Energy Conversion and Management 150 (2017) 941–948

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Review of urban energy transition in the Netherlands and the role of smart energy management

R.P. van Leeuwen [a,*], J.B. de Wit [a], G.J.M. Smit [b]

[a] Research Chair Renewable Energy Supply, Saxion University of Applied Sciences, Enschede, The Netherlands
[b] Department of Computer Science, Mathematics and Electrical Engineering, University of Twente, Enschede, The Netherlands

ARTICLE INFO

Article history:
Available online 1 July 2017

Keywords:
Urban energy
District heating
Renewable energy
Smart grids
Optimal capacity
Smart energy management

ABSTRACT

This paper gives a review of the most important backgrounds and trends of the present energy supply system in the Netherlands. Options are discussed for the integration of renewable energy and the present policies are reviewed that stimulate the energy transition. Last, the role of smart energy management as part of the integration of renewable energy into existing infrastructures is discussed.

1. Introduction

The use of traditional, carbon based fuels contributes to the accumulation of carbon dioxide in the earth's atmosphere with global warming as a consequence [1]. Governments and citizens of many countries in the world recognize the need for energy savings and a transition towards energy from renewable sources. The European Union developed legislation and member states are committed to reach energy savings and increased renewable energy shares for 2020 (so called 20–20–20 goals: 20% energy saving, 20% renewable energy share in 2020). Road maps are also developed towards 2050 to have a completely renewable energy system [2].

This paper reviews backgrounds of the Dutch energy transition and policies in place for the integration of renewable energy for urban areas. The paper explains the history of the Dutch energy system up to the present system which is supplied by a mixture of fuels and renewable resources and why the use of natural gas is still dominating within this mixture. The paper also explains policies developed for the transition to more renewable resources. For this paper, an urban area is interpreted as a district or community containing houses and possibly some other buildings like offices, schools and small companies. Such an area can be a village or a district of a city.

The paper starts with a review of the most important backgrounds and trends of the present energy supply system and the energy transition in the Netherlands in Sections 2 and 3. The present Dutch policies for stimulation of renewable energy integration are reviewed in Section 4. Options for renewable energy are discussed in Section 5, followed by the current issues for integration of renewable energy and the role of smart control in Section 6. The paper ends with conclusions and an outlook in Section 7.

2. Energy supply and consumption in the Netherlands

In the Netherlands, 3200 peta Joules (PJ) of primary energy (i.e. input energy from resources such as crude oil, hard coal, natural gas) is used per year. In Fig. 1 the distribution of primary energy towards consumption categories is shown for 2015. The built environment includes the whole category "households", a large part of the category "services" and a small part (only the buildings, not the processes) of the category "industry". The primary energy consumption in the Netherlands is 3060 PJ in 2015 and constitutes a mixture of sources, refer to Fig. 1. The final energy consumption (secondary energy, i.e. produced from primary energy) is 2070 PJ per year of which 1232 PJ is consumed for the thermal demand, 353 PJ for the electrical demand and 485 PJ to drive vehicles.

The built environment (households and services, i.e. office buildings) is the largest energy consumer: 33% of the final consumption, i.e. 490 PJ or 24% for heating buildings and hot water and 195 PJ or 9% for electrical appliances. The built environment has a low temperature (LT) heat demand (below 100 °C). On the other hand, the industrial sector (478 PJ thermal demand) has a

* Corresponding author.
E-mail addresses: r.p.vanleeuwen@saxion.nl (R.P. van Leeuwen), j.b.dewit@saxion.nl (J.B. de Wit), g.j.m.smit@utwente.nl (G.J.M. Smit).

http://dx.doi.org/10.1016/j.enconman.2017.05.081
0196-8904/

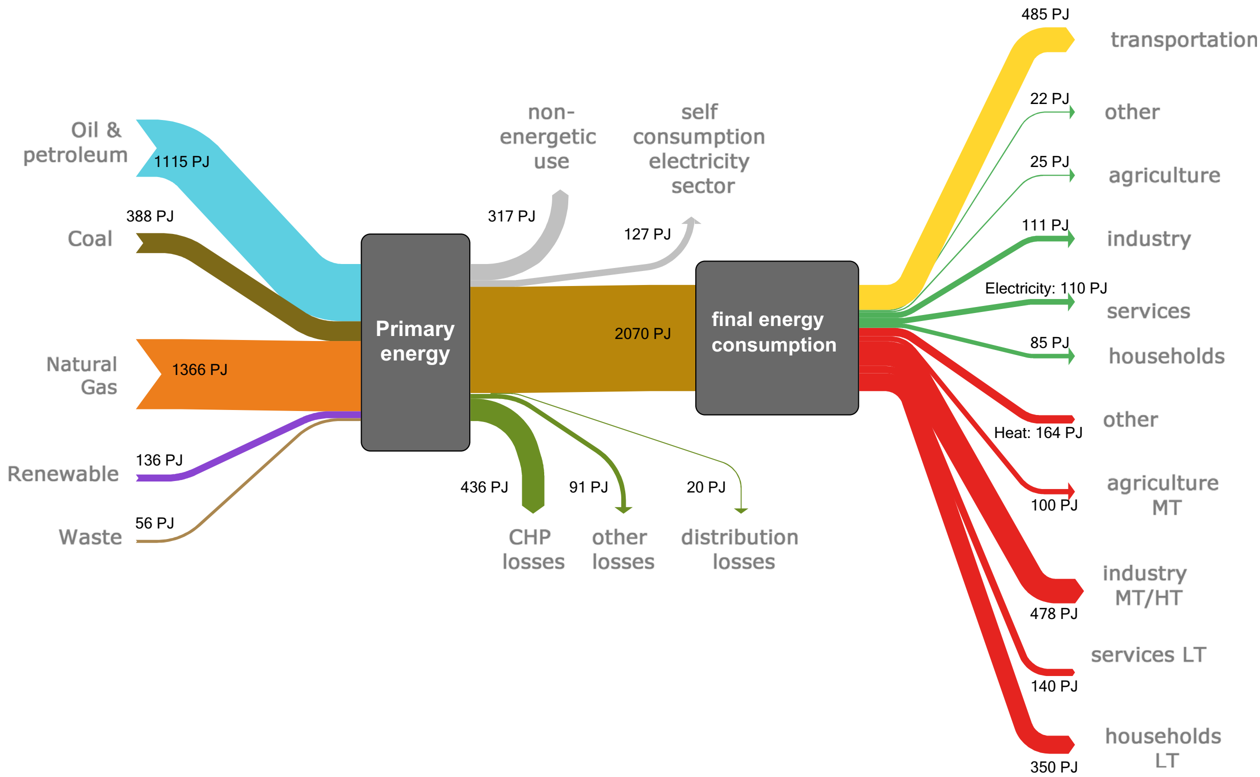

Fig. 1. Primary energy consumption.

