HEAT PUMPS: AN ESSENTIAL ROLE IN THE ENERGY TRANSITION

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ABSTRACT
In the Netherlands almost every municipality has an ambition to be energy neutral in the near future. In 2012 a study was made to establish the effects of the energy ambitions on the landscape and the energy grid.
For a grid operator it's essential to have an insight in the developments of the energy supply to ensure the energy grid is fit to handle the decentralized renewable energy production. A typical Dutch region was selected to make a concrete study on the technical possibility to make an energy neutral region.
Concluded was that it is possible to be energy neutral. Three necessary main changes in the existing energy system are dominant. At first there is the shift from petrol private cars to electric vehicles, secondly it's essential to reduce energy used for low temperature heating by insulation. Finally and thirdly it's important to introduce on a large scale heating by heat pumps. Not only because they use ambient energy in an efficient way, but also because they use electricity as source.

Key words: heat pumps, energy neutral, renewable energy, energy grid

1 INTRODUCTION

Following the international agreements on climate and CO2 reduction the local communities in the Netherlands translated these in their own local ambitions. These ambitions may vary from community to community, depending on the political situation. To get an insight in the effects of the ambitions on the landscape and energy grid a study was made in a specific area consisting of seven municipalities in the Netherlands. These municipalities agreed to be energy neutral in 2030. Together with PBL Netherlands Environmental Assessment Agency the network company Alliander looked into the ambitions in order to investigate the possibility to realize these in technical, political, financial and social way. Main question for Alliander as a grid company is whether the energy grid has to be changed if these ambitions are to be realized or it can stay the way it is now.

2 REGION STEDENDRIEHOEK

2.1 Specifications in general

The region Stedendriehoek is a combination of seven municipalities in the eastern part of the Netherlands. All seven municipalities are represented in a so called Board. The board is responsible for making decisions that affect all municipalities. Each municipality has its own district council and remains responsible for the municipality itself. The seven municipalities are: Apeldoorn, Brummen, Deventer, Epe, Lochem, Voorst and Zutphen. The common factor is that the municipalities each have one or two small urban centers and mostly a rather large rural area.
In the region live 420.000 people in about 175.000 households. It has some 28.000 companies and is approximately 1.100 km2.

2.2 Ambition energy neutrality

The ambition of the region Stedendriehoek to be an energy neutral region was only generally formulated. It originally was a political statement, without any scientific base. In order to make the ambition more concrete so calculations could be made, it was necessary to define energy neutrality. Energy neutral was defined as follows:
“An energy neutral region is a region where the annual energy consumption is equal to the annual energy production within the region itself.”
This means that the goal to be energy neutral can be reached by a combination

- reduction of the energy use within the region and
- the use renewable energy sources within the region.

The temporary difference in use and production of energy doesn’t play a role in this definition. A shortage of energy during night or winter and a surplus during day or summer is allowed. Of course this means an extra burden for the neighboring regions. The lack of balance in demand and availability is not addressed in this study.

Furthermore energy is taken into account when it crosses the border of the region, regardless of the source. This means that electricity is counted only in kWh’s as it is imported in or exported out of the region. The efficiency rate of energy conversion of electricity from coal, gas or other fuels is not taken into account. This is motivated as follows: nobody in the region itself can influence direct the source of electricity. The European Grid connects all production facilities and it’s not possible to point out an exact power plant or electricity supplier.

2.2 Method

In order to determine whether it’s possible to realize the ambition the following steps were taken. At first the present energy consumption was investigated. The energy consumption in 2030 was primary based on the present consumption.

The energy use in Dutch households has consequently decreased over the last 15 years. This is mainly influenced by the decrease of use of gas. Electricity is rather constant over the years, with a slight tendency of decrease in the last two years. This might be the effect of the financial/economic crisis.

