Renewable communities: sustainable energy transition in Leuth

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Abstract

It is widely recognized that the use of fossil fuels causes environmental and geopolitical problems. It is essential that we turn to sustainable and regional ways of producing energy. Both producers and consumers are directed towards renewable energy. Traditionally, the strategy of Trias Energetica is used when sustainable energy becomes an integrated part of urban planning. Trias Energetica promotes three main concepts of sustainable energy production: to reduce use, use renewables and be efficient with the remaining resources.

In the research area of Leuth, near the city of Nijmegen in the Netherlands, the Urban Harvest strategy has been introduced. In this strategy all available renewable energy sources are harvested. The outcome of the Leuth research is that the community applying the Urban Harvest strategy is theoretically easily able to fulfil its energy needs. The results are used to discuss Trias Energetica.
Keywords: renewable communities, trias energetica, urban harvest, renewable energy, biomass, wind energy, solar energy, energy from the road.

1 Introduction

1.1 Trias energetica

After Charles de Montesquieu and his famous “Trias Politica” in 1752, the issue of sustainable energy supply was introduced by Lysen in 1996 under the name of “Trias Energica” [15]. At that point the three step strategy was structured as follows:

1. A continuing improvement of energy efficiency
2. A greater use of sustainable energy sources
3. A cleaner use of the remaining fossil fuels

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This three step strategy did not have a concrete statement towards sustainability but Duijvestein in 1997 introduced a more structured method of the strategy, which placed the three steps in the context of sustainability. What was actually done was that the most favourable measurement was put on the top and the least favourable became the last step. This process has led to the current strategy of "Trias Energetica" (figure 1):

1. Use less energy by taking energy saving technologies
2. Use sustainable energy sources as much as possible
3. When there is still an energy demand left, then use fossil fuels as efficiently as possible.

Based on this same concept, new concepts are derived for the compartments of water, materials and space. In accordance with Trias Energetica, the terms "Trias Hydrica" (for water), "Trias Hylica" (for materials) and "Trias Toponoma" (for space-usage) are introduced [1].

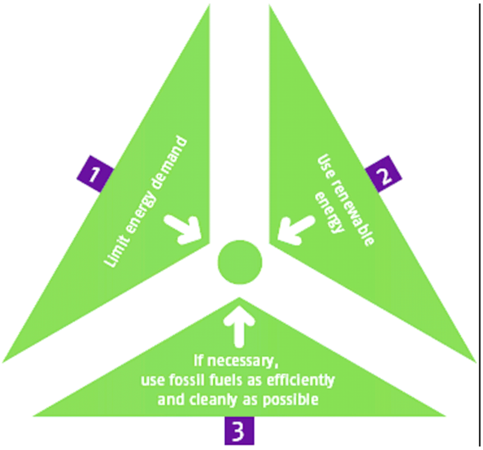

Figure 1: Trias energetica.

2 Research area

The Ubbergen municipality is situated to the east of the city of Nijmegen in the Netherlands, enclosed by a high hill and the low flood meadows of the river Waal. Beek is the centre of Ubbergen municipality and the villages of Ubbergen, Ooij, Leuth, Kekerdom, Persingen and a part of Berg en Dal surround it [6]. The target area is the community of Leuth, as divided by the surrounding areas of Leuth and the central neighbourhood. Recently the community approached Wageningen University in their quest for ideas about how to become a renewable community. As there is a plan for the construction of new houses and a community centre in the neighbourhood, the community came to the decision to introduce renewable technology in the new buildings and if possible produce energy from renewables to meet the energy needs of the whole neighbourhood. The basic request from the community, for the development of the energy scheme, was to introduce energy production from biomass as the primary resource of renewable energy.

3 Methodology

3.1 Urban harvest

The main strategy applied for the development of the renewable energy plan of the study area was the "Urban Harvest". The concept guidelines propose to harvest any available renewable resource, within an urban environment system, and to reuse these resources within the same urban environment system [17]. In the Urban Harvest approach we have identified six different streams. Resources are sorted into topics, and these "Urban Crops" are often unused and it is necessary to make them visible in order to expose their harvesting potentials. The "Urban Crops" according to the different streams are: Urban Forest, Urban Rivers, Urban Energy, Urban Farm, Urban Quarry and Urban Space.

