficiency is, the higher the exergetic efficiency gain is. Accordingly the less fuel is needed and the more additional exhaustion is prevented and the more feasible the system gets.

Micro-cogeneration does best fit the current energy system of single-household heat production but is not the most sustainable option. It can replace the conventional (high-efficiency) boilers as it has about the same measures and user interface. Nevertheless the micro-cogeneration units that are currently developed - based on Stirling engines - will not be able to fulfil the energy needs of Dutch households appropriately. This is due to the technology that is used as well as the capacity, resulting in a very low electricity/heat ratio and lasting dependency on external electricity and heat sources. A larger engine - mini-cogeneration - and another technology like fuel cells, piston or gas engines will increase electrical efficiency and with that save fuel, reduce exhaustion, costs and dependency.

The Stirling based micro-cogeneration unit does only suit badly-insulated houses as it produces a lot of heat. For better insulated houses fuel-cell based micro-cogeneration will be the only suitable technology as electrical efficiency can theoretically rise up to 70%. Unfortunately fuel cells are not available yet so micro-cogeneration is not a practical option yet.

Nevertheless cogeneration is a very interesting technology for electricity production on household scale. Mini-cogeneration is more interesting as it has a higher electrical efficiency and (maintenance) costs can be shared by the households that use it. The grid that is needed to share the energy is mostly already there (electricity grid and district or block heating) or in case of new estate it can be easily installed.

From our research we can derive the following factors that can help stimulating the implementation of cogeneration:

- Long-term certainty in energy policy so that large investments will be more secure;
- Taking measures to increase awareness of and believe in this technology among property developers and fitters;
- Increasing the return-rates for electricity so home-generation of electricity will not be unprofitable;
- Developing the technology in such a way that it fits the demands of the user (it should fulfil electricity and heat demand of a household, should be affordable and investments should be paid back by electricity generation).

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