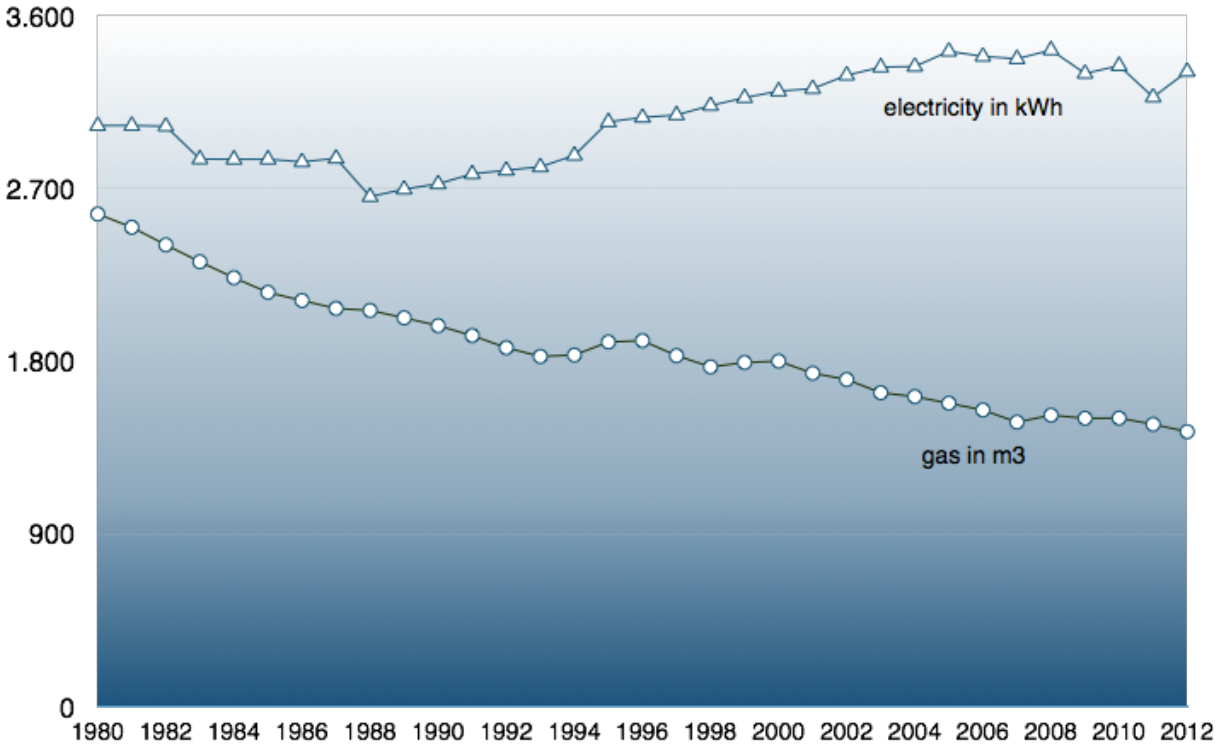

figure 1: residential energy consumption Netherlands [CBS]

The gas use decreased at approximately 2,1 % per year. This is about the same figure the government agreed on as savings in the next years. This effect is mostly caused by the regulations on new built houses, but is also an effect of insulation of existing houses. The electricity consumption is considered to unchanged, despite a modest increase over the years. This approach is supported by recent data on energy use in households as is displayed in figure 1.The national trends were translated to the regional use of energy and extrapolated.

Furthermore private cars have been considered to be all electric in 2030. This means that in this study no petrol driven private cars were meant to be present in 2030. The large trucks, busses and vans will use biobased fuel.

3 REGIONAL ENERGY SPECIFICATIONS

3.1 Energy consumption

As described in 2.3 the energy consumption in 2012 is taken as basis for the estimation of energy consumption in 2030. The actual consumption is given in table 1.

table 1: energy consumption Stedendriehoek 2012 [Aliander 2013]

2012 energy consumption Stedendriehoek			
Sector		**carrier**	**TJ**
households	electricity	electricity	1.655
	low temperature heat	gas	6.900
commercial	electricity	electricity	6.202
	low temperature heat	gas	8.369
	high temperature heat	gas	930
mobility	Private cars	petrol	7.834
	trucks	diesel	3.484
total			**35.374**

All gas used in the residential sector is considered to be used for space heating and hot water. 90 % of the gas consumption in the commercial sector is estimated to be used for space heating. The rest, 10 %, is considered to be used for high temperature purposes. As there are no chemical industries and only a few industries that apply gas for high temperature processes, this is a reliable estimation.