mediate to high temperature (MT/HT) demand (100–500 °C/500–1500 °C). Through industrial processes this heat is converted into a LT-heat waste stream, in the range 20–80 °C. Other LT-heat waste streams are conversion losses of the electricity sector, i.e. 436 PJ in the same temperature range. Together, this amounts to 914 PJ which could potentially be used to supply the entire heat demand (490 PJ) of the built environment. Fig. 1 is constructed based on information provided in [3–5].

The Netherlands relies for more than 90% on natural gas combustion in boilers for the supply of the building related thermal demand. For the electrical energy demand, 84% is converted by natural gas and coal combustion. Due to recent low prices of coal, the share of coal increased in recent years which also led to an increase of the related CO_2 production. The remaining part of the electrical energy demand is supplied by waste co-generation plants, wind turbines and solar PV [3].

While combustion of natural gas leads to 50% less CO_2 emissions compared to combustion of coal, the Dutch energy system was relatively environmentally friendly in the past, in comparison with many countries which use predominantly coal combustion. However, large scale combustion of fossil fuels increases the CO_2 concentration in the atmosphere, which causes temperature increase (global warming) on the planet. In the last decades it has become clear that this effect changes climate systems all over the world with serious consequences to nature and population. Hence, environmental policies aim to out-phase the use of fossil fuels entirely. Recently, new agreements on climate change are adopted by the UNFCCC (United Nations Framework Convention on Climate Change) [6] with a treaty to limit global warming to 2.0 degrees and to strive for a limitation of 1.5 degrees. The treaty is signed by many governments in the world, including the Netherlands.

The Dutch ministry of economic affairs, responsible for energy policies, has announced a shift of paradigm: initiatives towards integration of renewable energy in the heating sector will be encouraged in order to phase-out the use of natural gas completely by 2060 [7]. In [8], the Dutch government translates this vision into policy measures and proposals. An important step towards realization of the ambitions is the so called "energy agreement" between the government and the major economical sectors (energy, industry, services) [9,10] in which targets for the short to mediate term are agreed for energy saving, increasing the share of renewable energy, finance and job creation. Part of this deal is the structural plan for large scale offshore wind turbine fields [11] and support for local urban energy initiatives [12].

3. Backgrounds of the energy transition

Traditionally, thermal energy for heating purposes is delivered by fuel combustion. Since the discovery of fire, many thousands of years ago, people used wood as fuel. Population growth, formation of larger cities during the industrial period and increasing depletion of wood reserves in many industrialized countries led to replacement of wood by coal. In the Netherlands, from the early industrial period until the 1950s, coal has been the dominant fuel for households but this ended in a relatively short time period due to the discovery and exploitation of natural gas reserves. Today, natural gas is the dominating fuel for households and industry and Dutch manufacturers of natural gas boilers and appliances have a world leading position in efficient, innovative technology. The fast Dutch transition process of replacing coal with natural gas, is a prove in itself that countries can make the transition to new energy sources in a relatively short period of time [13].

Another example which proves that transition towards a high share of renewable energy is possible is Denmark. From the 1980s Denmark made a transition from complete dependency on fossil fuels towards the present situation where the country has the highest share of renewable energy from wind turbines and solar energy in the world [14].

The traditional picture of energy supply based on fuel consumption is changed entirely by renewable energy. Dominating options like wind turbines and solar PV directly produce electrical energy, which can be stored and transformed into work with higher efficiencies than the traditional fuel combustion machines. Hence, as a side effect, integration of renewable energy partly leads to electrification of functions which are nowadays still based on fuel combustion. Examples are: electric vehicles for transportation and electric heat pumps for heating, refer to [15,16].

Renewable energy requires geographical space and production is mostly decentralized. Some options like solar PV are relatively easy to integrate in an urban environment while other options like wind turbines and biomass plantations are mostly realized some distance from urban areas. For this, support of local communities for large numbers of tall wind turbines or biomass cultivation and conversion does not come by itself but has to be organized by creating awareness and developing a public interest. A wider public needs to be aware of the required transition and needs to be involved in eventual benefits. Although this is often a difficult process, this is also a chance for improving social coherence [17].

The traditional electricity networks are a means to transport renewable electricity between large scale and often rural generation locations and urban areas. With smart control it is possible to share generated electricity between households and companies. In this way, it is possible for urban areas in less dense populated areas, to become nearly energy independent from larger networks. Today, many communities in the Netherlands have this ambition. Often initiatives are taken by new collaborations between citizens and companies. The present situation in the Netherlands is that over 200 new local energy service companies (ESCO's) are established with the purpose to generate and self consume renewable energy locally [18].

In short, the energy transition is quite fundamental and involves the following transition areas:

(1) transition of energy source: move away from fossil fuels towards renewable sources,
(2) transition of energy consumption: other technology which use other forms of energy, i.e. electrification of heating demand,
(3) social transition: increased citizen awareness and involvement, e.g. development of local ESCO's,
(4) agricultural transition: balancing land use for food and biomass production,
(5) tax transition: shifting energy taxes in favor of renewable energy consumption and investments,
(6) macro economic trade transition: changing dependence of industrial activities and jobs from fossil fuel trade towards renewable energy trade.

