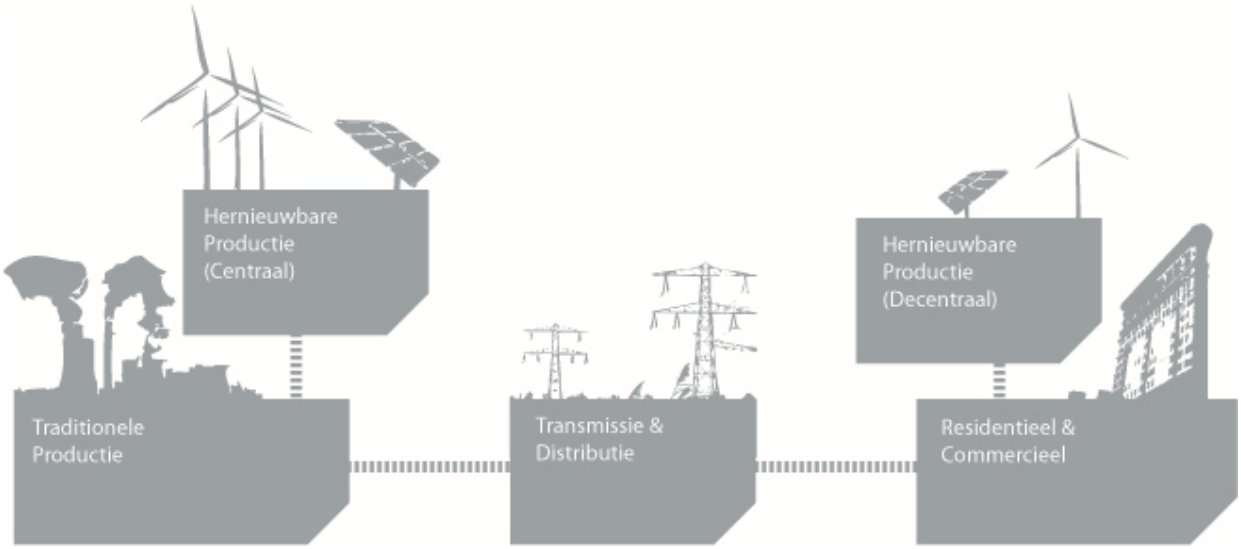

Translation: Renewable production (Centralised); Renewable production (Decentralised)
Traditional production; Transmission & distribution; Residential and commercial

The Storage of Sustainable Energy in the Built environment
Exploratory research on increasing sustainability using Smart Grids

TVVL Platform for People and Technology

19 April 2012
Final report
9W5041

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FOREWORD

Energy storage, decentralised energy generation and smart grids are multi-faceted subjects offering a great deal of scope for research. We were well aware of this and for anyone who starts working in the field it soon becomes even clearer. It is not surprising that there are professors specialising in smart grids. The term 'smart grid' is sometimes considered to be a buzz-word or a hyped-up subject. It is an umbrella term for something that is difficult to define and as with every innovation or transition there is a lot involved.

This is a subject of great interest to both Royal Haskoning and our client TVVL. Not to mention the subject 'The storage of (sustainably generated) electricity in the built environment', which forms just a part of this comprehensive and complex issue? Nevertheless we are of the opinion that in this report the correct questions have been asked and answered. But at the same time this report does nothing to reduce the complexity of this extensive subject. We could never have achieved this on our own. Firstly we would like to thank TVVL and Jan-Fokko de Haan for putting their trust in us to carry out this investigation. In addition Hans Besselink of TVVL and Bart van der Velpen of Royal Haskoning each made a substantial contribution by setting out the framework for the research. During an interview, Jan Mulder of Delft University of Technology provided us with an insight into the potential of hydrogen and batteries as storage media. Also the information from the speakers at the IIR Energy Congress 'Energy Production and Storage' that took place in October 2011 contributed to giving us an up-to-date view of the developments in the field of decentralised energy production, energy storage and smart grids. Finally we would like to thank Bob Meijer and Wilco van der Lans of Royal Haskoning for their critical reviews of this report.

Steven Lemain
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SUMMARY

TVVL, Platform for People and Technology, requested Royal Haskoning to investigate the subject of Energy storage and smart grids. Primary and secondary research questions were formulated jointly with TVVL, and then subsequently answered during the exploratory research. The primary issue is as follows:

Taking account of the solutions offered by smart grids, how desirable is the storage of energy at the domestic housing, building or district levels in both the short and long term, and which types of storage methods are the most feasible?

Several secondary questions were formulated to help answer the primary question. The secondary questions and their answers are handled below.

Secondary question 1: To what extent is there a need for the storage of electrical energy in the built environment, now and in the future?: The need for the storage of (sustainable) electrical energy in the built environment is quite low at present. In future the need for storage in the built environment will largely arise from the need for decentralised producers to be able to trade more effectively. Therefore the consumer/decentral producer with a storage medium will be able to charge up when electricity prices are low and discharge when they are high. Peak - valley compensation, supply and quality optimisation, and peak shaving are of minor importance at the level of the built environment. In addition it can be expected that policy at European and national levels will contribute to more development and use of decentralised electricity generation, which will consequently be an important driver for storage media in the built environment. Also trends such as multifunctional use of land, electrification, scale reduction and the trend towards the smart division of decentralised electricity production will provide stimulation, encourage the potential development and speed up the implementation of the storage of electrical energy. However, contrary to these developments that benefit the use of storage on a smaller-scale, the costs of realising large-scale flexibility are relatively low.

*Secondary question 2: Which methods of electrical energy storage could be considered at the building and district levels?: B*atteries and hydrogen are the storage methods with most potential when viewed from the perspectives of technical selection criteria, power discharge time, response time and energy capacity. Due to its extensive storage cycle hydrogen has the most disadvantages and its small-scale use will be complex. In the short term the system that is most suitable for the storage of electrical energy in the built environment is the battery. Batteries combine good energy density (stored energy per kilogram and stored energy per volume) with efficiency (small losses during the charging and discharging cycles). Large storage capacities using batteries are currently uneconomical due to the high costs of storage capacity (€/kWh). Battery systems are suitable for bridging the day/night cycle, but not for the seasonal cycle. Also battery-based systems can assist with the efficient use of energy by buffering between supply and demand. Extensive development is taking place in the field of battery technology. Lithium-sulphur and lithium-air batteries in particular appear to have considerable future potential.

Secondary question 3: To what extent is there an inhibiting or a facilitating link between the use of smart grids and the use of electrical energy in the built environment?
Imbalance between local generation and local consumption in the smart grid can be compensated by local solutions (storage or control of demand) or it can be left to higher-level networks. Aggregating at a higher level of imbalance can reduce the total risk of imbalance. This does involve costs for transmission and control power. Smart grids make this local balancing with the help of local storage technically possible and could thus be a stimulus. On the other hand because the smart grid is also linked to higher-level networks it makes the balancing possible at a higher level. The opposite also applies, as any potential imbalance at higher levels could be taken up by local smart grids.

Considering the stage of development of the current grid, its high operational reliability and the potential added value of information and communication technology, it is likely that in the short term most solutions will be found by further optimisation of the existing grid system into a smart grid. This does not mean that storage will not be used. When storage techniques have been further developed they will be a welcome extension of the smart grid concept, enabling practical applications that will primarily depend on the cost effectiveness of two scenarios: a rise in the use of storage and/or a rise in the amount of power being fed back into the grid. Due to the stage of development of smart grids, with the opportunities for feed-in and the lack of storage capacity, it is likely that in the short term increased feed-in will develop. Over the longer term the storage scenario will continue to develop and both could exist alongside each other.

Secondary question 4: What is the state of the playing field for the stakeholders in smart grids and electrical energy storage and what consequences does this have for the feasibility of the storage of electrical energy in the built environment?

What is the state of the playing field? Many stakeholders are involved with smart grids and the storage of energy. To some degree or another they all have an interest in the development of smart grids and any potential storage facilities within them. The playing field is characterised by the stakeholders involved having partly conflicting interests and goals. For example the traditional central producer who is not going to benefit from decentralised production, or the supplier who will benefit from smart grids (more trade) but will not benefit from decentralised storage. At the moment there appears to be no likelihood of fruitful cooperation or useful alignment of interests and goals.

What consequence does this have for the feasibility of the storage of electrical energy in the built environment? The current electricity grid (and certainly with the expected smart grid modifications) does not need decentralised storage for the power supply system in the Netherlands. Therefore it cannot be expected that mandatory policies and regulations governing storage will be introduced. However, one reason to go for storage could be economic. The cost effectiveness for the various stakeholders will therefore be a deciding factor. If decentralised storage does make progress then it is likely that the first party for whom storage becomes profitable will be the consumer/decentralised producer. A consequence is that shared (organised) storage will not take place for the time being for the ‘playing field’. It is most likely that one party will start on its own.

In the context of a number of sketched future scenarios it is probable that storage will go ahead, in the first instance the individualism scenario is likely to be at the forefront. Storage offers economies of scale, therefore when the smart grid, including storage, is further optimised, it can be expected that shared storage will eventually take place. Therefore we forecast a scenario such as Delayed Moderate Collectivism.

CONTENTS

1 INTRODUCTION

1.1 Background and objectives

We have become used to a world in which we meet our energy requirements using fossil fuels. We have built up extensive expertise in the extraction of fossil fuels and we are still improving our techniques. We are not just efficient at extracting fossil fuels; we are also becoming more expert in extracting and using the energy that these materials contain. As we all know there is not an endless supply of these fossil fuels and we will run out eventually. Opinions about when exactly are divided and nobody has a monopoly on the truth. It has been established that the number of newly discovered oil and gas fields is dropping, as well as the size of these (Buchan, 2010). The sales of fossil fuels are still rising (EIA, 2011). Also the demand for energy will continue to rise with the growing world population and increasing prosperity. As an indication, today the world population is almost 7 billion, and in 2050 the population is forecasted to rise to 9.2 billion (UN, 2008). Over the last 200 years the world's population has grown by a factor of six and the energy consumption by a factor of eight. These facts lead us to conclude that the exhaustion of fossil fuel sources will increase and that worldwide increasingly more people will be connected to an electricity supply. Today worldwide at least 1.5 billion people are not yet connected to an electricity grid. This is really a challenge even though in a prosperous land such as the Netherlands it is less of an issue. The higher our income the more energy we use. With the increase in demand, the limited availability and the severe impact of conventional energy sources on the environment, the need for a transition towards sustainable energy supplies is evident. The implementation of sustainable energy supplies is not simple and will require systematic changes in the production and consumption of energy.

