Guide report 2:

Technology catalogue

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Peter Bode Nielsen, Morten Hørmann, Jakob Nymann Rud and Frederik Møller Lauge

COWI A/S

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Contents

Introduction

This report presents energy technologies and systems relevant for the supply of renewable electricity and heat production in sparsely populated areas. The first part of the report has some general descriptions of technologies and systems. The last part of the report contains technology sheets for chosen technologies. The technology sheets are also present in the Excel tool. In this tool the key figures from the technology sheets are used.

1 Technology

In this section, we briefly describe the main technologies that we employ in this guide. The main theme of the guide is how electrification can support a transition towards renewable energy in heating as well as power generation. As a result, most of the technologies we present use electricity as energy source or produce electricity. More detailed descriptions of the technologies can be found in the technology data sheets from page 15.

The technologies we describe are split into three main categories. First we present technologies for heating. Second we present technologies for producing electricity. Last we present technologies for storing and smart management of heat and electricity.

1.1 Heating

Electrification of heating is all about creating synergies with the electricity generation by providing flexible demand and opportunities for storage. In Table 1 we list the main advantages and disadvantages of the technologies that we describe.

Table 1 Pros and cons of heating technologies

Technology	Pros	Cons
Heat pump	High efficiency	High cost
Electric boiler	Low cost	Low efficiency
Biomass boiler	Local RES fuel	No synergy with electricity generation

1.1.1 Heat pumps

Heat pumps use electricity to extract heat from the surrounding environment. Since a large proportion of the heat generated comes from the surrounding environment and not the electricity, the efficiency in terms of energy produced per energy used is very high. The COP (Coefficient Of Performance) varies in the range of 300% to 400% of the electricity used depending on the quality and size of the heat pump and the local climate.

Heat pumps are a very efficient way of converting electricity into heat. However, heat pumps are also quite expensive. The economic viability of heat pumps depends on operating them at close to maximum capacity as often as possible.

1.1.2 Electric boilers

Electric boilers are the simplest way of converting electricity to heat. The efficiency is usually close to 100%, which is still very low, compared to a heat pump. On the plus side is the very low cost of electric boilers.

Electric boilers are ideal as a supplement to heat pumps for boosting max capacity in peak load hours.

1.1.3 Biomass heat units

Biomass boilers (and other biomass combustion units) are included in the guide as an alternative to electrification. In some cases, electrification may not be an option, or biomass is readily available at low or no cost. Biomass boilers are typically cheaper than heat pumps.

Using biomass as a heat source instead of electrification may make it more difficult to balance the electric production from intermittent electricity sources like solar power and wind. On the other hand, the availability of biomass may also lead to a consideration of biomass for electricity production.

1.2 Electricity

In this guide, we have omitted most technologies based on biomass, as we foresee possible issues with procurement and documenting the CO_2 neutrality of biomass. Whether biomass is CO_2 neutral or not is still the subject of heated debate – a debate that we will not go into in this guide.

Table 2 Pros and cons of power generation technology

Technology	Pros	Cons
Wind turbines	Fuel is free	No control of when the wind blows
Photovoltaics	Fuel is free	No control of when the sun shines
Hydro power	Flexible production	Requires differences in altitude
Bio diesel generator	Flexible production	CO_2 emissions are debatable Expensive fuel

1.2.1 Wind turbines

Wind turbines come in a wide range of designs related to either the amount of electricity they can produce and the wind speeds they can produce at. Wind turbines are typically designed for a specific range of wind speeds at which they produce at their optimum. The less extreme wind conditions are, the easier it will be to find a suitable wind turbine.

The electricity produced from a wind turbine will be very volatile and will typically need to be balanced by production units or storage facilities under the control of the balancing responsible.

1.2.2 Solar power (photovoltaics)

Much like wind, the electricity produced from solar panels is very volatile. In order to deliver a stable and secure supply of electricity, solar power must be balanced by other sources.

Solar power will often be less than ideal in combination with electrification of heat, as the temperature is correlated with sunlight. At higher temperatures, the demand for electricity from heating will be lower, hence when solar panels are producing at their maximum capacity, demand for electricity will be at its lowest.