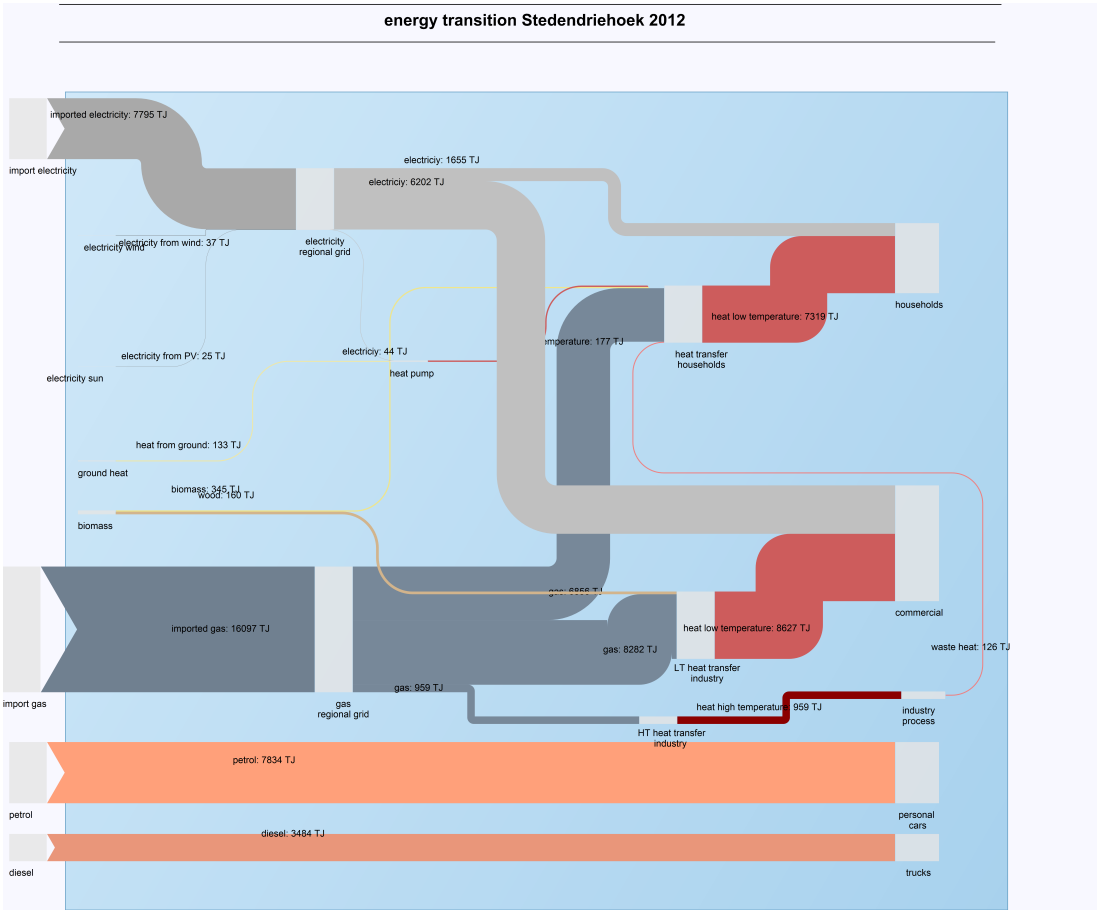

figure 2: energy flows in 2012

The energy consumption in 2030 is given in table 2. The assumptions as described in 2.3 were used for this estimation. In the first step only savings of 2 % per year in households and commercial activities were taken into account. The results are given in figure 3. The next step is the electrification of all personal cars. These results are given in figure 4. These results are also presented in table 2.