Urban Energy harvest was the main principle used. Urban Energy is one of the six streams identified in Urban Harvest and it deals with all energy available within the urban system, both virgin or primary to be harvested and waste or secondary energy to be captured and re-used [17].

4 Proposed exploitable solutions

The proposed plan takes into serious consideration the concept of Trias Energetica. The plan is divided into three sections according to the resource used for the energy production and is targeting mostly on the second step of Trias Energetica, the production of energy from renewable and not energy reduction and energy efficiency. Mainly in this proposal solar radiation, wind power and biomass are explored for the long term sustainable energy production from these renewable resources. The hybrid renewable energy scheme is presented in figure 2 and analyzed later on.

4.1 Biomass

Biomass is a simple term used for all organic material that comes from plants (including algae), trees, and crops. The energy, which is produced by biomass, bio-energy, has the advantage that it is CO_2 neutral, if the biomass is sustainable produced and transported. The community requested the introduction of biomass in their energy scheme as they have future plans to upgrade the system for the production of bio-diesel. Thus emphasis was given on biomass but additional technologies harvesting solar and wind energy were used to have a hybrid system with utilizing different resources for a more stable production. Generally biomass and biogas are significant potential renewable energy sources for a wide range of energy needs, including heating, electricity generation and transportation fuels for communities [24].

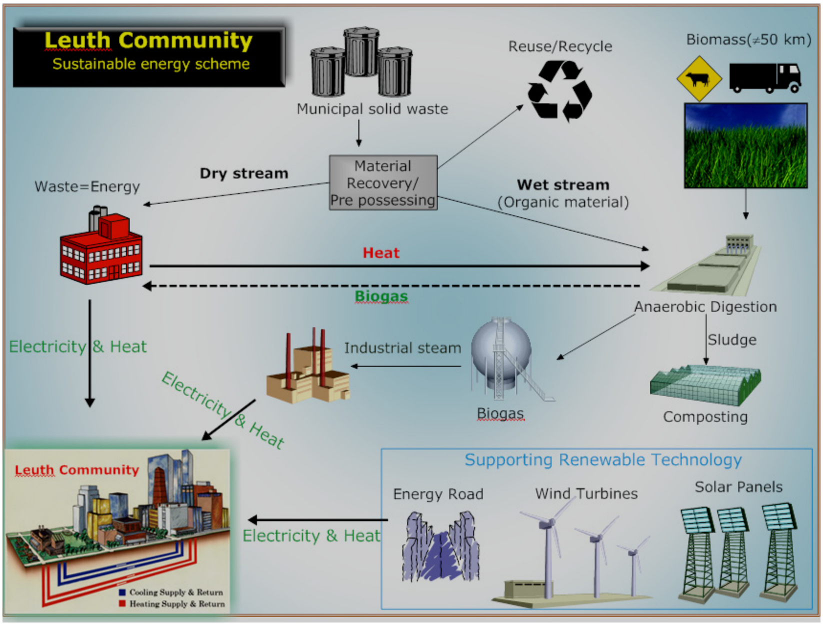

Figure 2: Renewable energy scheme for Leuth.

One of the proposed solutions for the energy needs of Leuth is the combination of municipal solid waste (MSW) and biomass for the production of energy in the form of electricity and heat. The expectations of combining these two techniques are to support each other and maintain the high and low energy picks during the whole day.