4. Energy transition policies

For the Dutch building sector, the following policies have been developed to lower energy demand and diminish the use of carbon based fuels within the coming years:

(1) Introduce subsequent lower EPC-levels (EPC = Energy Performance Coefficient) for new buildings. From 1995 the regulated EPC-level of new buildings is decreased in steps of 0.2 up to the level 0 (energy neutrality) to be effective from 2020. Due to this legislation, heat loss from buildings is decreased by better insulation levels, heat recovery ventilation and by avoiding outside air infiltration. Besides these measures, the EPC is lowered by installing RES as part of the house, such as solar PV and solar thermal installations and heat pumps. The legislation also includes a method of compensation for CO_2 decreasing measures taken on a district level, e.g. connecting a house to a district heating system which generates the heat from renewable sources.
(2) Execute large scale energy renovations (stroomversnelling, energiesprong) schemes for existing houses. A large part of the Dutch housing stock (approx. 4 million of in total 7.7 million houses) is relatively poor insulated and older than 40 years. In the Dutch energy labeling system, these houses are labeled F or G, while new houses are labeled A, A+ or A++. By renovations these houses are to be upgraded with higher insulation levels and energy saving installations like heat recovery ventilation, low temperature underfloor heating and heat pumps.
(3) Introduce subsidy schemes for heat from renewable sources, i.e. heat pumps and district heating projects utilizing waste heat streams and renewable sources. For all renewable heat sources, it is an advantage if the heat can be supplied with low temperatures (e.g. 30–60 °C), as this increases efficiency of solar heating and heat pumps. This is only possible if existing buildings are renovated such that low temperature heating is made possible.
(4) Stimulate investments in home solar PV, e.g. by offering feed-in tariffs which are equivalent to purchasing energy tariffs. Recent years have shown a sharp cost decrease of solar PV due to achieved economies of scale through industrial innovations.
(5) Increase self consumption, e.g. by changing energy tax policies which make it more attractive to store energy.
(6) Increase public awareness for Renewable Energy Systems, e.g. by creating a legal level playing field for local energy corporations. The local energy corporations provide services such as buying and selling electricity, organization of local energy saving competitions and increasing local electricity production by RES such as joint investments in solar PV or wind turbines.
(7) Increase electrification of domestic energy consumption as a replacement for using fossil fuels: electric cooking, dishwashing, hot water boiler, heat pumps and electric vehicles. However, increased electrification may cause problems for existing electricity grids. Besides grid strengthening, solutions include local RES, storage and demand side management or smart grids, refer to [19,16]. For this, the Dutch government financed various pilot projects within the urban energy subsidy program.

5. Renewable energy system aspects

Wind turbines, solar PV, solar thermal, biomass (solid/liquid/-gas) conversion and geothermal energy are the most suitable options for countries with shallow coasts and a relatively flat landscape like the Netherlands. In order to replace fossil fuels entirely, complex energy systems involving many of the renewable energy options available and energy storage are needed in a coherent mixture which is able to match the entire energy demand for a large urban area or country. Fig. 2 shows for the most suitable options mentioned, how the source energy is converted into useful energy, i.e. electricity, high temperature and low temperature heat. It also gives a first impression of the coherence between options. For each conversion, the applicable conversion efficiency range is indicated and discussed in the following.

Wind turbines convert kinetic energy present in the wind into electricity. The theoretic maximum efficiency is given by Betz's law and is approx. 59%. Friction and conversion losses from axle movement to electric power result in a somewhat lower total efficiency.

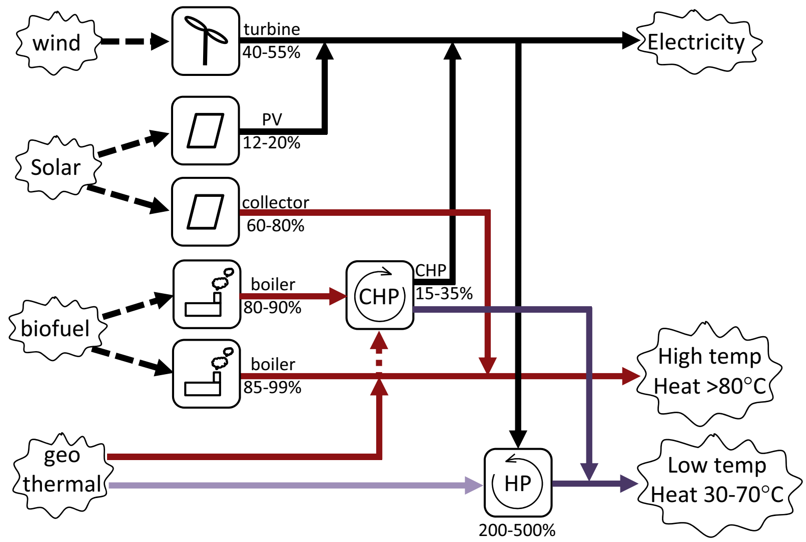

Fig. 2. Conversion of renewable energy sources to useful energy.

Solar PV (Photo Voltaic cells) convert solar electromagnetic radiation into electricity which is transformed by an inverter to compliant currents and voltages. Best available cell efficiencies now range between 15 and 25%, while the best possible cells used for outer space applications now reach 44%.

A solar collector converts solar radiation into heat. There are many collector types, vacuum tubes are the best possible technology as heat loss to ambient air is avoided as much as possible. Efficiencies range between 50 and 90% depending on the absorber temperature.

For biomass conversion the picture first shows conversion of the chemical energy of biomass into high temperature heat which is converted into electricity and low temperature heat by a thermodynamic Combined Heat and Power (CHP) cycle. The maximum efficiency is defined by Carnot's efficiency, i.e. approx. 79%. In practice, conversion and friction losses result in total efficiencies between 15% for small installations to 40% for large installations. Second, the picture shows conversion of biomass into high temperature heat which is used for industrial or domestic thermal demand.