The long road towards sustainable energy has already been taken. Many countries around the world are working to a greater or lesser extent with an energy mix of conventional and sustainable energy generation. Technologies for generating sustainable energy (mostly in the form of wind and solar energy) are being utilised on an increasingly large scale. Not only large-scale central production of sustainable energy (i.e. offshore wind farms for example) but also smaller-scale decentralised generation of energy (i.e. photovoltaic solar panels mounted on domestic houses and office buildings). From the perspective of climate change this is a highly desirable development, as well as from the perspective of certainty of supply and the targets set by the government for sustainable energy production and reductions in the emission of greenhouse gases.

For a transition to a more sustainable energy supply it is expected that energy storage and 'smart grids' (intelligent networks) will make an important contribution and ensure the certainty of supply and the proper matching of energy supply and demand. With this in mind, TVVL, Platform for People and Technology, requested an exploratory study to be carried out into the storage of decentrally (sustainably) generated energy. The mission of TVVL is as follows:

TVVL is an association of people involved in the development and implementation of the technology of building related facilities and the influence of these on people and their functioning. TVVL gatherers, compiles and develops knowledge and passes it on within the context of public debate, daily events and adjacent sciences. We translate the knowledge into innovative technological solutions and transfer it into practical guidelines (TVVL, 2011).

This exploratory research is in line with the mission of TVVL, the objective being to provide TVVL with information about the storage of energy in relation to smart grids. For TVVL this must contribute to knowledge gathering and compiling, to developments on this subject, and provide insight into the steps to be taken to contribute to the development of energy storage media within a more intelligent network. These issues are covered in more detail in the recommendations.

1.2 Scope

Before getting to the focus of the study it is important to be aware of the constraints within which this exploratory research has been carried out. Production, distribution, supply and consumption of energy cover an extensive field, even ignoring the extraction of primary raw materials. The following constraints were decided jointly with TVVL:

1. The Netherlands.
2. The built environment at the level of domestic housing, offices and districts.
3. The storage of electrical energy.
4. Electrical transport.
5. A time horizon of a maximum of 20 to 30 years.

This can be explained as follows:

Point 1:
Considering the large number of parties involved in these innovations, the investigation is limited to the use of energy storage and smart grids in the Netherlands; however developments outside the Netherlands are mentioned where relevant.

Point 2:
Considering the field of activity of TVVL, which is largely focused on the technology of building related facilities, the decision was made to restrict the scope to domestic housing, offices and districts. The built environment does limit the type of storage system that can be considered. Within this environment large-scale storage facilities are not usually possible because of the natural and geographical circumstances that may be needed for large-scale storage. Large-scale storage is covered in the selection process.

Point 3:
The storage of electrical energy could also cover the storage of thermal energy (heat and cold), the temporary storage of natural gas or other fuels as well as the storage of electrical energy. In this exploratory investigation the focus is on the storage of electrical energy that will be used once again as electrical energy after storage.

Point 4:
The use of electrical transport as an application for storage (batteries in vehicles) is not explicitly covered in this investigation. The discussions and recommendations cover this in more detail.

Point 5:
Considering the available information and the complexity of the subject no exact time horizon has been used.

1.3 Research requests

TVVL's initial research request to Royal Haskoning was refined during subsequent discussions between the two parties. The primary and secondary research questions for this project were as follows:

Taking account of the solutions offered by smart grids, how desirable is the storage of energy at the domestic housing, building or district levels in both the short and long term, and which types of storage methods are the most feasible?

1. *To what extent is there a need for the storage of electrical energy in the built environment, now and in the future?*

2. *Which methods of electrical energy storage could be considered at the building and district levels?*

3. *To what extent is there an inhibiting or a facilitating link between the use of smart grids and the use of electrical energy in the built environment?*

4. *What is the state of the playing field for the stakeholders in smart grids and electrical energy storage and what consequences does this have for the feasibility of the storage of electrical energy in the built environment?*

1.4 Approach

The following sources were used:

- Desk study based on literature research and information from Internet.
- An interview with Professor F.M. Mulder of the department of Fundamental Aspects of Materials and Energy (FAME), Radiation, Radio Nuclides and Reactors faculty at Delft University of Technology (see Appendix 2)
- Decentralised Energy Production and Storage Congress, 26 & 27 October 2011 (see Appendix 3 for list of attendees and speakers and Appendix 4 for the congress report)
- Smart grids workshops organised by TVVL in May and November 2011.
- TVVL New Year symposium, 10 January 2012: Is a smart grid the solution?

1.5 Document structure

Chapter 2 provides the answers to the secondary questions presented in the introduction. Considering the complexity of the subject, the secondary questions have been divided into subsidiary questions that are given at the beginning of each section. In Chapter 3, the conclusion, the primary question is answered on the basis of the secondary questions already answered. The discussion and recommendations are covered in Chapter 4. Here we reflect on the value of the conclusions and we make suggestions for additional research. Finally in Chapter 5 provides the recommendations for TVVL.

2 ANSWERING THE RESEARCH QUESTIONS

2.1 Secondary question 1

To what extent is there a need for the storage of electrical energy in the built environment, now and in the future?

In order to answer secondary question 1 the following sub-questions were asked:

a. *What are the characteristics of the current electricity grid?*
b. *What will be the characteristics of the future electricity grid (smart grid) and what relationship will it have with the current grid?*
c. *What are the reasons for storing electrical energy?*
d. *Is there a policy and are there identifiable trends that could influence the use of storage of electrical energy?*

2.1.1 The current electricity grid

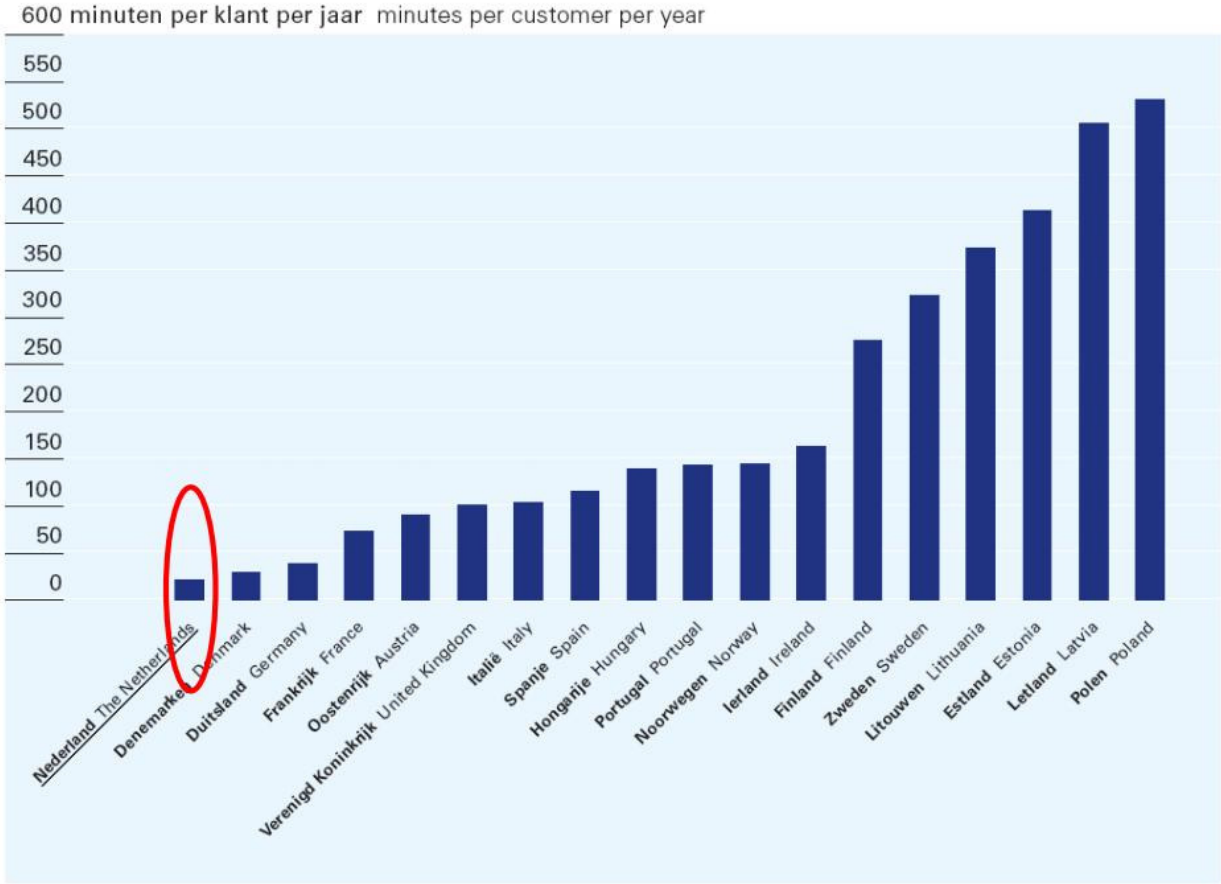
A short history
That there was a connection between phenomena such as the surge of current produced by an electric eel and lightning became clear more than 300 years ago. Once we were able to generate electricity it still took us two centuries before we could make practical use of it. The large-scale production of iron and steel began in the United Kingdom in the second half of the 18th-century. A step that could only have been taken as a consequence of this was the development of practically useful electricity by means of transmission through metal conductors. Electricity had a large influence on our society: firstly at the beginning of the 20th century lighting became possible and a few score years later electricity had grown to be an indisputable necessity of life (Mijn, 1978).

The quantity of energy produced (and distributed) is related to estimated consumer demand. Therefore the capacity of the electricity network has grown tremendously over the past century. At the end of the 19th century at least 5 MW was being generated for the various electricity grids in the Netherlands. At the end of the 20th century production had reached 15 GW (Ladiges, 2000).

Features of the current energy supply
By far the largest proportion of electricity in the Netherlands is generated using coal and natural gas. This production method is characterised by central production with controllable capacity. The most dramatic change that will take place is a transition to a sustainable energy supply. This will be characterised not only by increasing large-scale centralised energy production using wind farms, but also by increasing decentralised production with production capacity that will be difficult to control. This will call for significant efforts from grid operators to make electricity grids future proof. To enable the transmission networks to meet the needs of the energy market, the grid operators will have to focus on continuous improvements to the high, middle and low-voltage networks (TenneT, 2009).