The energy production is divided into two categories according to the moisture of the energy source as such:

- The MSW of Leuth are collected and separated into dry and wet stream. The dry municipal waste is separated from the wet stream as the heating value from the combustion is higher when the waste is drier. The combustion of dry MSW produces energy in the form of steam that can power a turbine to produce electricity. After electricity production the steam is liquefied, but still contains a high temperature. Energy cascading necessitates directing the warm liquid to the local community for heating and after using it within the Leuth neighbourhood, directing it to an anaerobic digester to support the anaerobic procedures.
- The Wet stream of MSW mentioned above, is organic waste that will be added to the biomass collected from the surrounding areas and it will be directed in an anaerobic digester, heated by the excess heat from electricity production. During anaerobic digestion methane is produced that can be stored for farther use in generating heat or electricity when the consumption pick rises [11]. The wet MSW have a better energy value if the content has more moisture. Therefore the separation is present to ensure more energy values for the dry steam and a more homogenous environment for the wet steam and the anaerobic process.

The principle of Cascading was introduced here, and consequently this hybrid system, is sited close to each other so that the heat recovery is exploited to the maximum. Produced steam for generating electricity can be used as industrial steam, if needed in the community and then utilized for district heating and for the anaerobic digester. This way the energy plan can double its efficiency and existing infrastructure can facilitate the distribution of compost products after the conversion of sludge. There is a relative large demand in compost within reasonable distance since Leuth is surrounded by agriculture areas.

The net energy output in biogas systems using different raw materials varies depending on transportation distance, means of transportation, conversion techniques and needs for handling of raw materials and digested residues. For Dutch conditions, from a life-cycle perspective, it appears that for transportation distances up to 50 km, the energy needed for running the biogas systems typically corresponds in low percentage of the energy content in the produced biogas [13]. All raw materials could be transported for 50 km before the energy balance turns negative.

In order to have an idea of the energy production capabilities of biomass simple calculations are contacted in order to demonstrate the potential. The calculations are in reference to different types of biomass that produce biogas. Biogas is used for heat production or electricity production or both. In our integrated energy plan we assume that both heat and electricity are produced by bio-energy.

Calculating the thermal value recovered by biogas (methane 65%): $65*0.099MWh/1000m^3=6.435MWh/1000m^3$. If the reactor produces $2000m^3$ of biogas per day, then the contained heat capacity may be calculated as follows: $(2000/1000\ m^3)*6.435MWh/1000\ m^3=12.87MWh$

Now the operating efficiency of the produced biogas affects decisively the amount of the energy produced. Operating efficiency if only heat is produced is up to 90%; the operating efficiency if both electricity and heat are produced is at 85% (35% electricity and 50% heat) and if only electricity is produced the operating efficiency is 35%. So if a biogas plant uses all the produced biogas for joint production of energy and heat, then the amount of energy produced during a whole day will be a total of 10.94MWh/day (12.87MWh*0.85=10.94MWh), thus for the whole year a total of 3993MWh/year is calculated (365*10.94=3993.1MWh).

Some digesters can yield 20 m^3 of biogas per ton of waste while others can yield as much as 800 m^3 per ton. It all depends on waste type and quality, digester design and the proper operation of the system. Each cubic meter (m^3) of biogas produced contains the equivalent of 6 kWh of energy. However when we convert biogas to electricity, in a biogas powered electric generator, we get about 2 kWh of useable electricity, the rest turns into heat which can also be used for heating applications. Just to illustrate the volume of one cubic meter of biogas producing electricity, the 2 kWh produced is enough energy to power a 100W light bulb for 20 hours or a 2.000W hair dryer for 1 hour [10].

Heat demand can be met with the use of biomass but if biomass is used for co-production of heat and electricity, then additional technologies must be also explored in order to cover the remaining electricity demand of Leuth. For that reason solar energy production and wind energy production is incorporate in the energy plan (biomass, municipal waste) in order to harvest the wind and the solar radiation of the area.

4.2 Solar radiation

The interactive maps of the European Union were used in order to identify the exact solar irradiation of the research area [12]. The online calculation shows daily irradiation of Leuth at 2642 Wh/m^2 (Table 2). Thus it is calculated that the horizontal solar irradiation through the year is 964 kWh/m^2 [(2642*365)/1000].

Table 1: Daily solar irradiation of Leuth.