Geothermal energy. The temperature in the earth's crust increases approx. 30 °C per kilometer. Geothermal energy from approx. 2.5–4 km can be used for high temperature thermal demand or to produce electricity with a thermodynamic cycle. Shallow geothermal energy from approx. 0–100 m with an average temperature of 12 °C is used as source heat for heat pumps which transform the energy to a higher temperature. Heat pumps consume electrical energy for this process. Electrical heat pumps are regarded as the most important option for the transition towards integration of renewable energy for the heating demand within the built environment [20,21].

5.1. Matching renewable energy production and demand

Like the amount of energy demand, the amount of renewable energy generation fluctuates in time between moments of minor generation and moments of peak generation. As an example, energy from solar PV is produced during daytime hours while domestic demand is mostly early in the morning and in the evening hours. Over the seasons, solar and wind energy are to some extend complementary on the Northern hemisphere, i.e. there is more solar energy production during summer months than during winter months, and more on clear days than on cloudy days, while there is more wind on cloudy days and during the winter months than during the summer months [22]. But this complementary property of solar and wind energy is far from perfect, hence regions with a high penetration level of solar and/or wind energy in the total energy mix, may face large scale unbalance problems within the electricity grid if no further adjustments are made to the energy system.

Biomass conversion can be used for combined heating and power purposes. The biomass conversion process requires a more constant operation for longer periods of time, which may be difficult to match with a fluctuating demand. Conversion processes of solid biomass are the least flexible due to time consuming starting up and cooling down times, e.g. a biomass CHP or boiler. Combustion of a bio-liquid or bio-gas can be as flexible as for instance the same process with natural gas, but inflexibility may exist on the supply side of the energy source. In the Netherlands, bio-gas is produced by fermentation of sludge from waste water treatment processes or by fermentation of manure from cows and pigs, mostly combined with agricultural, energy rich waste products [23]. It is not possible to stop fermentation processes and therefore, the produced bio-gas has to be either combusted, stored or flared if there is less demand for a longer time. The generated thermal energy from bio-gas is relatively easy to store, also for longer periods of time using methods of seasonal thermal storage, refer to [24] for such methods. Other options include purification of bio-gas into methane which makes it possible to inject it into the gas grid, or gas storage either by pressurization or cooling it to liquid form. The latter options are an attractive way to integrate bio-gas into existing gas infrastructures, but the technology also increases costs considerably, refer to [25,26]. Although recent years have shown an increase of bio-gas production in the Netherlands, the Dutch agricultural sector is looking for more competitive alternatives for manure and agricultural waste processing like refinery in which nutrients and water are recycled and energy in gas or liquid forms is produced, refer to [27,28]. The possibility to include an algae production step for food, chemical and energy purposes is also investigated, refer to [29,30].

Last is the application of energy from geothermal sources. In the Netherlands this is mostly limited to shallow geothermal sources in a combination with heat pumps to supply thermal energy demands. In a renewable energy system, the heat pumps are powered by renewable electrical energy, for which solar and wind energy may be used or biomass conversion with a CHP.

These examples demonstrate that renewable energy options are to some extend complementary and when combined are able to fully replace fossil fuels and to enhance stability of the energy production. However, even when options are combined, further adjustments to the energy system are necessary to solve unbalances between generation and demand. Adjustments presently available or in stages of development are:

- a large, interconnected grid with strengthened local power transmission lines. Such a grid is able to carry electric power to and from other areas and therefore serves as an artificial buffer which is able to level out the mismatch between energy generation and demand. This solution requires strengthening of grid cables and switching circuits and replacement of existing transformers with bi-directional transformers [19].
- implementation of local or regional energy storage. This can level out the mismatch on a local scale by storing energy in times of surplus generation and consuming energy from the storage in times of insufficient generation. In this way, the larger grid is relieved from generation and consumption peaks. An issue is the significant cost of storage assets.
- demand-side management, i.e. smart control of flexible, energy consuming devices. This has the same goal as the previous solution. Smart control however enables direct consumption of the generated energy and therefore limits the required storage capacity. This technique is only possible for so called flexible devices, i.e. a device whose operation may be shifted in time without significant consequences. Examples are: heat pumps, electric vehicle battery chargers and washing machines [31].

Demand-side management and storage are complementary and to some extend also contribute to lower costs for grid strengthening measures. Grid operators often participate together with prosumers (renewable energy consumers and producers) in smart grid development projects in which all solutions have a logic role in order to reach optimal costs for the operation of the energy system [18].

5.2. Energy conversion and storage

Surplus renewable energy can be converted into other forms of energy which can be stored or distributed. One conversion option is power to fuel, i.e. hydrogen gas, synthetic methane gas or bio-liquids. These conversion techniques are at present financially less attractive, mainly due to complex technology which has not yet reached an attractive economy of scale. Besides that, the round trip efficiency is quite low, i.e. 40% for final electricity and 60% if the heat generated by the final conversion is also used.

The most important area for this paper is power to heat. This option is usually combined with thermal storage on the scale of a single building or a district. Power to heat is possible in two ways, by electric resistance heating or a heat pump. The advantage of a heat pump is a much higher efficiency, but as shown in Fig. 2, a low temperature heat source is required. A variety of power to heat is power to cooling. The evaporator of a heat pump is then used to convert electricity into cooling energy.

A domestic power to heat system includes a heat pump, a low temperature source, e.g. ambient air, a radiant floor heating system and a hot water storage for supply of the domestic hot water demand. A district power to heat system is similar but on a larger scale. Experience with district heating in the Netherlands is traditionally related to large scale steam power plants (e.g. Amsterdam and Almere city heating network and many smaller city projects). More recently, decentral projects for new urban districts apply either biomass (wood) thermal conversion in boilers (e.g. muziekwijk Zwolle, [32]) or bio-gas co-generation (e.g. Apeldoorn [33], Zeewolde, [34] and Leeuwarden [35]). An overview of Dutch district heating projects and profitability investigation is presented in [36].

For thermal storage, available techniques are:

- sensible storage, i.e. increasing the temperature of a medium, for which mostly water is used,
- latent storage, i.e. changing the physical phase of a material, i.e. solid to liquid, liquid to gas,
- thermochemical storage, i.e. changing the chemical composition of a material.