1.2.3 Hydro power

Unlike wind and solar power, hydro power is a flexible renewable energy source. Hydro power can be based on the steady flow of water in a stream or river, or it can be combined with a reservoir to further increase the control of the production of power. Reservoirs can also be used for pumped storage, which will be covered in section 1.3.3.

Hydro power requires the availability of two main components: altitude differentials and large quantities of water. In addition use of water from the reservoir may come at an opportunity cost, as the same water cannot be used later.

1.2.4 Bio diesel generator

Using bio diesel in an existing diesel generator is a short cut to flexible electricity production on a renewable energy source. The bio diesel generator can fill the same role as hydropower by matching the balancing needs of the intermittent production from wind and solar power.

Biodiesel is a direct replacement for fossil diesel and emits the same amount of CO_2 when combusted. However, burning biofuels is technically considered CO_2 neutral, as the source of the CO_2 is expected to regenerate (and bind the CO_2 again) within a short (1-20 years) timespan. It is important to recognise, that the status of bio fuels as a renewable and "clean" energy source is debatable and may change. In the short run it is certainly a quick fix to the balancing needs of wind and solar power.

1.3 Storage

The ability to store heat and electricity is vital to small-scale systems. Storage provides the means to temporally separate consumption and production. This essentially means that energy can be produced whenever the conditions are beneficial and it can be consumed whenever the need arises. Without storage, energy would have to be produced when and only when it is needed.

Storage of heat serves two main purposes:

- To save up heat for periods when the maximum load is higher than the capacity of the heat sources

- To produce heat when the price of electricity is low and save it for periods with high prices

Storage of electricity also serves two main purposes:

- To store excess electricity produced when then sun is shining or the wind is blowing and use it when the sun is not shining or the wind is not blowing

- To even out spiky production from wind and solar power in the very short run

Heat and electricity storage are to some degree substitutes when heating is electrified. Excess electricity can be stored as heat as long as the consumption of heat is sufficiently high. Some electric heating components are sufficiently fast reacting to serve as balancing power when electric production from solar and wind power is spiky.

1.3.1 Hot water tank

The concept is simple – heat water up and store it in an insulated tank for later use. Designing hot water tanks for minimal heat loss and maximum heat recovery is complicated. Even though the design is complicated, hot water tanks are easily scaled to match the system and are relatively low cost.

Hot water tanks cannot convert heat back into electricity.

1.3.2 Batteries

Batteries store electricity as electricity and can be discharged with a loss of 15%-30%. The price of batteries has been steadily dropping for long time, but batteries are still quite expensive. The price of batteries is high enough that long term storage of electricity in batteries is still not realistic.

Batteries may have a role to play as short term (minutes) balancing for intermittent production. On the Faeroe Islands the local energy provider SEV is using batteries to balance a 15MW wind farm in Thorshavn with good results.

1.3.3 Pumped hydro storage

Energy can be stored in water by pumping water up into the reservoir of a hydro power facility. The increasingly efficient pumps available today coupled with basically free excess electricity from wind and solar power is what makes this solution attractive. Several conditions must be met before pumped hydro storage is viable:

- The availability of a reservoir upstream of the hydro power plant
- Excess capacity in the reservoir – if the reservoir is full or is expected to be filled by precipitation or glacial runoff then filling it with pumped water will only lead to overfilling
- Excess electricity production from sources like wind and solar power
- A source of water downstream – if the hydro power plant is not producing then the discharge in the river may be too low.

Pumped hydro storage could also be designed to work without connection to a fresh water source. Instead the facility could pump sea water up into a tank on a hilltop or some other elevated location.

1.4 Smart energy management

Smart energy management and smart grid are two sides of one coin. These terms refer to a wide range of technologies aimed at increasing the synergies between energy production and consumption. The common themes are communication, coordination and control. In the following we present three of the most common components to a smart grid and smart energy management. In chapter 3 we go into more detail with the system benefits that can be achieved using these technologies in combination with electrification of heating and 100% renewable electricity production.