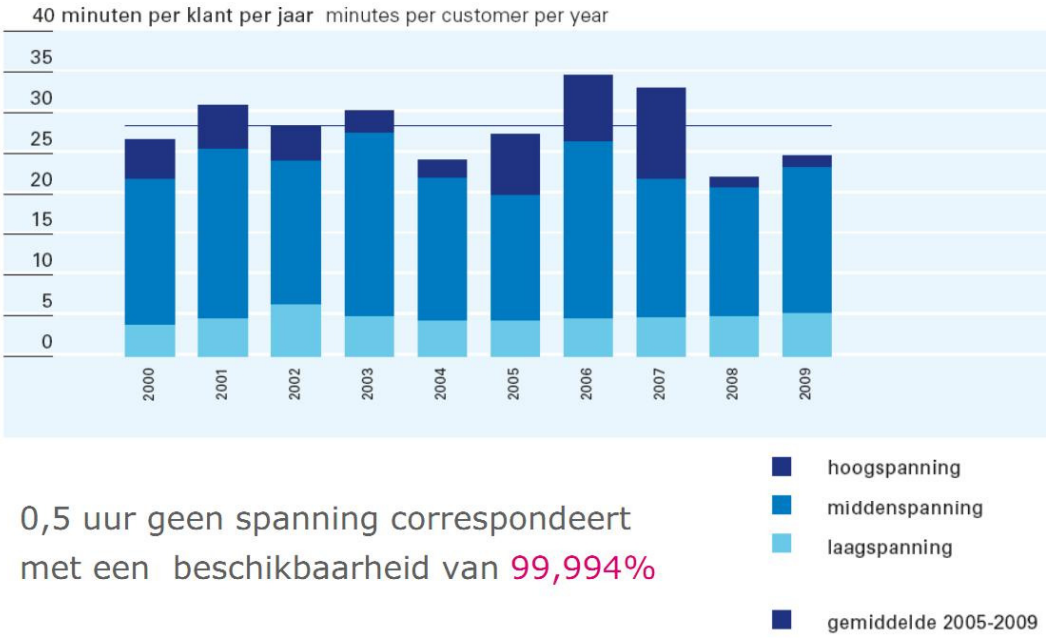
Reliability of electricity grids
As can be seen in the figure below the Dutch electricity grid is extremely reliable. In comparison with other European countries we are at the top when it comes to the shortest power cut time per customer. Also European electricity grids are highly reliable when compared to the United States (Nieuwenhout, 2011).

Figure 1: Dropout in minutes (Slootweg, 2011)



Although the high-, medium- and low-voltage networks are very reliable there is a difference between the three. This is illustrated in the figure below.

Figure 2: Reliability of the high-, medium-, and low-voltage networks in the Netherlands (Slootweg, 2011)



Translation: 0.5 hours without electricity corresponds to an availability of 99.994%
high-voltage; medium-voltage; low-voltage; average 2005-2009

In 2009 the power dropout was an average of 40 min per customer per year. The medium-voltage network is relatively the least reliable, but in spite of that in an absolute sense it provides good performance. Moreover there is still plenty of capacity available for the transmission and distribution of extra electricity on all three networks (Slootweg, 2011).

2.1.2 The future electricity grid: Smart Grids?

As stated above, changes in electricity supply facilities are expected, driven by changes in the nature of the supply of energy. While the current energy infrastructure is characterised by a large centrally generated supply of electrical energy, in future the infrastructure will increasingly consist of small-scale sustainable and locally generated electricity in intelligent networks that are better able to handle the predicted increasing complexity of supply and demand. These networks of the future are known as the smart grid. As yet there is no commonly accepted definition of a smart grid. Some definitions follow to give an idea of the nuances.

TNO:
Smart grids are infrastructures for electricity, gas and heat. These grids contain ICT systems for measuring energy flows with applications for controlling and regulating the consumption and production of energy. They collect information that is brought to places where it can be further processed, so that communication is possible with all types of peripheral apparatus and applications located at the premises of the parties involved. (Huygen, 2009)

AgentschapNL:
A smart grid or intelligent network is an all-encompassing concept within which different innovative energy infrastructure developments fit. Although intelligence is also associated with gas and heating networks, it generally refers to electricity networks, because the ICT influence in these is the most radical. This includes both technological innovations and innovations in the value chain. ICT developments in particular will function here as enablers. There is more potential for information exchange, enabling energy flows to be controlled and managed more effectively. A key element within the intelligent network concept is the emergence of two-way distribution between energy users themselves and producers, creating more options for the users of the energy infrastructure. (EZ 2010)

The Smart Grid European Technology Platform:
A smart grid is an electricity network that is capable of forecasting and intelligently anticipating the behaviour and all activities of the actors involved - producers, consumers and those involved in both activities - so that an efficient means of delivering reliable, cost-effective and sustainable electricity and related services can be supplied. (ETP, 2011)

These three definitions of smart grids overlap considerably, but there are also significant differences. TNO's definition includes gas and heat infrastructures as a part of smart grids. The Intelligent Networks Task Force places the emphasis on electricity infrastructure, because they the influence of ICT is the most far-reaching. The Smart Grid ETP definition involves an electricity network and the electrical applications associated with it. What is also striking about the Smart Grid ETP definition is that the smart grid has predictive ability to respond to the behaviour of all electrical applications that are connected to both electricity consumers and suppliers. Because we have limited ourselves to electrical energy in this study, we have limited our definition of smart grids to a similar framework. The definition of smart grid used in this report is therefore the above Smart Grid ETP definition.

The table below gives a comparison of various aspects of the current and the future electricity networks (smart grid). Summarising, and as an answer to secondary question 2.1.b, it can be stated that that the development towards smart grids involves a development from a centralised hierarchy to a self-controlling network.

Table 1: Comparison between the current grid and the smart grid (based on EZ, 2010; ETP, 2011 and EnergyGov, 2011)

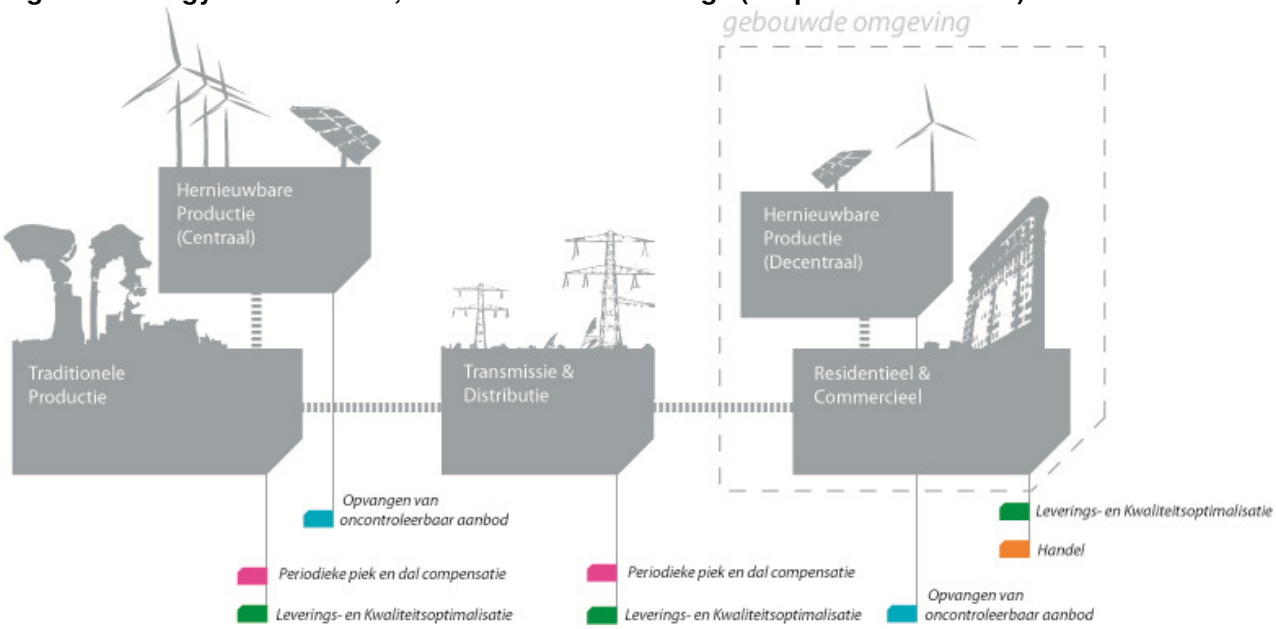
Aspect	***Current network***	***Smart grid in the Netherlands***
Users	Users are not informed and do not participate.	Users will be informed, involved and active; savings due to smartness (with privacy). Users will play a role in optimising the system.
Production	Mostly central generation.	In addition to central production, all types of decentral production. Consumption can be linked to the type of production. Users will have more options and choice.

Aspect	*Current network*	*Smart grid in the Netherlands*
Storage	Scarcely any or no decentralised storage options.	Availability of market-driven storage facilities.
Sustainable energy	Integration of (decentral) sustainable energy possible to a limited extent and sometimes with difficulty.	Standardised plug-in for sustainable production, controlled by electronics and IT.
Smart technology	At the decentralised level relatively little utilisation of smart technology.	The network will be provided with Smart technology (both centrally and decentrally) to optimise the electricity demand from consumer electronics etc.
Environmental impact	Little insight into environmental impact.	Users will be kept informed and can optimise the 'colour' of their energy consumption (sustainable, core etc). This will provide more insight into the environmental impact of the entire electricity production system.
The market	Mainly producers and large-scale industrial users active in the market.	Large (price dependent) demand response based on new services and innovative applications.
Quality	The focus is on supply interruptions.	Dynamic interaction between price and quality with fast response to quality issues.
System management	Limited integration of asset management, operations and operational data.	Real-time system information available for company operations, with prevention being at the core. Use will be made of technology to enable energy consumers to function optimally.
Reliability	System security focuses on preventing damage to components.	System security will react automatically in such a way that supply will remain guaranteed (self-healing).
Disasters	System sensitive to (natural) disasters and terrorist attacks.	The system will be relatively insensitive to disasters (it will be dispersed and have efficient recovery mechanisms), but will be potentially sensitive to cyber-attacks.

2.1.3 Reasons for the storage of electrical energy

There are various reasons to optimise the electricity network using storage. The following applications can be defined (EAC, 2011; Pike Research, 2011) and provide the answer to secondary question 2.1.c. The figure below provides a simplified image of the energy infrastructure and the stakeholders in relation to the reasons for energy storage.

Figure 3: Energy infrastructure, stakeholders and storage (simplified illustration)



Translation: Built environment
Renewable production (Centralised); Renewable production (Decentralised); Traditional production; Transmission & distribution; Residential and commercial
Absorbing uncontrollable production; Supply and quality optimisation; Trade; Periodical peak and valley compensation

1. Periodical peak and valley compensation (load levelling/peak shifting; Figure 3 pink)

For traditional and renewable production at the transmission and distribution location (central production and decentralised production) the storage medium is charged during valley periods and discharged during peak periods. Cost efficient base load can then run continuously and peaks can be absorbed by electricity that has been stored when demand is below the base load. This use is important for the energy producing parties.