For electrical energy storage, a variety of techniques are available. Pumped hydro storage is widely applied in the mountains of Central Europe and Norway. Compressed air energy storage (CAES) is an alternative. Pumps are used to transport the water to a higher altitude, a compressor is used to increase the pressure of the air. In both cases, a turbine and generator are used to generate electric power. The total efficiency of both options is approx. 80%. Due to the installations and space required, pumped hydro and CAES are applicable only on a larger scale. Chemical storage in batteries has the advantage of portability and availability for small scale applications. Within a smart grid, many stationary domestic batteries and batteries in electric vehicles together constitute a very large battery. The total efficiency of existing battery technologies is approx. 70–85%. New technologies such as redox-flow batteries and sea-salt batteries are moving out of the research phase, promising larger scale application of batteries and solving environmental issues [37,38].

5.3. Increasing energy efficiency

As introduced in Section 5.1, increasing energy efficiency by reducing energy consumption and temperature levels of heating demands is an important aspect of complete renewable energy systems. For this, a guiding principle exists and is called the trias energetica, which is basically a three step implementation method as shown in Fig. 3.

The left side of Fig. 3 shows steps dedicated to energy savings and integration of renewable energy. The right side is dedicated to another thermodynamic quantity called exergy, i.e. the amount of useful work (or electrical energy) that is potentially available from a system or process which is operating at a certain elevated temperature level. The higher this temperature level, the more work there is potentially available before the system reaches an equilibrium state with a surrounding, lower temperature.

The first step involves reduction of energy consumption (energy-side) and reduction of temperature differences (exergy-side). We illustrate this with the following examples for the built environment.

(1) increasing building insulation reduces heat loss but also reduces the temperature difference between interior wall surfaces and the interior air,
(2) heat recovery ventilation reduces heat loss but also decreases the temperature difference between inlet and outlet air flows to and from the interior,

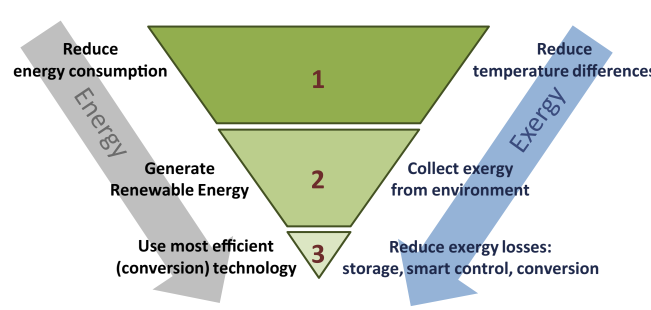

Fig. 3. Trias energetica principle.

(3) reducing the surface temperature of a radiator has two effects: first, some reduction of heat loss of the entire building or district heating system. Second, when renewable heat is used e.g. a heat pump or solar thermal collector, a significant increase of efficiency is achieved.

The last example illustrates the importance of exergy for the second step of the Trias energetica: implementation of renewable energy. Besides that, implementation of the first step contributes in general positively to the energy transition in the following ways:

- on a local level, less (land) space is required for renewable energy generation when there is less local energy demand,
- lower investments are required into energy generation and storage assets,
- less CO_2 is emitted during the entire energy transition period if significant reduction of energy consumption is achieved at a relatively early stage of the energy transition period.

The second step involves the generation of energy from renewable resources (energy-side) and the collection of exergy from the environment (exergy-side). The latter can be achieved directly by wind turbines and solar PV or by thermal conversion (co-generation) of a bio-based fuel. A heat pump is a special case: exergy (electrical energy) is used to generate heat at a useful temperature from a low temperature source. This results in less output exergy than was used as input. However, compared to a gas boiler which converts high exergy (chemical energy of a fuel) into low exergy, the exergy performance of a heat pump is better. From an exergy point of view, collecting heat with a useful temperature from waste-heat sources or from a geothermal source is preferable.

The third step involves using the most efficient conversion technology (energy-side) and the reduction of exergy losses from a system (exergy-side). Some examples to illustrate the exergy-side: for an electric vehicle, most of the electrical input (exergy) is used to drive the vehicle, hence the exergy loss is very small. Contrary, a fuel driven car wastes a large part of the exergy (fuel) input. As another example, if we assume a district as a closed system then electrical energy (exergy) generated within the district should also be consumed by the district. Exergy exported to the surrounding area is in this case regarded as exergy loss for the district. To avoid this as much as possible, energy storage and smart control may be used within the district to increase self-consumption of the generated exergy.

To illustrate the application of the Trias energetica, we consider house heating systems. In [39], optimal fuel saving options are investigated for Dutch households using the Trias energetica approach. Application of the first step leads to relatively high levels of insulation, heat recovery ventilation, good air tightness of the envelope to avoid air infiltration and measures to reduce overheating and cooling demand during the summer months. During the second step, the optimal renewable heating system for an average house is determined, i.e. a heat pump with air source and thermal storage for domestic hot water. To generate the required electricity of the households, rooftop solar PV systems are nowadays an affordable option. For the third step, it appears to be financially more attractive to co-install a highly-efficient, condensing natural gas boiler which only produces heat during moments of peak heat demand. Because of the low cost of boilers, the entire installation is smaller, and the operation cheaper and more reliable than a larger heat pump installation without a boiler.

5.4. Smart energy control and demand-side management

It is widely recognized that enabling technologies such as electrical energy storage, controllable electric devices and smart grids are important ingredients to match the available renewable energy with the demand [40]. As explained in Section 5.1, there is often a mismatch in time between renewable energy production and demand. However, part of the electric demand is to some extend flexible. As an example, heat pumps used for space heating or washing machines. These can be controlled to consume electricity at times of production peaks. In [19] various cases of smart control are investigated with the purpose to avoid costly grid strengthening measures.

A specific solution and relatively new research area is a so called smart controlled hybrid micro-grid, i.e. an integrated low voltage power and heating grid on the scale of a single building up to the scale of a district. A hybrid micro-grid matches supply and demand of electricity and heat locally, decreasing peak loads on the larger electric distribution grid.