Month	Irradiation (Wh/m2/day)
Jan	612
Feb	1409
Mar	2140
Apr	3678
May	4744
Jun	4628
Jul	4764
Aug	4033
Sep	2705
Oct	1635
Nov	824
Dec	455
Year	**2642**

Great opportunities arise in Leuth since new houses and the community centre will be constructed. That provides the prospect of integrating solar panels in the architecture designs of these facilities.

Other possible technologies were also investigated that can harvest solar radiation. Research revealed the Thermal Asphalt Collector (TAC). A TAC system is an option that is suitable for the Dutch climatic conditions. This is a fresh idea for harvesting solar energy for heating and cooling buildings and roads. The system is comprised by an asphalt concrete layer with a reinforced structure and a water-bearing medium. Asphalt concrete's dark colour has an excellent heat-absorbing property. The water-bearing medium is able to cool the building or the road in summer time (energy extraction) and heat it during winter time (energy addition) [18].

The energy harvested from the road itself using TAC systems is in the form of heat and is approximately 92kWh/m^2/year. Considering that 11% of Leuth's space is used for roads, which means that approximately 462m^2 of the total space are used for the transportation network; then it is possible to calculate the theoretical potential of installing TAC systems in the roads. As 462m^2 of space is used by the road network, then the theoretical production potential is calculated up to 42,5MWh/year [(92*462)/1000]. TAC's can be combined with deferent storage systems, usually heat wells (figure 3), and energy can be stored for future use. For the same reason these systems allow you to exploit available solar energy and use it either heating or for cooling. Roads are elements of the most typical infrastructure in modern societies and they can be harvested in this way for the production of energy.

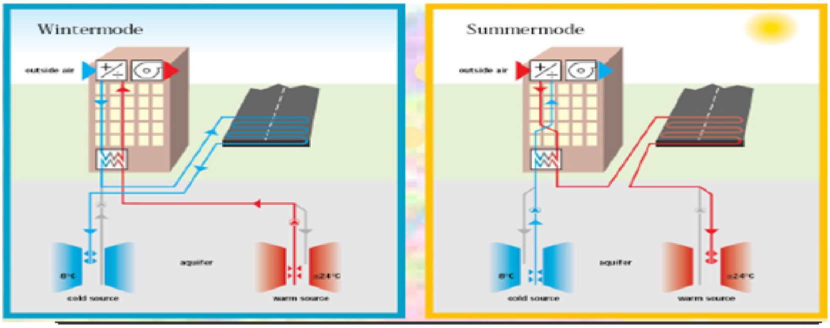

Figure 3: Storage of energy from the road.

4.3 Wind speed

According to the wind map of the Netherlands (figure 4), Leuth is situated in the zone with a mean wind speed of 3.5-4 m/s. Using the interactive online software of the Danish Wind Industry association [7] we can calculate according to deferent wind turbines the energy output in reference to the characteristics of the site.

As wind speed is relative low in Leuth, comparing with the rest of the Netherlands, wind turbines have to be built in specific positions according to wind direction, in order to have maximum production. But there are always special limitations.

In that case there is always the option of using *Vertical-axis wind turbines* (VAWT) that has the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable. VAWTs can utilize winds from varying directions. With a vertical axis, the generator and gearbox can be placed near the ground, so the tower doesn't need to support it, and it is more accessible for maintenance [21].

4.4 Production capabilities

An energy matrix is developed combining the different technologies mentioned above to produce enough energy to meet the needs of the community. Energy