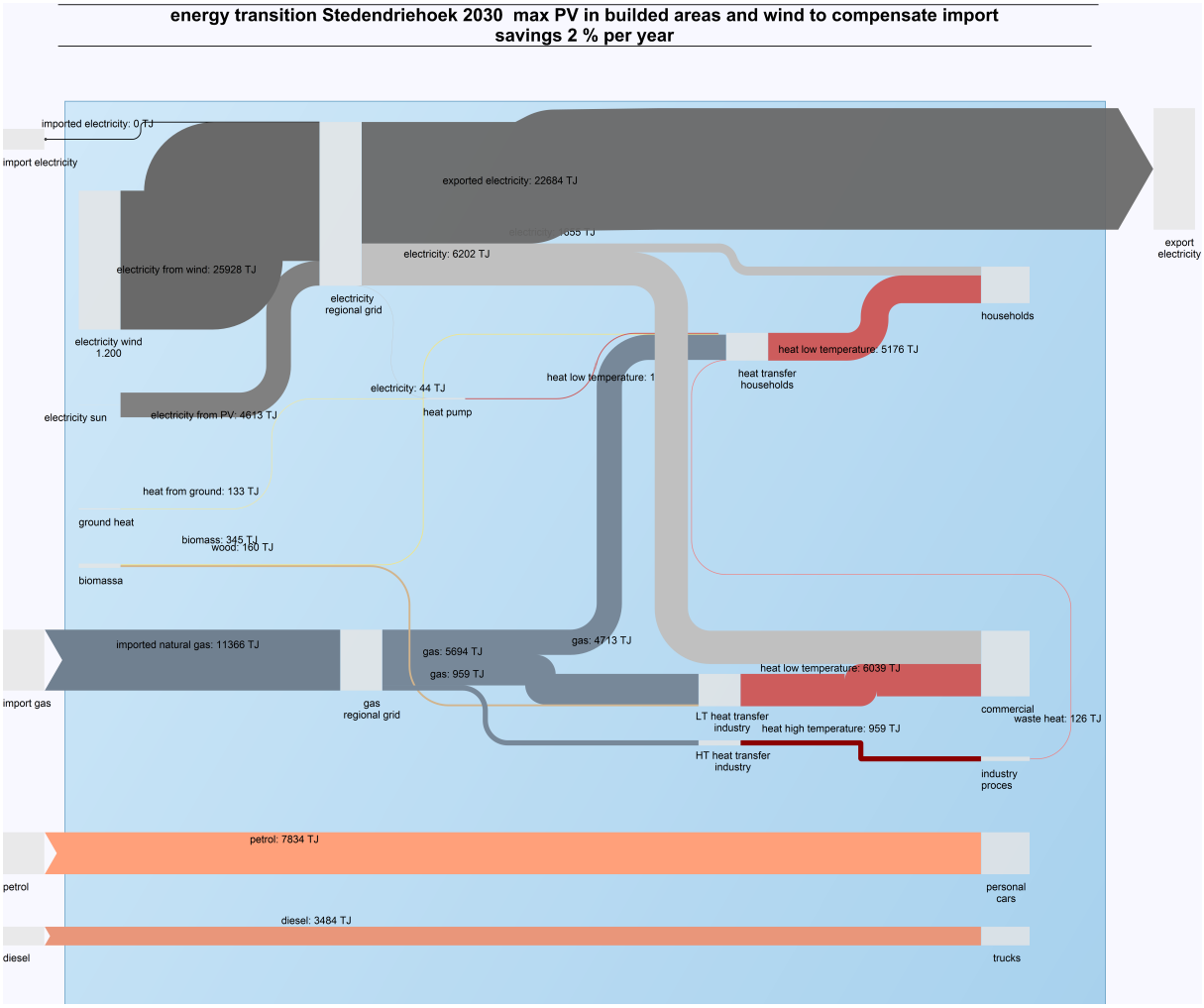

figure 3: energy flows in 2030 with 2 % savings per year

table 2: energy consumption Stedendriehoek 2030 with 2 % savings and electrification of transport [Alliander, 2013]

2030 energy consumption Stedendriehoek			
sector		**carrier**	**TJ**
households	electricity	electricity	1.655
	low temperature heat	gas	4.713
		wood	160
		waste heat	126
business	electricity	electricity	6.202
	low temperature heat	gas	4.758
		biomass	802
		waste heat	479
	high temperature heat	gas	959
mobility	private cars	electricity	1.880
	trucks	diesel	3.484
total			**25.218**

As can be seen from the table the use of energy in 2030 is 25.218 TJ. A reduction of 10.156 TJ or nearly 30 %. A very large part of this reduction is achieved by the switch from petrol-fueled cars to electric vehicles. The efficiency of electric vehicles is nearly 100 % versus 35 % of conventional cars. The reduction due to insulation is only the 2 % reduction per year.