2. Supply and quality optimisation (Figure 3 green)

At the production and transmission & distribution location the key issue is the presence of black start storage; a stock of energy to restart the power plant when this has shut down and energy from an adjacent power station is not readily available. At the end user's location, storage can serve for power quality optimisation if there is a power outage (compensation for fluctuations).

3. Absorbing uncontrollable supply (peak shaving) (Figure 3 blue)

Energy can be stored at the central production location at the moment that there is an excess (e.g. at night when the wind is blowing). The energy can be consumed later when there is a shortage (e.g. calm conditions during the day). Large-scale storage is already deployed for this purpose, i.e. when needed overcapacity in the Netherlands' high-voltage grid can be compensated by electricity transmission to Norway via the NorNed cable. In Norway it is possible to pump reservoirs full of water (see also pumped hydroelectric in section 2.2.2).

At the user/decentral producer's location, energy storage can also be used at the moment that there is an excess (e.g. in the afternoon for domestic solar energy panels), because the energy will otherwise be lost or because the local load on the network must not be excessively high. Decentralised production can lead to overloading of the network if it is not designed to handle this (Yahoo News, 2011).

From a technical perspective, local energy storage could provide a solution here. As described in section 2.1.1 and shown in Figures 1 and 2 this is not usually a motive in the Netherlands.

4. Trade (Figure 3, orange)

Trading of energy has been done for many years. A new aspect is that consumers who have started to produce electricity themselves can also take part in this business. A storage medium would enable consumers to exercise more control over their own consumption and sales to the market. Consumers with a storage medium would be able to charge when the electricity prices are low and discharge when prices are high. This could be the case when:

1. Energy from the network is purchased cheaply by a party, stored and sold when the price is high.
2. Energy produced by the consumer is stored when the price is low and sold when the price is high.

2.1.4 Policy and trends that influence decentral energy production and storage

A highly relevant energy-related development is taking place in the built environment: the design of buildings is taking increasing account of the energy question. Buildings are increasingly being designed to be energy neutral. This means that during the use phase the building produces just as much energy as it consumes. This section investigates whether policy and trends that will influence the use of electricity storage are identifiable.

Policy

European and national goals

The European Union is taking the fight against climate change very seriously and is making efforts to counter climate change at both the European and international level. The following three objectives for 2020 (compared to 1990) were agreed in March 2007:

- 20% reduction in the emission of greenhouse gases.
- 20% less energy consumption.
- 20% of the total energy use must come from renewable energy sources such as wind and solar energy.

For the latter point, legally binding objectives have been agreed for every member state and if a worldwide climate treaty is agreed the European Union will increase its goal to 30% reduction in emissions of CO_2 in 2020. For the Netherlands this means that the proportion of energy obtained from sustainable energy sources will have to increase to 14% in 2020. In 2005 this proportion amounted to 2.5% and in 2008 it was just 3.4% (Europe, 2011).

Roadmap
On 8 March 2011 the European Commission adopted the *Roadmap for Moving to a Competitive Low Carbon Economy in 2050* which states that the aim will be an 80 to 95% reduction in greenhouse gas emissions by 2050 compared to 1990 (EU, 2011). Sustainable central and decentral energy generation will provide an important contribution towards achieving the 80% objective. From the European Union as well as nationally there is little preference for large-scale central or small-scale decentral generation (Nieuwenhout, 2011).

Directive 2003/96/EU
On 29 April 2004 the European Council accepted a proposal to offer a stimulus to sustainably generated electricity. Member states may, under fiscal control, provide total or partial tax exemptions or reductions for electricity derived from:

- Solar, wind, wave, tidal or geothermal sources.
- Water power from hydroelectric power stations.
- Biomass or biomass derived products.
- Methane emitted from abandoned coal mines.
- Fuel cells. (EU, 2003)

Directive 2010/31/EU
In the context of energy and CO_2 reduction, decentralised energy production developments relating to buildings have also been stimulated by the EU, as stated in Article 9 of the EU directive on Energy Performance of Buildings. This states that from the end of 2020 all new buildings will have to be 'nearly zero energy buildings'. Directives for current buildings are less drastic, but still aim to achieve the highest possible net energy efficiency. [EU, 2010]

EPC
New buildings must meet specific energy efficiency requirements. This is expressed in the energy performance coefficient (EPC) - the lower the EPC, the more efficient the building. The use of technology for generating sustainable electricity also increases the EPC of a building.

<u>Subsidies</u>
Renewable energy is in many cases more expensive than conventional energy (Tennet, 2010). However governments are creating financial stimuli by means of subsidies for consumers to encourage them to contribute to sustainable energy production and the reduction of greenhouse gas emission objectives.

Balancing & settlement
The price of oil and other exhaustible energy sources will eventually rise, while the price of energy from renewable sources will decrease. Eventually (decentralised) renewably generated electricity will become cheaper than conventional energy. At the decentral level, except where energy costs and also transmission costs and taxation are counted, balancing & settlement against private consumption can enable the breakeven point (grid parity) to be reached earlier than in the wholesale electricity market. In the case of balancing & settlement, a (central) energy supplier buys energy from the consumer. The price for this energy is not the same as the price that the consumer pays for energy. The latter includes transmission costs, service costs and taxes. In many cases nowadays

this difference will be eliminated by the balancing & settlement regulations. In this case suppliers are charged only the positive balance of their own consumption, minus the feed-in (up to the legally determined maximum of 5000 kWh). The electricity network operates like a virtual storage capacity for the consumer. This regulation is intended to stimulate sustainable decentral power generation. The regulation means that (up to 5000 kWh) the price for purchasing and selling energy is set at the same level for the consumer. This regulation will be extended in the short term to also allow the Homeowners Association (Verenigingen van Eigenaars) to benefit. In the longer term this regulation, introduced as a stimulant, may well gradually disappear as decentral generation becomes mature (Appendix 4, Congress report 2011).

SDE
The Netherlands has decided to stimulate the sustainable energy market in general (SDE, 2011) using the SDE($^+$) scheme. This scheme focuses primarily on the implementation of existing techniques. The introduction of the subsidy on solar panels in 2008 (under the SDE) stimulated the purchase of solar systems by consumers. The SDE subsidy for consumer purchases of solar panels was scrapped early in 2011.

Experimental facilities
Up to September 2011 subsidies could be requested for setting up experimental intelligent networks, for which the Ministry of Economic Affairs, Agriculture and Fishery made €16 million available (Agentschap, 2011).

<u>Trends</u>
Central energy production
In the period 2010 to 2016 more than 20 GWth of large-scale central energy production facilities will be installed (TenneT, 2009). This capacity will consist mainly of coal and gas fuelled generation. In addition to the currently installed 2.3 GW_{el} of wind turbine facilities (offshore and onshore), in the near future (to 2020) in the most favourable scenario an additional 6 GW_{el} will be installed (Windenergie, 2011).

Technology for small-scale electricity production and demand
There are several relevant technology developments/trends in the built environment both for the supply and demand of electricity, which could be of great influence in the future. On the production side the further development of PV solar systems, micro-CHP and small-scale wind energy in the built environment are likely candidates. On the demand side, heat pumps, electric cars and an increased demand for cooling (Planbureau, 2009).

Changes in favour of storage
Many developments are taking place that could simulate the requirement for the storage of electrical energy in the built environment, including:

- *Multifunctional land use:* Due to the rising population density and increasing land prices, multiple use of space by integrating sustainable energy technologies such as PV are a welcome development.
- *Electrification:* The use of electrical transport is expected to increase. Although hurdles have yet to be overcome, the potential for the storage of electrical energy is very large.

- *Scale reduction:* Production of electricity can be as small-scale as desired and is legally tenable. This will create a movement from a centralised hierarchy to a self-controlling network in which the consumer will play a more important role.
- *Smart sharing:* Technological developments will make the sharing of information easier. (Hoekstra, 2011)

The trends point towards more self-organisation, which will have consequences for the manner in which the energy market is organised. From the idea of transition (Rotmans, 2004) it is expected that renewal will take place from niche markets. By scaling-up from niches, regimes will be created that in turn will form part of technological and cultural trends within a transition to a sustainable energy supply.

All in all the large-scale use of sustainable energy in the built environment will require more flexibility and this could be provided by storage (Slootweg, 2011).

Market share of energy storage
The expectation is that the value of the worldwide market for energy storage will rise from $1.5 billion in 2010 to $21 billion in 2020 (Pike Research, 2011). Pike Research allotted each application a market percentage:

- Absorbing uncontrollable supply (renewable sources, particularly wind) 50%.
- Periodical peak/valley compensation 31%.
- Trade (arbitration) 12%.
- Certainty of supply/quality (including transmission and distribution upgrade) 7%.

2.1.5 Answer to secondary question 1

To what extent is there a need for the storage of electrical energy in the built environment, now and in the future?

The need for the storage of (sustainable) electrical energy in the built environment is quite small at present. In the future the storage of electrical energy in the built environment is likely to take place due to the need for the decentral producer to be able to trade more effectively. This means the consumer/decentral producer with a storage medium will be able to charge when electricity prices are low and discharge when prices are high. Peak-valley compensation, supply and quality optimisation and peak shaving are of minor importance in the built environment. In addition it can be expected that policy at European and national levels will contribute to more development and the use of decentrally generated energy, which could subsequently be an important driver for storage media in the built environment. Also trends such as multifunctional land use, electrification, scale reduction and the tendency towards decentralised smart shared electricity production will potentially stimulate and speed up the development and implementation of the storage of electrical energy. However in contrast to these developments in favour of the use of storage at a smaller-scale, the costs of the realisation of large-scale flexibility are relatively low.

2.2 Secondary question 2

Which methods of electrical energy storage could be considered at the building and district levels?

To answer this question the following subsidiary questions will be considered:

a. Which selection criteria must be used for the storage of electrical energy in the built environment?
b. Which storage methods might be feasible?
c. Which storage methods are most suitable for the built environment?

2.2.1 Selection criteria

Not every method for the storage of electrical energy is suitable for use in the built environment. Applications for the storage of electrical energy can be typified in by the following technical characteristics that have been used in this investigation as exclusion criteria for use in the built environment:

- Power (W) in relation to domestic housing, offices and districts.
- Discharging time for a given power in actual application(s)
- Response time (s);
- Energy capacity (kWh) in relation to domestic housing, offices and districts.

Relating to our research question, the use of the storage of electrical energy in the built environment, these technical characteristic criteria form the basis on which storage methods at building and district levels have been selected.