1.4.1 Data hub

The ability to communicate and coordinate production and consumption relies heavily on a constant two way flow of information. Real time data on consumption patterns flow from consumer to producers, while real time data on energy prices flow from producers to consumers. This is a very large amount of data which may require investments in improved data infrastructure.

1.4.2 Centralized override

In some cases the control of heating units and other installation using electricity may be turned over to e.g. the local balancing responsible. In this way, energy demand becomes and asset to the balancing responsible on the same level as backup generation. To make it worthwhile, the consumer is typically compensated for the loss of control. This kind of centralized control takes advantage of the data flow described above.

1.4.3 Autonomous units

Another way to improve the flexibility of demand is to install "intelligent" semi-autonomous units in the consumers' homes. These units are able to tap into the flow of data between producers and consumers in order to optimize energy consumption.

The most common example of this would be a refrigerator which shuts off for shorter periods of time whenever the frequency of the electricity falls below a certain threshold. Another example could be household battery units which charge when the price of electricity is low and discharge when the price is high.

2 Energy systems

In this section, we combine the technologies into systems. In small-scale systems, it is very difficult to achieve the same flexibility as large-scale systems because of a lack of technological diversity. We combine technologies to achieve as much flexibility and as many synergies as possible within the limited frame of small-scale energy systems.

2.1 System benefits

In this guide, we use the term "System benefits" to signify the monetary benefit from the synergies generated by electrification of heating and storage of heating. These synergies result in a more stable, predictable and flexible energy consumption pattern which has a direct impact on the price and cost of energy. Producing heat when there is an excess of electricity being produced (eg. plenty of wind and sun) is privately profitable because the price of electricity will often be lower at these times.

The same privately profitable actions are also a benefit to the power generator and the system responsible for two reasons:

1. The increased demand from heating reduces the need to curtail wind or solar power production units – thus increasing the overall utilization and profitability of these units

2. The stored heating can potentially be used in periods with very low electricity production (eg. no wind and no sun) reducing the need to produce electricity on less efficient units – ultimately reducing the need to invest in generation capacity

These two benefits should over time lead to lower costs of producing and balancing electricity and in turn to lower prices of electricity.

System benefits play different roles in on-grid and off-grid systems. In on-grid systems, any system benefits that electrification of heating can provide may be used as a bargaining chip to negotiate favourable electricity prices for heating. In off-grid systems the joint heating and power generation system should be designed to take advantage of system benefits in order to minimize investments and to maximize the share of renewable energy.

2.2 Heating (On grid)

The heating systems described below are all based on heat pumps – either individual heat pumps or large heat pumps providing district heating. All require a water based system of heat dispersion in the homes. In Norway and Sweden, many homes are heated by electric resistance radiators. Converting these homes to water based heat systems is likely not feasible, as it would require a significant investment in retrofitting the house with hot water pipes and radiators.

Even in small communities, it is unlikely that all households' heating installations are the same age. This can be a challenge when it comes to implementing collective solutions like district heating, as these solutions would require a rapid conversion of all household installations in order to be feasible. Households which have recently invested in a new heat installation will have very little incentive to replace their brand new installations.

2.2.1 Individual heat pumps

Each home replaces its existing heat source with a heat pump drawing heat from e.g. the ground or the air. The heat pump is backed up by a small electric boiler and a hot water tank.

This is the solution with the highest household investment. On a positive note, this solution does not require any kind of collective decision and it can be implemented whenever the existing heat source reaches the end of its technical life.

2.2.2 Individual heat pumps with collective heat source

Each home replaces its existing heat source with a heat pump drawing heat from a collective low temperature water distribution net. The heat pump is backed up by a small electric boiler and a hot water tank.

This solution has lower household investment, but in return requires a collective investment in the cold water distribution system. The individual heat pumps provide some flexibility to the rate of implementation among the households, but the feasibility of the collective distribution system will depend on most households connecting to it.

2.2.3 Large heat pump district heating

A large heat pump delivers heat to a district heating system. The heat pump is backed up by a large electric boiler and a large hot water tank.