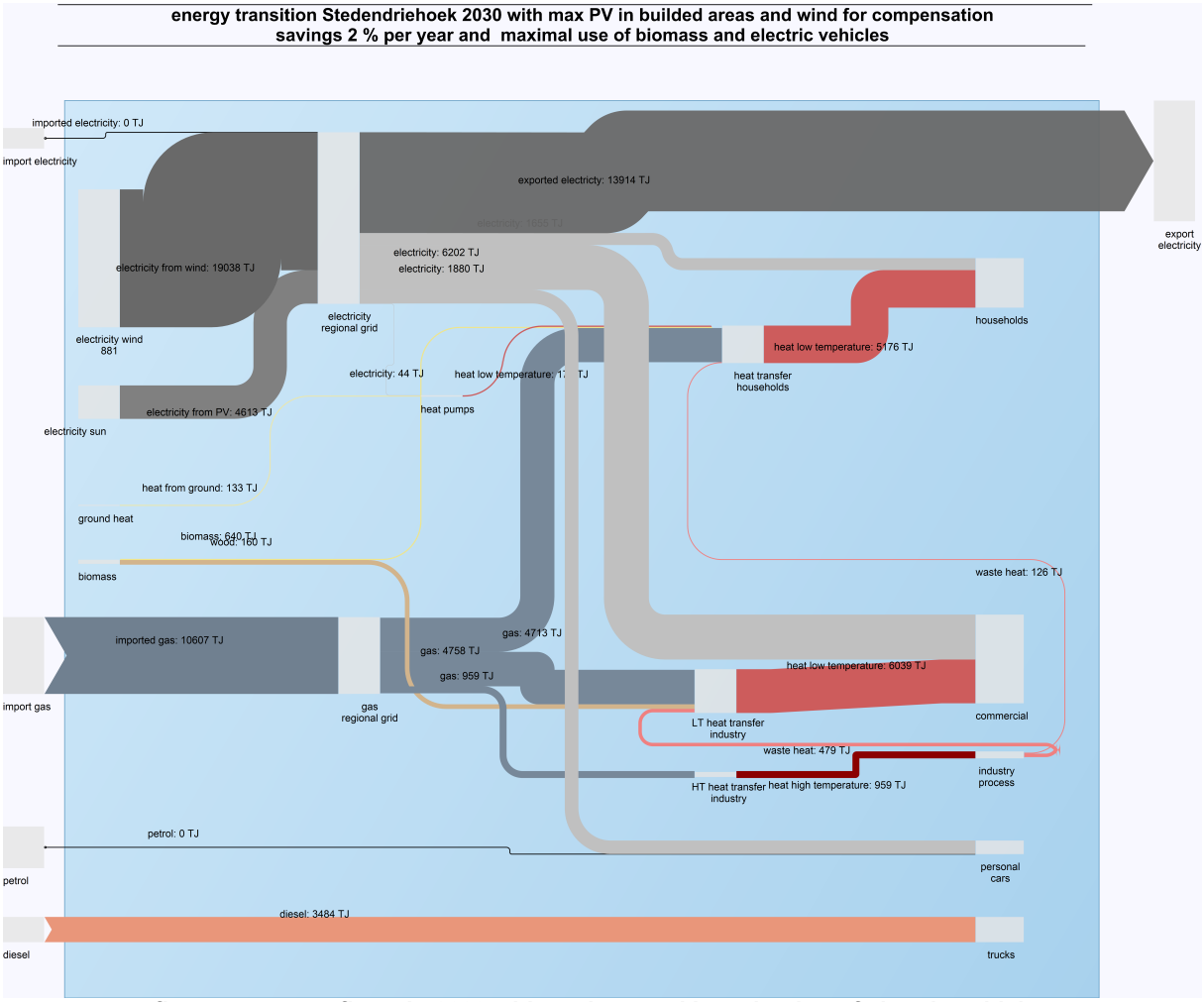

figure 4: energy flows in 2030 with savings and introduction of electric vehicles

3.2 Energy production

In the 7 communities there very little energy is produced. The main part of local energy is produced by solar panels on roofs, 3 wind turbines and some biomass. In table 3 there is given an overview of the production in 2012.

table 3: renewable and local produced energy Stedendriehoek 2012 [Alliander, 2013]

energy production Stedendriehoek 2012	
source	TJ
solar PV	25
solar thermal	38
wind	37
bio mass	160
waste heat	126
heat pumps (thermal output)	177
water	-
bio gas	262
total	**825**

In order to produce the required energy in 2030 in order to become an energy neutral region the production needs to expand dramatically from 825 TJ to 25.218 TJ.

4 NEED FOR INTEGRAL APPROACH

4.1 Creating insight by simplification

The discussion with different stakeholders such as politicians, civil servants, industry, commerce and civilians is a complex one. The meaning of energy units as TJ doesn't ring a bell. Therefore the goals or ambitions have been translated into number of wind turbines and roofs covered with solar panels.

Strictly speaking the region is energy neutral when the annual consumed energy is also produced within the region.
Compensation of the energy demand in 2030 will take a production of 25.218 TJ (table 2). This can be produced by wind and solar energy. For wind energy the most common solution is a 3 MW turbine, working at approximately an equivalent of 2.000 hours at maximum capacity per year this means a production of 6 million kWh per year or 21,6 TJ.

If is chosen for only wind, it will take 1.167 wind turbines to compensate the annual regional energy consumption. If all energy has to be produced from solar panels, it will take about 6.879 ha or 2.3 million houses with each 30 m^2 PV cells installed.

As wind turbines are rather controversial, people tend to prefer as few turbines as possible (the well known NIMBY-effect, Not In My Backyard). It is theoretical possible to produce 4.613 TJ of solar power in the Stedendriehoek only in the urban areas (industrial areas, cities etc.). The additional needed number of wind turbines is then 881.
It's needless to say that PV are more preferred than wind turbines. In the discussions the number of 881 turbines is still considered as too high. Especially politicians fear the protests of the voters in their communities. On the other hand they are also not prepared to lower the ambition

Summarized the figures are displayed in table 4.

table 4: necessary wind and solar power [Alliander, 2013]

Capacity to produce 25.218 TJ		
needed volume PV	6.879 ha	available urban area for PV is max 5.420 ha
needed volume wind power		1.167 turbines

4.2 Optimization by combination: role for heat pumps

So far production and consumption of energy have been described seperately. The minimal number wind turbines is given as 1.167. Taken into account was an energy reduction (only the low-temperature-heat demand) and a reduction of fuel use by switching to electrical vehicles.