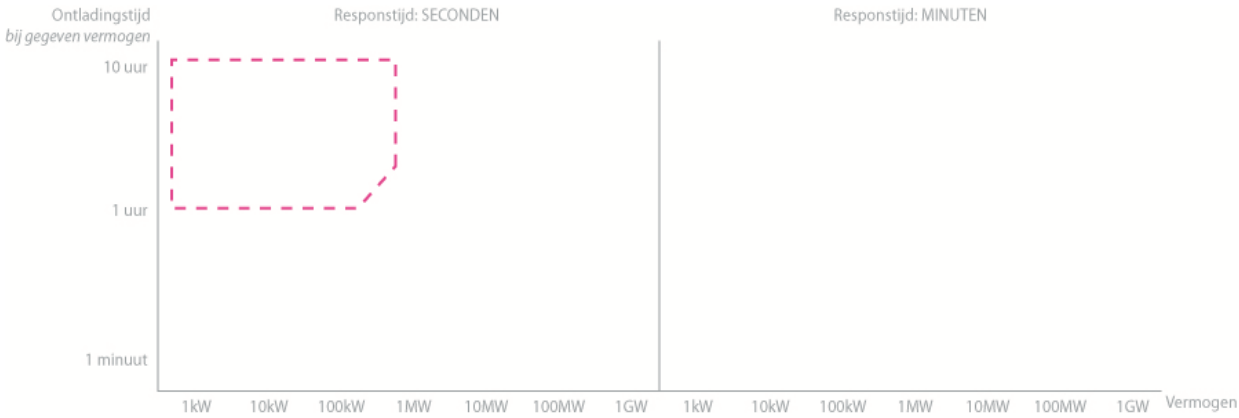
Power: Only a limited amount of power is required. Only one house, building complex or district has to be provided with electricity. An average district of 500 houses has been estimated to have a demand of a maximum of 1 MW (assuming the simultaneous use of 2 kW per household). Decentrally generated electricity is equally limited. As an indication, a ready-made solar panel package for a single household has a maximum power of 2.66 kW (MetDeZon, 2011). The power of the storage medium is therefore estimated to be in the range up to 1 MW.

Discharge time: The discharge time is the time that a storage system needs for complete charge or discharge. Considering the drivers for storage in the built environment (from trade to supply optimisation, from day- night compensation to season cycle bridging) a charging and discharging time of a few hours is assumed to be a suitable profile. A longer discharge time is acceptable for bridging the season cycle.

Response time: The response time relates to the time in which the system can react to the (change in) supply and demand. Consumer behaviour is characterised by direct access to electricity supply from the storage medium and an expected response time of a maximum of a few seconds. In addition sustainable energy supplied by solar panels for example will experience a lot of fluctuation in the supply of energy. In order to store this energy, the storage system must react immediately and a response time of a few seconds is needed.

Energy capacity: In principle the capacity of the system has already been defined by the discharge time and power described above. Because capacity provides an emotionally satisfying measure, this is stated as a separate property. The power of the storage medium is estimated at 1 MW. With a discharge time of a few hours (2 to 5 hours) the capacity is in the order of a few megawatt hours (2 to 5 MWh). As an indication, an average household uses 3480 kwh/year (NIBUD, 2012). This is roughly 10 kWh/day per household and 5 MWh for 500 households. The Royal Haskoning office on George Hintzenweg in Rotterdam consumed an average of 3.5 MWh per day in 2010.

The figure below shows the specifications for storage media. The storage media that meet the criteria for storage in the built environment lie within the pink dotted line.



Translation: Discharging time at stated power; Response time: seconds; Response time: minutes; 10 hours; 1 hour; 1 minute

Sustainability

In addition to the technical criteria it is important to consider sustainability. Sustainability is often defined as the bringing into balance of People, Planet and Profit (PPP), or as in the Cradle-to-Cradle principle, as a balance between Economy, Ecology and Equity (Braungart, 2008). It is expected that the storage of electrical energy in the built environment will make it easier to make energy supply more sustainable. However, if a scarce material is used in a specific storage medium, in time it will become exhausted and not contribute to overall sustainability, however it will potentially facilitate the use of decentrally generated sustainable energy. Also if we consider the sustainability of a storage medium individually (i.e. not incorporated in the entire sustainable energy supply) there can be inconsistencies, such as the potentially long service life of a storage system with respect to the use of toxic materials. All in all sustainability in general, and certainly within the framework of this investigation, is a difficult issue.

A number of sustainability aspects have been implicitly included in this investigation. In addition to the stated technical characteristics, additional characteristics of the various storage methods have been covered, e.g.:

- Costs
- Efficiency
- Service life
- Stage of development
- Toxicity
- Safety
- Ecosystem
- Availability of materials

As stared the earlier mentioned technical criteria were used as definitive criteria for the selection for use in the built environment. The criteria mentioned above are considered to contribute towards the insight into the feasibility of storage in the built environment.

2.2.2 Survey of storage methods

The survey of the storage methods is included in Appendix 1. Also value judgements are given for the stated selection criteria where possible. To provide a picture of electrical energy storage methods at various levels, in general only the most highly developed storage methods are discussed. Not all these methods are equally suitable for use in the built environment and therefore have been considered only in outline. If a specific literature reference is not included in the survey, it is based on [Cole S, 2006] and [Baxter, 2007]. The following section 2.2.3 outlines the most promising storage methods for the built environment. This is based on the information included in Appendix 1.

2.2.3 Selection of storage methods for the built environment

As already stated, various technical selection criteria can be used for determining a suitable system for a building (or building complex) or district. The desired power should lie within the range of kW to MW with a charging and discharging time of a few hours (for which an energy capacity in the order of megawatt hours has been established). The response time must be a maximum of a few seconds. Up to now consumers are used to an immediate response to their demands for electricity. Of course the other aspects as stated in section 2.2.1 are important and in some cases even crucial.

The figure below provides an overview of the storage methods in relation to the discharging time, the power and the response time. Also the red frame indicates the border within which the storage methods must fall in order to meet to the technical selection criteria.

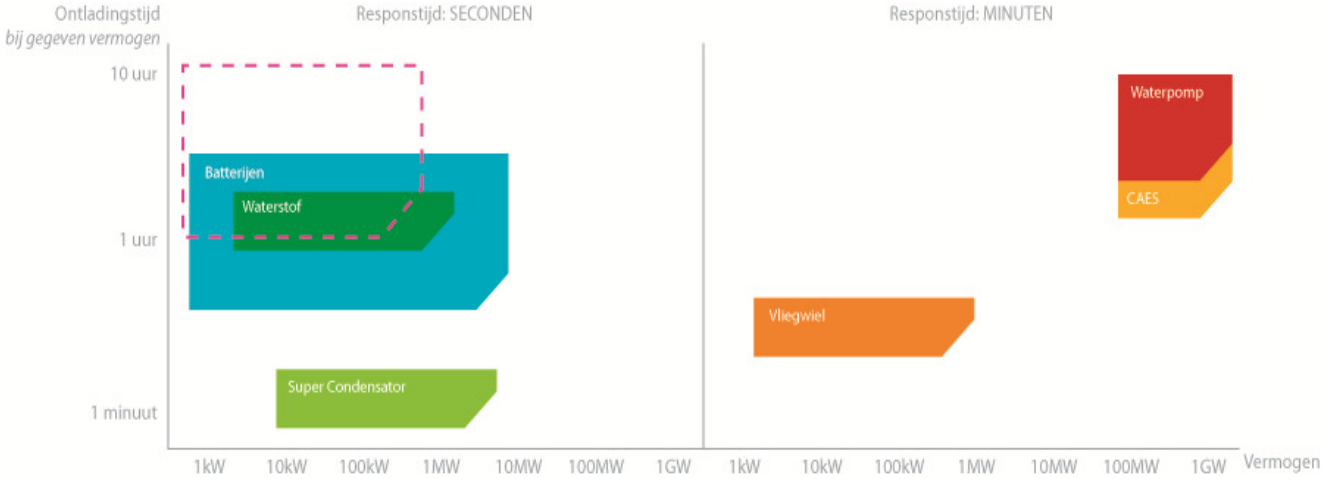


Figure 4: Storage methods in relation to discharge time and power
Translation: Discharging time at stated power; Response time: seconds; Response time: minutes; 10 hours; 1 hour; 1 minute; Batteries; Hydrogen; Water pump; CAES; Flywheel; Super Capacitor

In the first instance the storage methods were checked against the technical selection criteria. Considering the response time of the stated systems, the flywheel, compressed air energy storage (CAES) and pumped hydroelectric systems can be excluded for the scale being considered. Also it can be concluded that specific local geological characteristics are needed for the storage of energy using pumped hydroelectric systems and CAES.

The costs of the systems were also investigated (see figure below). Here a distinction should be made between the costs for power (€/kW) and the costs for storage capacity (€/kWh). Different energy storage systems with different characteristics result in different costs for these properties. As shown in the figure there is no system that is both the cheapest in terms of power and in terms of storage capacity. The power and the storage capacity are both important for an energy storage system; therefore from the economic viewpoint the super/ultra-capacitor was rejected.

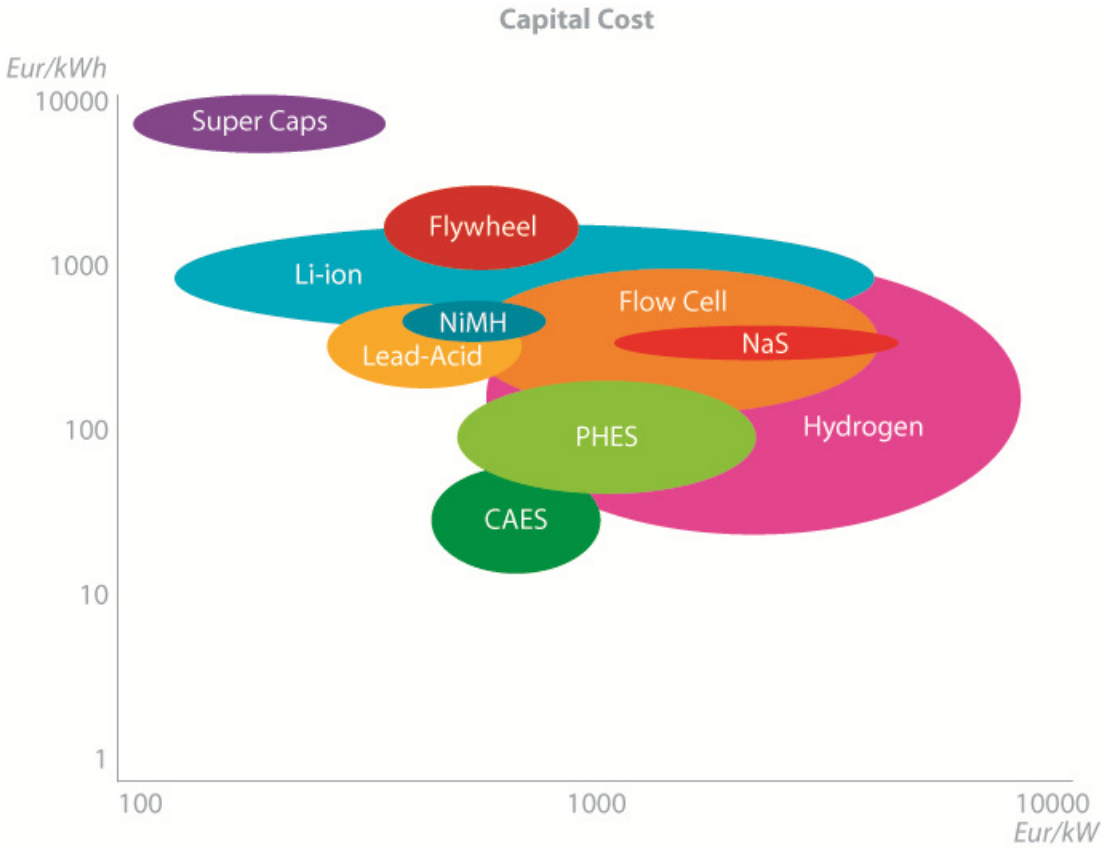


Figure 5: Costs of storage of electrical energy (based mainly on [Wagemaker, 2011])

The two remaining systems that can be considered for use in buildings or districts are batteries and hydrogen. These two options are discussed below.