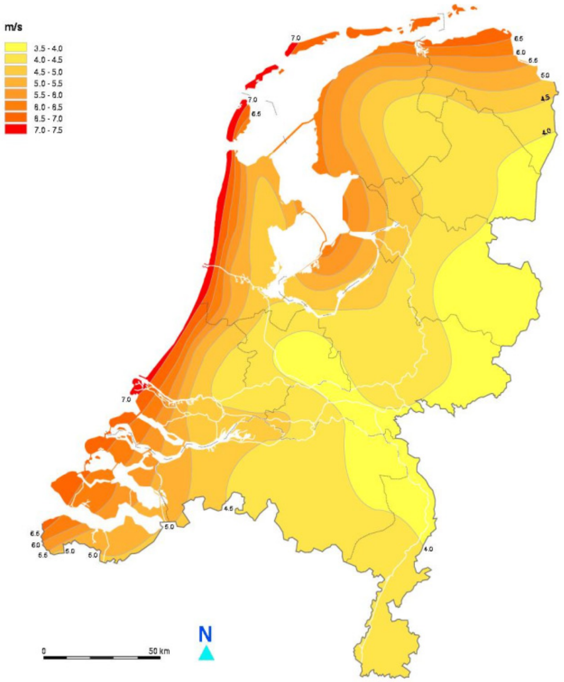

Figure 4: Wind speed map of the Netherlands.

Table 2: Energy matrix calculations, face 1 of project.

Elements/Energy output	Wind energy	Solar energy	Biomass	Solar energy	Total energy production
Type	Wind turbine Bonus 2300/82.4	PV panel SHARP ND-167U1	2000m^3 biogas	Road energy	Combination
Energy output (KWh/year)	934923	141616	3993100	92	
	1	42	1	100	10885095
	wind turbines	solar panels	2000m^3 tank	m^2	kWh/Year
				MWh/year:	10885.1

consumption is calculated for the needs of the houses constructed, to 8680MWh/year. With the assumption that the energy needs of the community centre is approximately 2170MWh/year, as no specific data are available, then for the first stage of the project the consumption need is 10850MWh/year (2170+8680=10850MWh/year). As seen in table 2 it is calculated that with a combination of wind energy, solar energy and bio-energy it is possible to produce enough energy for transforming the new houses and the community centre in energy autonomous by using renewables within the limits of Leuth.

In continuation, the production for total energy autonomy of Leuth community by utilizing renewable recourses is calculated. Energy consumption is calculated for Leuth needs to 164920MWh/year [6]. In table 3, the results are presented for one of the possible scenarios. Here it is demonstrated that energy produced from renewable resources available in Leuth, is possible to meet the whole energy demand of the community.

Table 3: Energy matrix calculations, face 2 of project.

Elements/Energy output	Wind energy	Solar energy	Biomass	Solar energy	Total energy production
Type	Wind turbine Bonus 2300/82.4	PV panel SHARP ND-167U1	2000m^3 biogas	Road energy	Combination
Energy output (KWh/year)	934923	141616	3993100	92	
	30	685	10	300	165013250
	wind turbines	solar panels	2000m^3 tank	m^2	kWh/Year
				MWh/year:	165013.3

Surveys show strong customer preference for sustainable electricity but renewables will be unable to compete fairly with conventional technology for energy generation until new policies are adopted to internalize the public costs of the fossil fuel sources (Porter [20]).

5 Conclusions

Analyzing the concept of the Trias Energetica we realize that an important part of this sustainable energy strategy is the use of renewable resources. Using the Urban harvest methodology, all available renewable resources, within the limits of the community of Leuth, are harvested in order to produce energy in the form of electricity and heat, to meet the needs of the community. Calculations were carried out and it is verified that the production of energy from renewable resources can reach a point that can satisfy the energy needs of the whole community.

Wind and solar technologies can produce supplemental electrical energy during the whole day, in association with biomass that is the primary producer of heat and electricity. Having a hybrid renewable energy system indicate that energy production is not based only on one resource and the management of the energy production is flexible according to the availability of the resource at the time of the production. Hybrid energy plans give the possibility of this flexibility by switching to deferent energy production methods utilizing all available recourses within the limits of a small community and by storing the excess energy produced for upcoming energy consumption.

As the results verify that production from renewables can transform the community of Leuth into 100 per cent renewable community, the discussion is so as to the additional emphasis that should be given in the second step of the Trias

Energetica, the use of renewables, in designing sustainable energy systems. Still the application of the Urban Harvest strategy, with a primary emphasis on using renewables, will face economic obstacles that need to be solved first.

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