The reduction in energy consumption due to the savings of 2 % per year and the switch to electric vehicles was 10.609 TJ. An equal step might be reached by introducing heat pumps.

As stated in 3.1 all residentially consumed gas and 90 % of the commercially used gas is used for space heating. That means heat is only used at a maximum temperature of 60 – 100 °C (necessary for preparation of hot tap water). The total low temperature heat demand, from gas, is 10.407 TJ (4.713 TJ from residentially use and 5.694 TJ from commercial consumption). At a COP=4, the electricity consumption for heating purposes will be 2.602 TJ. This will result in a decrease of total energy use (not taken into account the heat from the environment) of 7.805 TJ. A COP of 4 as average for space heating was used. This may differ from situation to situation of course.

If heat pumps are introduced on a large scale this may change the necessary production as given in table 5.

table 5: installed capacity with heat pumps

Production capacity needed when heat is produced with heat pumps		
maximum production PV in urban areas	4.613 TJ	available for PV business and residential areas sums up to 4.701 TJ
needed wind energy	10.569 TJ	489 turbines

In this newly optimized situation the energy flows are given in figure 5.

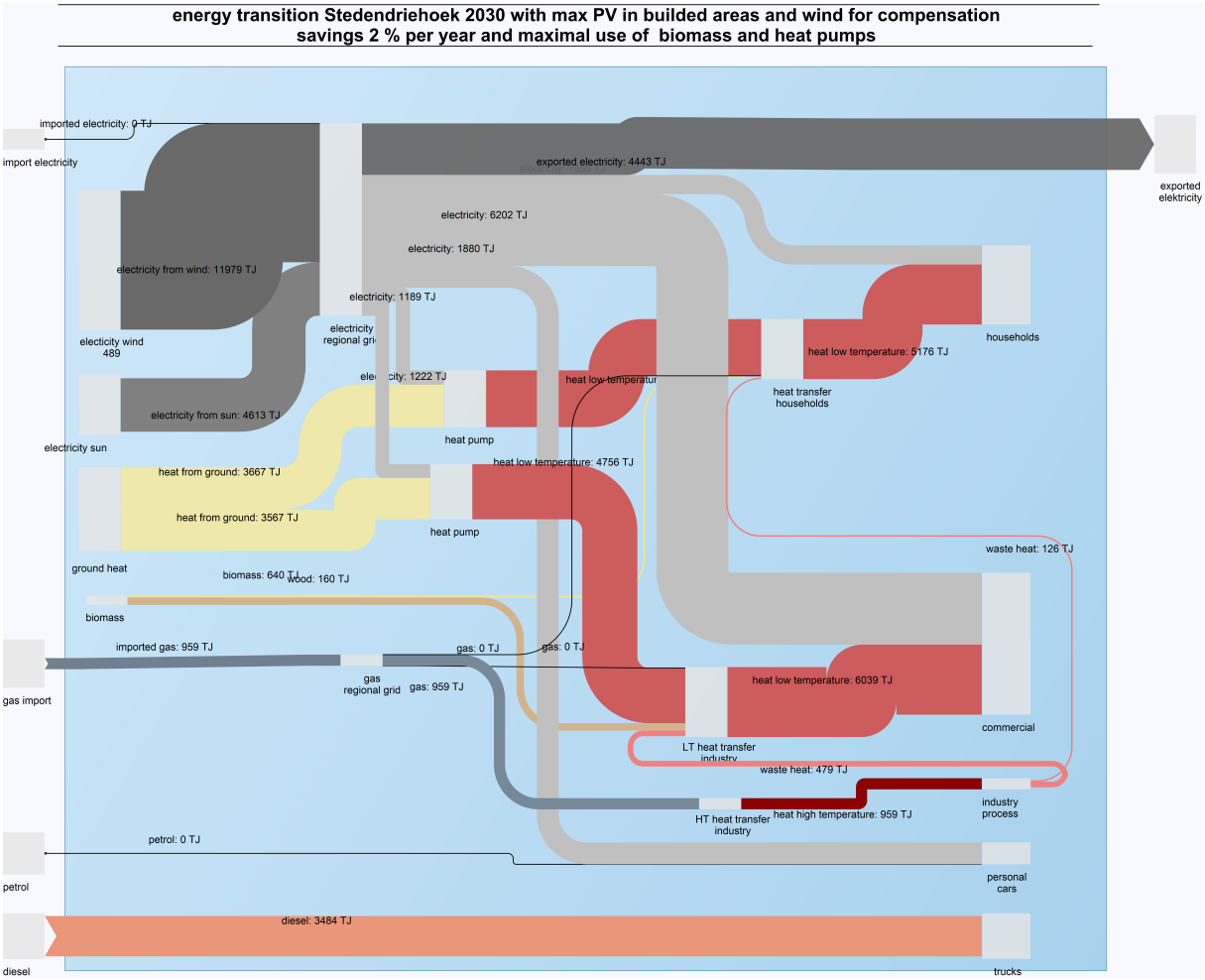

figure 5: optimized energy system for an energy neutral region with optimal use of heat pumps

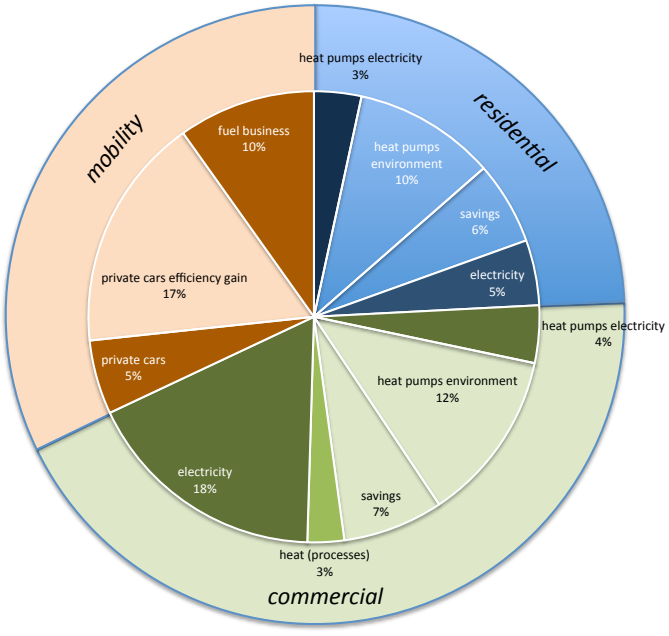

figure 6: energy use and savings in Stedendriehoek [Alliander, 2014]

An important property of the heat pumps is that they use electricity. The direct gas fired boilers will have to be replaced by the heat pumps. This is also logical, as the main energy production will switch from a traditional gas source (in the Netherlands gas is the main energy carrier) to electricity. Wind turbines and solar panels produce electricity that can be used in the heat pumps.

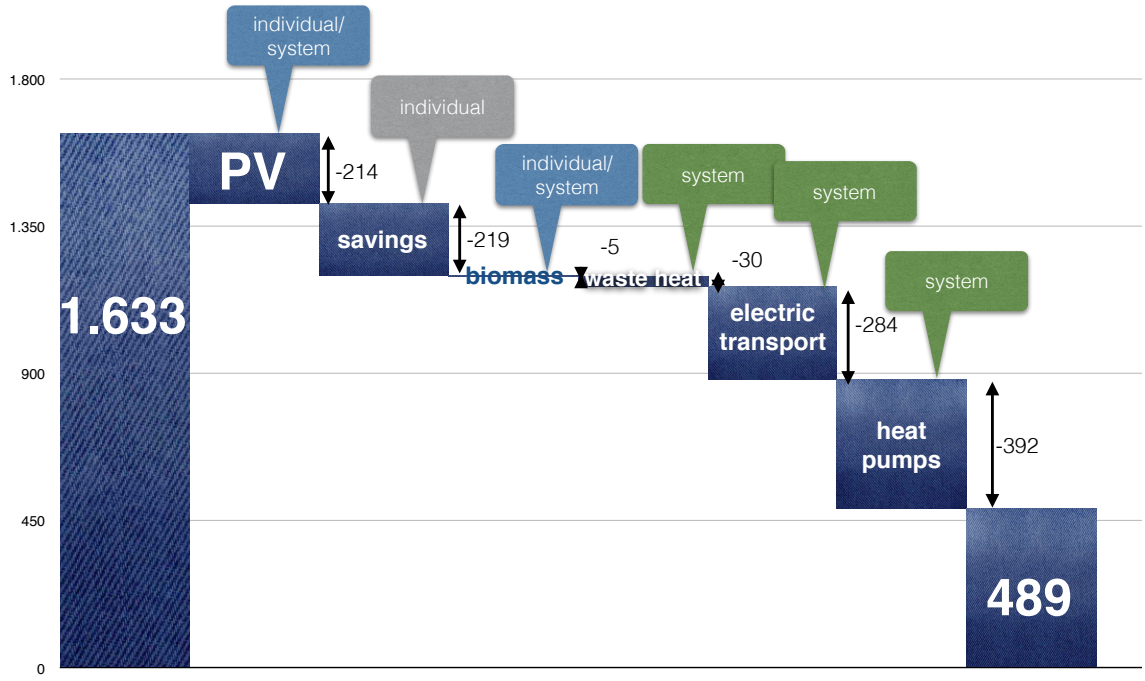

figure 7: change of necessary wind turbines in region as result of measures such as introducing savings, electrical tranport and heat pumps [Alliander, 2014]