<u>Batteries</u>

Lithium batteries are a suitable storage method due to their good energy density and conversion efficiency. The service life of the current generation of Li-ion batteries is acceptable and relating to toxicity, safety and the availability of materials the use of this type of battery is feasible (Wagemaker, 2011). According to Wagemaker there is sufficient *easily* obtainable lithium for the production of three times the current amount of vehicles in use worldwide. However this reasoning does not take account of political issues (relating to location of extraction), the development of other markets that might demand lithium and the quantity of more difficult to obtain lithium that may be available.

From an economic perspective, due to the relatively low storage capacity per euro spent, the battery is unsuitable for the storage of large quantities of energy (large-scale, > 100 MW installed power). This type of battery could certainly be used in buildings for overcoming short cycles, such as the day/night cycle (Mulder, 2011). Also the battery is particularly suitable for balancing variations in the network, making the entire energy network more efficient. This means that fewer losses occur because the supply exceeds demand and excess energy is stored rather than being lost.

In addition it should be noted that a great deal more research will be carried out in the field of batteries and significant developments are expected (Wagemaker 2011). The market for lithium batteries is growing fast due to the emergence of electric and hybrid cars and work is being carried out on new and improved types of batteries such as lithium-sulphur and lithium-air.

It can be concluded that in the short term at the scale under consideration use can be made of lithium-ion batteries for bridging short cycles. In the longer term lithium-sulphur and lithium-air batteries are expected to have a broader spectrum of applications. The large-scale use of batteries will certainly require a (further) price drop (Slootweg, 2011).

Hydrogen

Hydrogen has a very high energy density making it suitable for energy storage. However, at a small-scale, storage systems based entirely on hydrogen are expensive and inefficient. This is because energy is lost in every step of the storage cycle (production of hydrogen from water, storage of hydrogen and converting to electricity in a fuel cell). Although converting water to hydrogen, the storage of hydrogen and conversion to water in a fuel cell are technically possible, from a cost perspective the process is not efficient. Moreover for every component in the storage cycle there are additional options possible that all have specific characteristics each with its own benefits and disadvantages. Within the framework of this investigation it is complex to select the best general hydrogen-based system to be used at the building or district level due to the large number of potential systems for storage using hydrogen.

A great deal of research is still taking place in the field of energy storage using hydrogen. Significant efficiency gains are expected, particularly in the areas of fuel cells and storage methods.

It can be stated that storage using hydrogen offers considerable potential, particularly for large-scale storage (Mulder, 2011). We should be thinking in terms of integration into industrial complexes and non-urban areas. The hydrogen can then be stored centrally in the form of ammonia. Storage as ammonia is more efficient than storage using water from the perspective of energy[1]. This makes the system more economically attractive. However, at the building and district levels this form of storage using hydrogen is unsuitable because of the toxic nature of ammonia. (Mulder, 2011)

[1] The energy of formation of ammonia (NH_3) is lower than that of water (H_2O) from its individual elements. The formation of ammonia, $N_2 + 3H_2 \leftrightarrow 2NH_3$, has an energy of formation dH = 31 kJ per mol H_2 (Chemguide, 2011) compared to an energy of formation dH for water, $2H_2 + O_2 \leftrightarrow 2H_2O$, of -286 kj per mol H_2 (Hyperphysics, 2011). The reaction for the formation and dissolution of ammonia proceeds more easily under standard conditions (room temperature and standard pressure) than the equivalent reaction for the formation and dissolution of water.

2.2.4 Answer to secondary question 2

Which methods of electrical energy storage could be considered at the building and district levels?

From the perspective of the technical selection criteria - power, discharge time, response time and energy capacity - batteries and hydrogen are the most suitable storage methods. The use of hydrogen has disadvantages for smaller-scale applications due to the extensive storage cycle required. In the short term the system most suitable for the storage of electrical energy in the built environment is therefore the battery. A battery has good energy density (stored energy per kilogram and stored energy per volume) and efficiency (minimal losses during charging and discharging cycles). Due to the high cost of storage capacity (€/kWh) a large storage capacity is not yet economically feasible. Thus a battery system is suitable for bridging the day/night cycle, but not for the season cycle. Also a battery system can be used to make the use of energy more efficient (buffering between demand and supply). Finally it should be noted that a great deal of development is still taking place in the field of battery technology. Particularly lithium-sulphur and lithium-air batteries are expected to be of considerable interest in the future.

2.3 Secondary question 3

To what extent is there an inhibiting or a facilitating link between the use of smart grids and the use of electrical energy in the built environment?

In an ideal situation no storage of electrical energy is needed in the grid or in the built environment. In the ideal situation the quantity of energy produced and time would be exactly the same as the quantity of energy consumed and time. This ideal situation is purely theoretical and we can consider it to be an impossible reality. Matching of supply and demand is not so simple for both conventional and renewable energy production. As stated in Chapter 1 buffering and the use of smart grids can be a solution for this. This chapter provides an overview of the relationship between energy storage and smart grids in terms of conflict and dependence, or inhibition and facilitation. In the following sections smart grids are considered as a *rival* to the development and use of electrical energy storage, and smart grids will also be considered as a *condition* for electrical energy storage.

2.3.1 Smart grids as a rival to the storage of electrical energy

Metering and communication

The smart grid is based on very accurate metering of demand; more precise than the current situation. This enables a smart grid to provide more precise control of supply. Direct communication between central and decentral producers and users should make it possible for all energy producers, central or decentral, to find users for their energy in real-time. The improved predictability of demand for electricity and the improved communication will insure that there will always be sufficient consumers, minimising over-production. This will reduce the need for storage.

Demand control

In the current grid the supply of energy is matched to the demand - when there is demand the power stations produce. Many conventional power stations are not particularly flexible and not easy to control to handle fluctuations in demand. For renewable solar and wind energy, control of the supply is more or less impossible - the only option is to set a maximum capacity. In a smart grid the idea is to control the demand rather than the supply. A period of time is given within which a specific quantity of energy is demanded, so that subsequently the smart grid can determine which times during the period will be the best for energy consumption. An example of this is cooling installations that over-cool at night when excess energy is available and energy prices are low. During the day less cooling is needed: all the energy required was used in a short period during the night.

Other types of demand control are for example real-time control or demand response. This can be done on the basis of the current energy price as an incentive or on the basis of agreements with the power supplier. Consumers receive a more attractive price if on request they reduce consumption during periods of imbalance. This can happen automatically for some types of apparatus (electric boilers, dishwashers, washing

machines, air conditioners, clothes dryers and deep freezers for a short period etc) (ECN, 2003).

Controlling demand improves the ability to tune supply and demand, reduces the likelihood of over or under production and at the same time reduces the need for storage.

Infrastructure: 'The entire world' is connected

The basis of the smart grid is a much improved infrastructure - a grid where each consumer is connected to each provider. In relation to sustainable energy the idea is that 'the wind will always be blowing somewhere', 'the sun will always be shining somewhere' and 'there will always be demand somewhere'. If a strong wind in Germany causes overproduction, it is possible that there is a lull in Spain along with high demand. In this example an improved infrastructure would mean that it would not be necessary for the Spanish to construct a buffer.

ECN indicates that Europe is already controlling this. Examples are the cable connection between the Netherlands, Belgium and Germany, particularly also overseas with the UK and more recently Norway. (Nieuwenhout, 2011) Small-scale activities are of more relevance within the scope of this investigation, i.e. connecting the entire district, or the entire office complex. The medium- and low-voltage networks currently have sufficient capacity to handle a potential increased in decentral supply. (Appendix 4, Congress report).

2.3.2 Smart grids as a condition for the storage of electrical energy

Metering and communication

Storage has its uses in the present network, and also in a network where increasingly more renewable energy sources are connected. The usefulness of energy storage only really comes into its own when considering the supply or purchase from a storage medium versus the supply or purchase directly from the grid at any given moment and therefore not being tied for a longer period to tariffs based on forecasts. The decision will be made based on the price of electricity and the loading on the grid and will therefore depend mainly on the measurement of supply and demand. When considering traffic with the grid or making storage media available at any moment, the predicted improved metering and communication associated with the smart grid creates a favourable climate for the introduction of storage media to the market.

Infrastructure: divided loads

In a situation with a conventional network a storage medium would be connected to a production facility. Costs for storage in this case would be relatively high, because they would be paid by a single producer. Within the smart grid concept it is possible that the storage medium is not just linked to one production facility, but is connected to several at once. This is because decentrally generated energy can be delivered to the grid and in this way electricity from an entire district for example can be stored in a central storage medium. In this way the smart grid could lower the cost of storage and speed up its introduction.

2.3.3 Maturity of smart grids and storage media

The present networks in Europe are in good condition; they have a large capacity margin and a certain degree of redundancy (Appendix 4, Congress report). The latter means that part of the network is available for backup. When decentral generation is in use the redundancy will increase because energy can be obtained from different locations and via different routes. In short we already have a network that that appears to be prepared for the evolution towards a smart grid.

The current network has all types of demand control. Consider day and night tariffs, which stimulate people to use energy at night when there is overproduction. The first experiments with measuring and communication have already been carried out (ECN, 2011). The smart grid appears to have already taken its first steps. ECN has stated that is prepared to go further by focusing on the strengthening of the infrastructure and making the European market less rigid (Nieuwenhout, 2011).