At the University of Twente, a smart grid control methodology called Triana is developed. Triana algorithms contain three steps or modules for: (1) prediction of energy demand and generation, (2) planning of flexible devices and converters and (3) real-time control of flexible devices and converters. The basic control principle, backgrounds and algorithms of Triana are explained in [41,42,31,43].

6. Integration of renewable energy in the built environment

Urban areas in the Netherlands contain a mixture of older and newer houses, offices and public buildings. As discussed in Section 2 natural gas boilers are today the dominant heating system for these buildings. From various examples of recently built, new districts, two approaches towards integrating renewable energy options for the thermal energy demand of buildings are distinguished:

(1) Individual approach. As a power to heat concept, the individual natural gas boiler for each building is replaced by a heat pump which electrifies the heating demand. The electric demand is supplied by renewable energy from solar PV and an increasing number of regional wind turbines. For balancing energy production and demand, electric and thermal storage are part of the building energy system. This approach is adopted in some cases of new building projects [44], and renovation projects [45].

(2) Collective approach. In a collective heating system, buildings are connected to a district heating system. Due to the scale of district heating stations, a wider choice of renewable sources is possible like: waste, biomass or bio-fuel conversion, solar thermal plants, power to heat, shallow and deep geothermal energy, and seasonal thermal storage. Presently, waste and biomass conversion is mainly used, for an overview of installations see [46].

Recently, district heating projects and so called all-electric buildings receive much attention. The collective approach of district heating has advantages for the integration of renewable energy, especially for existing buildings in densely populated areas [47]. However, new low-energy houses require less energy for space heating which makes individual heating systems in many cases a more attractive option, although integration of renewable energy and a suitable thermal source for heat pumps are important drivers to consider low temperature district heating in this case [8].

A choice for one of these approaches is fundamental while it determines which options for renewable energy can be used to cover the heating demand. The individual approach relies on the capacity of electricity grids. In the ideal case of a complete renewable energy system, electricity within this approach is to be generated by wind turbines and solar PV, as the other options shown in Fig. 2 are presently only applicable on a large, centralized scale and they also generate heat which cannot be distributed when the individual approach is followed. As the electric power grid also supplies the demand for appliance usage and electric vehicles in the future, the capacity of the electricity grid needs to be increased significantly. The required capacity of the electric grids is however diminished if buildings have a low thermal demand and low supply temperatures, while this reduces the electricity demand for heating purposes. Hence, in the individual approach, a strong focus on low building thermal demands has a positive effect on the energy costs of residents and network costs for grid owners. This coheres with the step-wise approach of the Trias energetica shown in Fig. 3.

At this stage of technological development, the collective approach enables integration of renewable energy options on larger, centralized scales and is possibly more cost-effective than the individual approach. The collective approach is less dependable on the capacity of the electricity grid. However, an additional heat grid is added to the energy system with its own constraints for a positive business case. For the profitability of the heat grid it is less obvious to invest in lower building heating demands as this results in lower revenues from heat sales. However, district heating systems are more efficient when approach and return temperatures are lower [48]. Second, low approach temperatures enable more efficient heat generation by heat pumps, solar thermal energy, geothermal energy and thermal energy from waste/bio-mass/bio-fuel CHP [49]. Olsen et al. [48] argues that low building heating demands are also positive for the business case of district heating systems using renewable energy. These aspects are also recognized internationally and a name is given to this new direction, i.e. 4th generation district heating [50]. In this concept, supply and return temperatures are as low as possible, to decrease system thermal losses and to enable integration of heat from renewable sources. Supply temperatures can be reduced further if heat pumps are used to increase the temperature at the household level, i.e. using a collective low temperature thermal source. In [51], a case for including low temperature geothermal heat into an existing district heating system is investigated and feasibility of using heat pumps for this purpose is demonstrated.

As future renewable energy systems are powered predominantly by renewable electricity from solar-PV, wind turbines, geothermal energy and bio-fuel, district heating systems can provide large amounts of cost effective flexibility to balance energy generation and demand [47,8], predominantly by "power to heat" technologies and large scale thermal storage. Dutch policies [52,8] however, are more aimed at reducing the heat loss of buildings and increasing the share of renewable energy within the power grid than to stimulate district heating. Therefore, the positive role that (district) heating systems can play in the energy transition is presently overlooked by national and regional policy makers in the Netherlands. Therefore, it is interesting to investigate cases which demonstrate the possibilities that arise when the (district) heating system plays a central role within an integrated, renewable energy system, in order to contribute to a better understanding of these possibilities.

7. Conclusions and outlook

As discussed in Section 2, the present energy supply system in the Netherlands depends largely on the consumption of fossil fuels, which through CO_2 emissions has a large contribution to the global warming problem. However, Section 3 argues that there is an increasing sense of urgency for a transition towards a completely renewable energy supply system and that the transition involves much more than just the technology of energy systems. Past and recent examples of policies and measures to increase public awareness of the transition and investments into reducing energy consumption and renewable energy generation are discussed in Section 4. Section 5 introduces the most suitable options for renewable energy generation and concludes that for complete renewable energy systems, only a combination of options is capable to match the fluctuations between energy demand and supply. This however results in rather complex energy systems with many variables to be taken into account and to be optimized. Besides energy generation, such energy systems require various forms of energy storage and smart control.

Considering the built environment, Section 6 concludes that there are two approaches possible to integrate renewable energy for the thermal energy demand of buildings: an individual and a collective approach. It is found that both approaches have common requirements for reducing the heat demand and lowering temperatures of heating systems while this enables integration of renewable energy options much more efficiently and economically. It is also addressed that the choice for an approach should be made with great care and requires a holistic analysis and vision on the future energy system of an urban region.

Historically, the Netherlands has shown a relatively slow pace to integrate renewable energy. However, recent progress includes large scale offshore wind turbine parks and a steady growth of investments in solar PV, Near Zero Energy Buildings and bio-energy. In recent years, prices for renewable electricity generation by solar PV and wind turbines have dropped towards or even below price levels of electricity produced from fossil resources. This trend, combined with low interest rates and balanced energy policies will determine the pace of the energy transition in the near future. For the thermal energy demand, national policies are formulated to gradually out-phase the use of natural gas for building heating purposes and to have this process completed in the year 2060. This leads to a steady increase of investments into heat pumps for building heating and district heating utilizing waste heat and renewable sources. The role of smart ICT to maintain power balance is also acknowledged by Dutch research institutes and companies. Hence, there is reason to be optimistic about the upcoming pace of the energy transition in the Netherlands.