5 Challenge

5.1 Working together and necessity of planning

It's obvious that a combination of reducing the energy demand and the switch to renewable sources is the only way to reach the goals. The number of 489 wind turbines in the environmental friendly and rather rural region is considered quite high. Nevertheless people start to discuss more and more about wind turbines and realize it's necessary to accept. Of course it will take a couple of years to install the turbines and it will take a lot of legal procedures before all protests will be gone. As can be seen some measures will take steps on a system scale other ones can be done on an individual level. The more systemic measures need a system change. That can only be done on a regional, if not national level. Government will have to play a role.

A larger problem is the insight, or lack of it, in the heat supply. To be energy neutral in 2030 and the essential role of heat in it, is far more complex. There are nearly no plans for new houses of offices. The most effects on energy demand are therefore to be expected from the existing houses. They need to be more insulated, but even more important: the existing buildings have to change the heating system. Gas boilers have to be replaced by electrical heat pumps. This will be a major operation where installers have to work closely together with building companies.

5.2 Only guts and long-term visions will work

In the region Stedendriehoek, and this is only an example of how other regions operate, major decisions are postponed. This is however not the way the ambitions may be met. In the older cities, a collective heat system will be needed. The most older and monumental buildings cannot be made energy neutral or energy producing in itself. Because of the cultural and historical status of most of the buildings in the centers of the Medieval towns insulation is only possible to a certain extend. The only way of introducing a renewable heating is a collective system that will be supplied by heat pumps. Individual systems in the compact areas are not likely to be installed at first by cost and secondly by the interference of ground sources. The houses and buildings are to closely build.

The building of a district heating system in an existing area takes the support of the local municipal authority. There has to be an assurance that houses will be connected to the system. This may even result in an obligation so that will be guaranteed that all buildings will be connected. In this way gas boilers can be replaced by district heating.

The problem is that steps in to this direction have to made right now. All parties involved have to work in the same direction. In nearly 17 years the region wants to energy neutral, then is time to act now.

If all urban houses and buildings are connected with a district heating system, nearly 60-70 % of the low heating demand is covered. The rest of the houses is built in less dense populated areas. Those buildings will need an individual heat pump.

That means that approximately 105.000 houses and 16.000 companies are to be connected to a district heating system and 70.000 houses and 10.000 offices have to be heated by an individual system. This is an enormous switch in an extremely short period.

Politicians need to have guts to decide on regulations that make this transition possible. Investors need to have faith in future developments and stability in economics and politics to make the projects possible. People, inhabitants and voters need to have confidence in technique and stability to make the switch. Of course the people who have to do it have to be fit for the job. Installers and builders need to be professionals on low temperature systems, heat pumps and insulation.

It’s a pity to see how bad the performance of some heat pump systems are. The misery of some projects is widely spread in the media and makes decision makers hesitate. Too many heat pump projects fail. There is a need for efficient, reliable and comfortable heat pump systems.

5.3 Heat pumps essential in two ways

Heat pumps can play an essential role in the energy transition. At first introducing heat pumps will establish the reduction of nearly one third of the total energy consumption. And secondly the production of energy will shift from mainly gas to nearly all electricity. Wind turbines and solar PV cells produce electricity so gas will be banned out of the energy supply. Heat pumps are one of the most efficient ways to use electricity for space heating. The produced energy can directly be used by the heat pumps. Especially in houses where the solar energy is converted into electricity the heat pump can direct use this electricity to convert into heat which can be stored in a boiler vessel or in the mass of the building. In this way the storage of heat can be used to make the whole energy supply efficient as in this case there is less need for batteries.

6 CONCLUSION

Heat pumps have an important role in the energy transition on two ways: 1. Heat pumps use electricity that is produced locally with wind or solar installations; 2. Heat pumps lower the conventional use of energy by using environmental heat. As the heat demand is, and will be, a substantial part of the energy demand, heat pumps are one of the most important solutions in the struggle for an energy neutral society. Through heat pumps is it is possible to reduce the impact of renewable energy in the landscape (40 % less wind turbines).