Large-scale storage media such as hydroelectric power stations and compressed air have been in existence for many years (Baxter, 2006) and we can consider them to be mature technologies. Storage media for use in buildings and districts are still very much at the development stage. Considering storage, particularly on a large scale, it makes sense to first consider tried and tested (and moreover much less expensive) methods such as hydroelectric power and compressed air rather than small-scale storage. ECN has stated that it considers decentral storage to be the last option for improving the grid (Nieuwenhout, 2011).

<u>Costs</u>

Sustainability and security of supply are important drivers for the development of sustainable energy supply, of which renewable energy and smart grids form a part. Cost is of course a very important aspect and in addition to other aspects it will be decisive in a further revolution towards sustainable energy supply. In the question as to whether storage media will ever get off the ground there is also the component of cost comparison with alternatives to avoid imbalance. For example this can be in the coordination of energy production, transmission or storage in a medium. Incidentally this question applies not just to the central producer, but also to the decentral producer. The latter must generally make other cost considerations before proceeding with supply or storage.

The costs and benefits of both smart grids in general and storage in particular are difficult to calculate for large-scale facilities (Slootweg, 2011). Therefore it was decided to clarify the costs of storage in relation to the tariffs for electricity from the grid and from feed-in for decentral generation in the built environment. More information about costs is included at the end of secondary question 4.

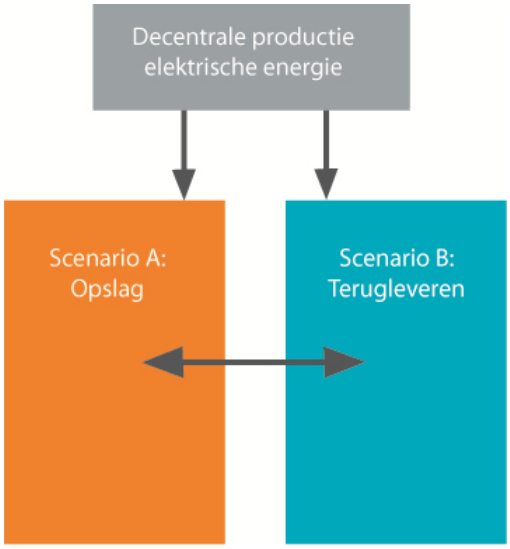
2.3.4 Answer to secondary question 3

To what extent is there an inhibiting or a facilitating link between the use of smart grids and the use of electrical energy in the built environment?

Imbalance in local generation and local consumption in the smart grid can be handled by local solutions (storage or demand control) or by a higher network. Aggregating imbalance at a higher level can reduce the total risk of imbalance. This does involve costs (e.g. transmission and control power).

Smart grids make this local balancing using local storage technically possible and could therefore have a stimulating effect. On the other hand, due to the linking with higher network levels the smart grid could make balancing possible at a higher network level. And vice versa, potential imbalance situations in the higher network levels could be taken up by the local smart grid.

Considering the stage of development of the current grid, its high operational reliability and the potential added value of information and communication technology, it is likely that in the short term mainly solutions aimed at optimising the existing grid in the direction of a 'smarter grid' will take place. This means that storage will not be used. When storage techniques have been further developed they will be a welcome extension of the smart grid concept in which the actual use will mainly depend on the cost-effectiveness of various double scenarios. The figure below illustrates this.



Translation: Decentral production of electrical energy; Scenario A: Storage; Scenario B: Feed-in

Scenario A relates to a rise in the use of storage and scenario B relates to a rise in the amount of feed-in of electricity to the grid. Due to the current stage of development of smart grids, particularly the possibility of feed-in and the presence of storage, it is likely that in the short-term scenario B will develop. In the longer term scenario A could develop alongside B and the two could exist together. This will be covered in more detail in the answer to secondary question 4.

2.4 Secondary question 4

What is the state of the playing field for the stakeholders in smart grids and electrical energy storage and what consequences does this have for the feasibility of the storage of electrical energy in the built environment?

The insights provided in the sections above make it partly clear that the actual implementation of the smart grid, whether or not in combination with energy storage, will strongly depend on the interaction between various stakeholders. It must therefore be made clear which stakeholders will have the most influence on making the use of smart grids and/or energy storage in the built environment possible. To answer this secondary question, the following sub questions need to be asked:

a) Who plays which role?
b) What is the cost structure within the playing field?
c) What are the potential future scenarios?

2.4.1 Stakeholders: who plays which role?

Central energy producer

The role of the energy producer is to supply a given amount of energy of a specific quality. Should the central producer decide to deploy a storage medium, then for various reasons (organisational, operational and financial) it is probable that this will also be located centrally.

When the production of energy is central it is also likely that any potential storage will take place centrally. The central energy producer has a dual relationship with decentral electricity production. Decentral producers can be seen as competition, but also as the colleagues of the central producers. A central energy producer can generate business by extending its services to the smaller-scale decentral generation in the built environment. In this scenario, when a central producer is responsible for decentral production, it is possible that the central producer will decide on decentral storage of electrical energy. There is no sign of this happening in the Netherlands as yet.

Network operators

Smart grids are relevant for network operators in as far as they will alter the load on the network. Networks could come under pressure locally due to increased decentral production. With the expected rise in the future of the overall loading, storage could provide a solution. However the high-voltage grid, as well as the medium and low-voltage networks, are not expected to have capacity problems over the short to medium long-term. Energy storage linked to the medium- and low-voltage networks could be cost-effective for decentral producers. The network operator could play an investing, managing and/or exploiting role in this (Slootweg, 2011).

Government and local government

National and local authorities have the task of creating a climate that allows the development of an optimum and sustainable energy supply. They do not have the task of generating energy, but are responsible for creating favourable conditions (RWS,

2011). That a government body would become the owner of storage media in the built environment is not likely, just as it does not now own the current grid[2]. A government body can award a commission for carrying out maintenance and, due to the monopolistic position of the grid operator, can set tariffs (capacity tariffs).

The national government does play an important role in stimulating the development of smart grids, also in relation to storage. As described in section 2.1, in the past subsidies were given and there are plans for future subsidies to stimulate decentral energy production and the development of smart grids.

Consumers/decentral energy producers

The only benefits the consumer has from storage are the security of supply and quality optimisation. The current and also the future grid appear to have no problems with these points (Appendix 4, Congress report). Another situation arises when consumers do not just consume, but also produce. Not just for themselves, but also for feed-in to the grid. The phenomenon of balancing & settlement of electricity provided to the grid with the electricity bill was handled in section 2.1. In addition, from the perspective of the consumer, the rise in the use of electric vehicles would mean that an excess of electricity could be taken up by the charging of the mobile batteries[3]. The status of the current grid and the expected rise in the use of electric vehicles could actually reduce the need for stationary storage solutions in the future.

Laws and regulations: Your own network

Energy producers and suppliers are taxed by the government. Consumers producing energy for their own use do not fall under this regulation. However when these consumers begin to supply to 'their neighbours 'they will be seen as producers/suppliers and will have to pay tax. This will make supply to neighbours significantly less profitable than many people have been expecting. In practice consumers are likely to be better off feeding-in excess power into the grid (balancing & settlement). Energy suppliers are obliged to pay 'reasonable compensation' for feed-in electricity (Electricity Act, 1998). There are initiatives aimed at extending this regulation, e.g. in the case of the Homeowners' Association (*Vereniging van Eigenaren*) or in the case of energy supply within a street (e.g. solar panels on the roof of a block of flats which could be used by all flats in the building). Currently it is not clear what will happen in the near- and more distant future regarding this issue (Appendix 4, Congress report). Moreover there is no clear legal framework that facilitates the supply of sustainable energy by decentral producers (Appendix 4, Congress report).

[2] The province Limburg has stated that it is prepared to participate in the first phase of the development of a pumped storage plant for large-scale storage of energy. This will involve an investment of several million euros (FD, 2011)

[3] The use of batteries in electric vehicles arises from the need for electric transport and not primarily from the need for storage of decentrally generated electricity.

Energy suppliers/traders

Energy traders may well consider storage to give them some flexibility in the market, i.e. purchasing electricity when the prices are low and selling when the prices have risen. They have a business model without the investment risk of a power station or storage medium, so it is unlikely that an energy supplier will become the operator of a storage medium. The trader could indeed be interested in storing energy but does not have a direct interest in operating a storage medium.

A number of energy suppliers are also energy producers. An example of this is Greenchoice a company that invests in decentral production using solar panels (Greenchoice, 2011). It is quite probable that these types of parties with combined interests will be interested in storage.

Large-scale consumers

Large-scale consumers could be interested in storage to increase security of supply. Power failures can have disastrous consequences and therefore form a huge risk for a number of sectors (e.g. hospitals and companies with continuous operating processes). In many instances this type of organisation has emergency generation facilities. This investigation does not cover large-scale users and storage for these purposes in any further detail. This may well be worth looking at in any subsequent investigation where storage in a wider context than the built environment is being investigated.

Investors, housing corporations and project developers

The incentive for an investor is financial. Investors will choose smart grids or storage as soon as they have the idea that these will be profitable. Storage is viable on a large-scale (e.g. reservoirs and compressed air systems), but on a small-scale there is currently no interest. This also applies to project developers, who in this report are considered to be investors in the housing sector. Housing corporations may collectively choose to integrate energy production into their houses and complexes in the context of the energy footprint of their buildings, as discussed in 2.1.4. In this case the housing corporation is an energy producer and from that perspective could choose to incorporate a storage system and in turn to incorporate this into the rental of its houses. This would make the housing corporation an energy producer with the associated responsibilities. However for the locating of energy production units and storage media the housing corporation would not need to be the owner of the installations. One possibility would be to let a third party operate power generation and possibly also storage facilities.