Acknowledgment

The authors would like to thank the Dutch national program TKI-Switch2SmartGrids for supporting the project Meppelenergy, the STW organization for supporting the project I-Care 11854 and the Euregio and Interreg organization for supporting the project WIEfm.

References

[1] Pachauri R, Meyer L. Climate change 2014: Synthesis report. contribution of working groups i, ii and iii to the fifth assessment report of the intergovernmental panel on climate change. IPCC, Geneva, Switzerland. Tech rep; 2014.
[2] E.E.R.E. Council. Renewable energy technology roadmap; 2008. <http://www.erec.org> (visited May 30, 2015).
[3] ECN. Nationale energie verkenning. ECN-Dutch energy research centre; 2016. <http://www.pbl.nl/ sites/default/files/cms/publicaties/pbl-2016-nationale-energieverkenning-2016.PDF>.
[4] C.D. bureau of statistics. Compendium voor de leefomgeving; 2016. <http://www.clo.nl/indicatoren/nl0053-energiebalans-nederland-tabel>.
[5] C.D. bureau of Statistics. Statistical energy balance netherlands (in dutch: Statline energiebalans kerncijfers). <http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=37281&D1=a&D2=0-1,4,7-12&D3=53,78,128,143,148,l&HDR=G1&STB=T,G2&VW=T>.
[6] UNFCCC. Summary of the kyoto protocol; 2016. <http://bigpicture.unfccc.int/#content-the-paris-agreemen>.