This solution has the lowest household investment, but the largest community investment in heat pump and high temperature water distribution net. The collective nature of this system requires a very high rate of connection among the households. It also limits the flexibility in terms of timing of the conversion for the individual household.

2.3 Electricity and heating (Off grid)

Off grid communities need to produce their own electricity. Converting such small scale power generation to renewable energy poses some challenges, but it also provides the opportunity to base the generation on 100% renewable energy. Something users connected to a large scale power grid do not have much influence over.

Unless the community is situated close to an unused source of hydro power, wind turbines and solar power will play a vital role in reached the goal of 100% renewable energy. The volatile nature of wind power and solar power poses a big challenge as they need to be balanced by other more flexible sources or by storage.

Below we present three different scenarios for providing electricity in sparsely populated areas.

2.3.1 Wind/solar with balancing power

The simplest possible 100% renewable energy setup that includes intermittent production would be to replace fossil diesel with bio diesel. The diesel generator will provide the balancing of the volatile electricity from wind and sun.

This setup has the benefit of having a high margin for error and it will allow the community to reuse any existing diesel generator. The downside is that bio diesel is expensive and the climate impact is debatable, especially when taking into account energy used for producing it and transporting it.

2.3.2 Wind/solar with short term storage and backup

Combining electrification of heating with intermittent power production provides some interesting system benefits. A heating system with an electric boiler as backup and hot water storage tank can provide a significant amount of balancing power and storage. It might even be feasible to use the electric boiler even when the heat is not needed simply as an alternative to balancing with a battery or a flexible generation unit.

The system will still depend on a backup bio diesel generator or a small hydro power unit for those cloudy days with no wind.

2.3.3 Long term storage

Pumped hydro storage is an option that could solve a lot of the challenges posed by intermittent power production. Pumped hydro storage does not need to be connected to a river, stream or lake. It could be based on pumping sea water instead.

Combining pumped hydro storage and electrification and storage of heat provides a very flexible system. No single component of the combined heat and power system needs to be designed to take the full load. Heat pump and electric boiler backup combined with a heat storage tank will be able to deliver plenty of heat. Intermittent power production combined with balancing from the electric boiler and hydro power and storage in heat and pumped hydro can shift large quantities of electricity in time.

3 Technology data sheets

In the following pages, technology sheets are presented. For each sheet both key figures and description of the technology is included. Technologies described are:

- District heating
- DH unit and branch pipes
- Oil boilers
- Biomass boiler (only solid biomass)
- Surplus heating[1]
- Electric boiler
- Large heat pumps
- Hot water tank
- Individual HP (small brine)
- Large brine
- Individual HP (large brine)
- Wind turbines
- Batteries
- Solar power
- Hydro power
- Pumped hydro storage.

The chosen technologies have one thing in common. They only use non-fossil fuels or they use electricity which could be based on non-fossil fuels. The only exception is oil boilers. These are traditional fossil based oil boilers. The reason for their inclusion is that they are used in the Leirvík case reference scenario. The technology is quite common in sparsely populated areas. Their presence in the catalogue is exclusively with the purpose of comparing parameters such as costs with the other technologies.

In the technology sheets efficiency is defined as the outcome energy compared with the input energy. For thermal power technologies this will be the heat produced compared with the fuel consumptions. For heat pumps it represents the COP and for district heating systems the efficiency is '1 minus the heat loss'.

For all technologies, the parameters used are linked to the chosen capacity of the unit. In the feasibility tool the data will be scaled linearly which is important to highlight.

[1] Surplus heating is dependent of specific parameters such as temperature and fluctuating production during the year. Because of this there it is not possible to include key figures for the technology.

Reports and materials in this series

- Renewable energy supply and storage: Guide for planners and developers in sparsely populated areas.
- Guide report 1: Heat supply in Leirvík - Case Study
- Guide report 2: Technology catalogue
- Guide report 3: Economic and financial analysis
- Guide report 4: The project development process
- Fornybar energy og lagring i spredtbyge områder (an Excel based screening tool: Include data for your own local community and analyse the feasibility of optional solutions for renewable energy systems.)

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