[7] Kamp H. Kamerbrief warmtevisie. <https://www.rijksoverheid.nl/onderwerpen/energiebeleid/documenten/kamerstukken/2015/04/02/kamerbrief-warmtevisie>.
[8] Energierapport: transitie naar duurzaam; 2016. <https://www.rijksoverheid.nl/documenten/rapporten/2016/01/18/energierapport-transitie-naar-duurzaam>.
[9] S.D.S.E.A. Board. Energy agreement for sustainable growth; 2013. <http://www.energieakkoordser.nl/doen/engels.aspx>.
[10] S.D.S.E.A. Board. Energy agreement for sustainable growth. <https://www.ser.nl//media/files/internet/talen/engels/2013/energy-agreement-sustainable-growth-summary.ashx>.
[11] R.N.E. Agency. National policy wind energy (dutch: Nationaal beleid windenergie); 2016. <http://www.rvo.nl/sites/default/files/Nationaalbeleidwindenergie2013-07-15.pdf>.
[12] D. ministry of economic affairs. Nationaal actieplan voor energie uit hernieuwbare bronnen; 2009. <https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2010/06/23/rapport-nationaal-actieplan-voor-energie-uit-hernieuwbare-bronnen/10093332-1-bijlage.pdf>.
[13] Verbong G, Geels F. The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the dutch electricity system (1960–2004). Energy Policy 2007;35(2):1025–37.
[14] Ropenus S, Klinge Jacobsen H. A snapshot of the danish energy transition: objectives, markets, grid, support schemes and acceptance. Study. Agora Energiewende; 2015.
[15] Hu X, Zou Y, Yang Y. Greener plug-in hybrid electric vehicles incorporating renewable energy and rapid system optimization. Energy 2016;111:971–80. <http://www.sciencedirect.com/science/article/pii/S0360544216308118>.
[16] Pudjianto D, Djapic P, Aunedi M, Gan CK, Strbac G, Huang S, et al. Smart control for minimizing distribution network reinforcement cost due to electrification. Energy Policy 2013;52:76–84. Special section: transition pathways to a low carbon economy <http://www.sciencedirect.com/science/article/pii/S0301421512004338>.
[17] I.I.R.E. Agency. Renewable energy innovation policy: Success criteria and strategies; 2013. <https://www.irena.org/DocumentDownloads/Publications/Renewable_Energy_Innovation_Policy.pdf>.
[18] G. here (Dutch: Hier opgewekt). Local energy monitor (dutch: lokale energie monitor) 2015; 2015. <https://www.hieropgewekt.nl/sites/default/files/u20232/lokale_energie_monitor_2015_-_uitgave_januari_2016.pdf>.
[19] Nykamp S. Integrating renewables in distribution grids - storage, regulation and the interaction of different stakeholders in future grids. PhD dissertation, University of Twente; 2013.
[20] Janssen-Visschers I, Lee Gvd. Vision on electricity sector production and tax development (in dutch: Visie op productie- en belastingontwikkelingen in de elektriciteitssector). Tennet, Tech Rep; 2013. <http://www.tennet.eu/nl/fileadmin/downloads/About_Tennet/Publications/Technical_Publications/Visie_Ontwikkelingen_Netbeheerdersoverleg.pdf>.
[21] Scheepers M, Seebregts A, Hanschke C, Nieuwenhout F. Influence of innovative technology on the future electricity infrastructure (in dutch: Invloed van innovatieve technologie op de toekomstige elektriciteitsinfrastructuur). ECN, Tech rep; 2007.
[22] Burger B. Electricity production from solar and wind in germany in 2014; 2014. <https://www.ise.fraunhofer.de/en/downloads-englisch/pdf-files-englisch/data-nivc-/electricity-production-from-solar-and-wind-in-germany-2014.pdf>.
[23] Holm-Nielsen J, Seadi TA, Oleskowicz-Popiel P. The future of anaerobic digestion and biogas utilization. Bioresource Technol 2009;100(22):5478–84. {OECD} Workshop: Livestock Waste Treatment Systems of the Future: A Challenge to Environmental Quality, Food Safety, and Sustainability <http://www.sciencedirect.com/science/article/pii/S0960852408011012>.
[24] Xu J, Wang R, Li Y. A review of available technologies for seasonal thermal energy storage; 2014. p. 610–38.
[25] Ryckebosch E, Drouillon M, Vervaeren H. Techniques for transformation of biogas to biomethane. Biomass Bioenergy 2011;35(5):1633–45. , <http://www.sciencedirect.com/science/article/pii/S0961953411001085>.
[26] Wellinger A, Murphy JD, Baxter D. The biogas handbook: science, production and applications. Elsevier; 2013.
[27] Gebrezgabher SA, Meuwissen MP, Prins BA, Lansink AGO. Economic analysis of anaerobic digestion-a case of green power biogas plant in the Netherlands. {NJAS} - Wageningen J Life Sci 2010;57(2):109–15, <http://www.sciencedirect.com/science/article/pii/S1573521409000049>.
[28] Van Dael M, Márquez N, Reumerman P, Pelkmans L, Kuppens T, Van Passel S. Development and techno-economic evaluation of a biorefinery based on biomass (waste) streams–case study in the netherlands. Biofuel Bioprod Bioref 2014;8(5):635–44.
[29] Yan C, Zhu L, Wang Y. Photosynthetic {CO_2} uptake by microalgae for biogas upgrading and simultaneously biogas slurry decontamination by using of microalgae photobioreactor under various light wavelengths, light intensities, and photoperiods. Appl Energy 2016;178:9–18. , <http://www.sciencedirect.com/science/article/pii/S0306261916307875>.
[30] Zhu L. Biorefinery as a promising approach to promote microalgae industry: an innovative framework. Renew Sust Energy Rev 2015;41:1376–84. , <http://www.sciencedirect.com/science/article/pii/S1364032114008132>.
[31] Molderink A. On the tree step methodology for smart grids. PhD dissertation, University of Twente; 2011.
[32] Gehrels M. Warmteopwekking in de muziekwijk; 2014. <http://www.biowkk.eu/wp-content/uploads/2014/12/1418830954Cogas-dhr.-Gehrels-141210_presentatie-Muziekwijk.pdf>.
[33] EN-Natuurlijk. Factsheet apeldoorn-zuidbroek; 2016. <http://www.ennatuurlijk.nl/downloads/401/LR_Sheet_Zuidbroek_Ennatuurlijk_feb2016.pdf>.
[34] EN-Natuurlijk. Factsheet polderwijk zeewolde; 2016. <http://www.ennatuurlijk.nl/downloads/402/LR_Sheet_Zeewolde_Ennatuurlijk_feb2016.pdf>.
[35] R.N.E. Agency. Voorbeeldprojecten restwarmte; 2013. <http://www.rvo.nl/sites/default/files/bijlagen/Voorbeeldprojecten%20Restwarmte.pdf>.
[36] Schepers B, Valkengoed MV. Warmtenetten in nederland - overzicht van grootschalige en kleinschalige warmtenetten in nederland. CE-Delft. Tech rep 09.3031.45; October 2009. <http://www.ce.nl/publicatie/warmtenetten_in_nederland/976>.
[37] Wang W, Luo Q, Li B, Wei X, Li L, Yang Z. Recent progress in redox flow battery research and development 2013; 23(8): 970–86.
[38] Palomares V, Serras P, Villaluenga I, Hueso KB, Carretero-González J, Rojo T. Na-ion batteries, recent advances and present challenges to become low cost energy storage systems. Energy Environ Sci 2012;5(3):5884–901.
[39] Gilijamse W. Fuel saving options in heat supply systems; 1993.
[40] U. department of energy. The smart grid: an introduction. <http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_SG_Book_Single_Pages(1).pdf>.
[41] Bakker V. Triana: a control strategy for smart grids: Forecasting, planning & real-time control. PhD dissertation, University of Twente; 2011.
[42] Bosman M. Planning in smart grids. PhD dissertation, University of Twente; 2012.
[43] Toersche HA. Effective and efficient coordination of flexibility in smart grids. PhD dissertation, University of Twente.
[44] EN-Natuurlijk. Factsheet paleiskwartier den bosch; 2016. <http://www.ennatuurlijk.nl/downloads/406/LR_Sheet_Paleiskwartier_Ennatuurlijk_feb2016.pdf>.
[45] R.N.E. Agency. Passief-renovatie kroeven roosendaal. <http://www.rvo.nl/initiatieven/energiezuiniggebouwd/passief-renovatie-kroeven>.
[46] van Klink L. Toekomstscenario's voor afvalverbranding in nederland 2015-2022; 2015. [Online]. Available: <file:///D:/Profiles/LeeuwenRP/Downloads/toekomstscenario-s-voor-afvalverbranding-in-nederland-2015-2022.pdf>.
[47] Lund H, Möller B, Mathiesen BV, Dyrelund A. The role of district heating in future renewable energy systems. Energy 2010;35(3):1381–90.
[48] Olsen P, Lambertsen H, Hummelshøj R, Bøhm B, Christiansen C, Svendsen S, et al. A new low-temperature district heating system for low-energy buildings. In: Proceedings of the 11th international symposium on district heating and cooling, Iceland; 2008.
[49] Li H, Svendsen S. Energy and exergy analysis of low temperature district heating network. Energy 2012;45(1):237–46. The 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy, {ECOS} 2011 <http://www.sciencedirect.com/science/article/pii/S0360544212002599>.
[50] Lund H, Werner S, Wiltshire R, Svendsen S, Thorsen JE, Hvelplund F, et al. 4th generation district heating (4gdh): integrating smart thermal grids into future sustainable energy systems. Energy 2014;68:1–11. , <http://www.sciencedirect.com/science/article/pii/S0360544214002369>.
[51] Østergaard PA, Lund H. A renewable energy system in frederikshavn using low-temperature geothermal energy for district heating. Appl Energy 2011;88(2):479–87. The 5th Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems, held in Dubrovnik September/October 2009 <http://www.sciencedirect.com/science/article/pii/S0306261910000826>.
[52] Action plan sustainable energy. Netbeheer Nederland, techreport; 2013. <http://www.netbeheernederland.nl/publicaties/position-papers-factsheets/>.