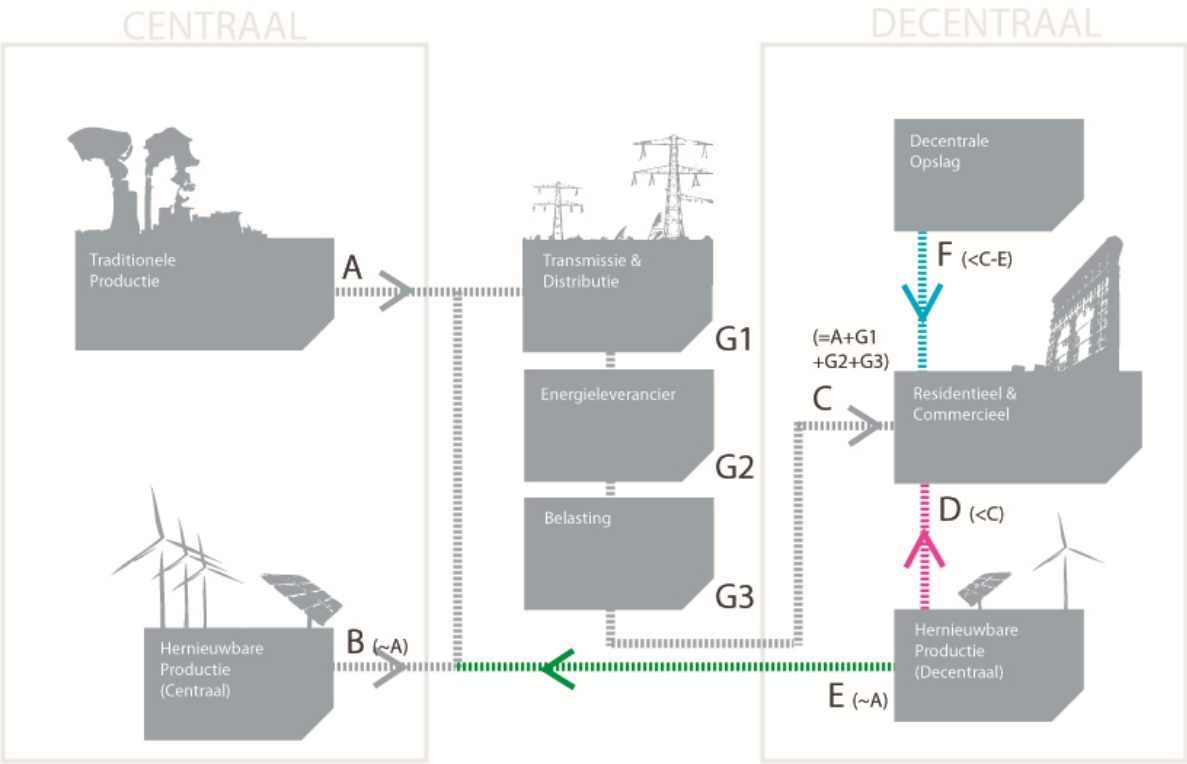
2.4.2 Costs

At large-scale both costs and profits for smart grids and in particular for storage are difficult to calculate (Slootweg, 2011). However to provide an indication of the cost structure, in this exploratory research the cost of storage in the built environment has been compared to the tariffs for electricity from the grid and feed-in tariffs.

The figure below illustrates the relationship between stakeholders and storage costs in a simple application for a consumer/decentral producer who has a storage medium and is connected to the grid. (Variants could be a storage medium owned by multiple

consumers or a storage medium owned by another party. Section 2.4.3 provides more information about this).

Figure 6; Relationship between stakeholders and costs of storage



Translation: CENTRAL; DECENTRAL
Decentral storage; Traditional production; Transmission & distribution; Residential and commercial; Energy supplier; Residential & commercial; Taxation; Renewable production (central); Renewable production (decentral)

The left half of the figure illustrates the centralised activities, the right half the decentralised. The arrows show the flow of electricity. The letters next to the arrows stand for the values allocated to these electricity flows.

<u>A, Cost price of traditional production</u>

The value of A is determined by the costs plus margin of the energy producer. In practice this comes to around €0.04.

<u>B, Cost price of central renewable production</u>

The value of B is also determined by the costs plus margin. This form of energy generation is profitable when it can compete with traditional production, or when B is equal to A. Reasons other than pure economics (such as sustainability) could result in B having a higher value than A.

G1, G2, G3

The G group interprets the value of 'the grid' and consists of costs and margin for distribution and transmission, trading costs and tax.

C, Consumers' tariff

The consumers tariff consists of the cost price for energy production (A or B), plus the costs to transmit the energy to the consumer (G group). As a formula: C = A+G1+G2+G3.

D, Costs of decentral renewable production

In the first instance consumers install production units to produce energy for themselves. Decentral production competes with central production and will only be profitable if D is smaller than C. Other reasons for choosing decentral energy production rather than central production (e.g. sustainability) have not been considered.

E, Feed-in tariff

As shown in the diagram centrally generated energy is competitive with decentrally generated energy. Not only in domestic houses, but also on the energy market. The consequence of this is that the price for decentrally generated energy in a free-market situation must be the same as that of centrally generated energy. Or, E = A. In the current situation E is being held artificially high. Through the netting regulations, the consumer is paid a feed-in tariff that is the same as the tariff for consumption. In that case E = C.

F, Costs for decentral storage

F is the value at which the consumer will be prepared to consider storage. In this situation storage competes with feed-in. Because, from the consumer's perspective, F is a cost and E is a profit, this results in the formula F < C–E. Subsidy in the form of balancing and settlement works against the use of storage. Indeed, with full settlement C = E, with F = 0 as a consequence. The storage medium would therefore need to be free. As long as sustainable energy production in the form of decentral sustainable production is supported by (full) settlement it will not be economic (i.e. not profitable) to store electrical energy.

Illustration of the costs of decentral storage

Energy in the European energy market costs an average of around 4 ct/kWh; equal to A. The maximum price paid in the market for energy is approximately 7 ct/kWh; equal to B. The consumer pays 4 or 7 ct above this up to a total of around 23 ct/kWh; flow C. Energy from decentral generation that goes directly into the energy market (flow E) is traded for a 'reasonable price' - equivalent to approximately the maximum price for energy in the market, about 7 ct (E = A to B).

If balancing & settlement is not carried out, the costs per kWh from a storage medium need to amount to F < C–E or 23 – 7 = 16 ct to be profitable. If the balancing & settlement regulation is used then E = C = 23 ct. F is then 23 – 23 = 0 ct, or in other words the medium must be cost free to be profitable.

The following section covers a few possible future scenarios based on this cost structure.

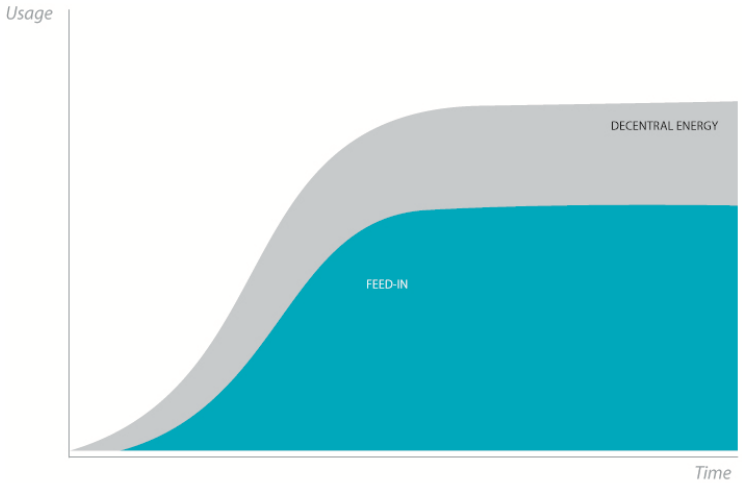
2.4.3 Scenarios for decentral storage

As indicated in this chapter various different interests are involved and it is difficult to predict what exactly will happen in the future. This section considers four scenarios that fall within the scope of the investigation.

The four scenarios for the relationship between the use of decentral electricity generation, feed-in, individual storage and communal storage are presented schematically in the figures below. A constant factor here is the assumed rise in the use of decentrally generated energy. Each of these scenarios provides a realistic assessment of the future and in the answers to the subsidiary question we discuss which of these scenarios we consider the most plausible.

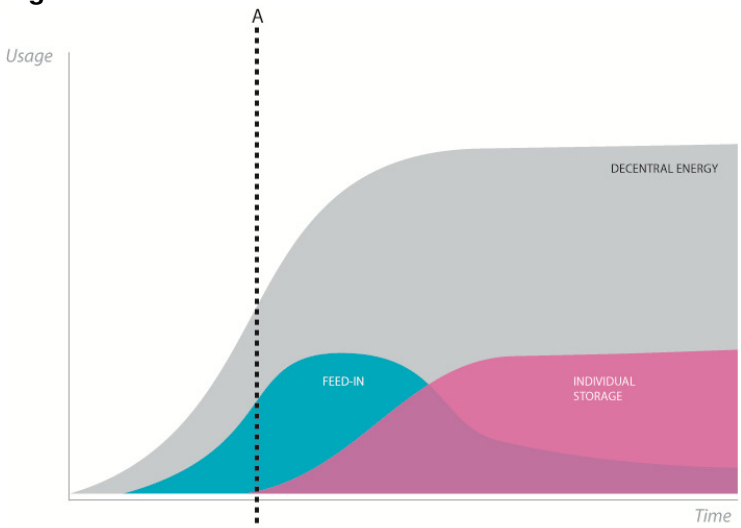
NB. A fifth scenario relating to mobile storage falls outside the scope of this project and has not been covered. In this scenario, which principally considers electric transport as a mobile storage medium, the use of both individual storage and feed-in are involved. In this case feed-in facilities are essential to provide the mobile medium with a connection. A characteristic of this scenario is that the development in the use of the storage medium is independent of the development in the use of decentral energy production.

Figure 7: Collectivism



Future image 1: Collectivism
In the transition to the smart grid we are not making use of the stationary storage of electrical energy in the built environment. Feed-in to the grid is the most cost-effective for the decentral producer. The reasons for this lie in the fact that there has been no drop in the price of storage media, new cost constructions relating to (local) feed-in, continuing subsidy for feed-in, good balance between supply and demand and a combination of these.

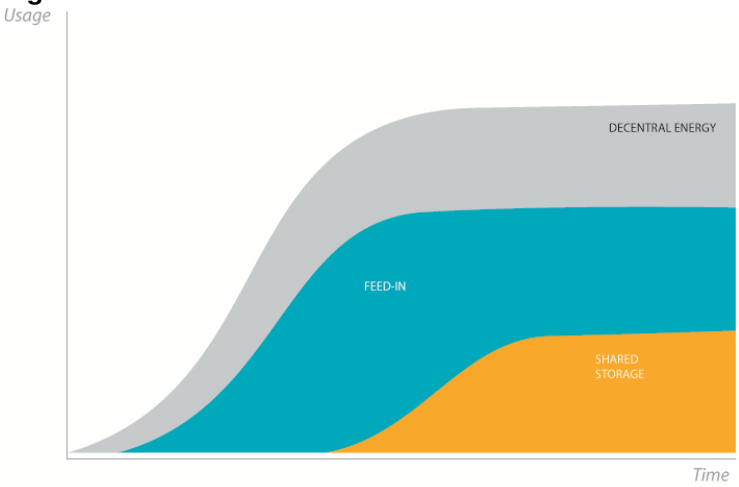
Figure 8: Individualism



Future image 2: Individualism

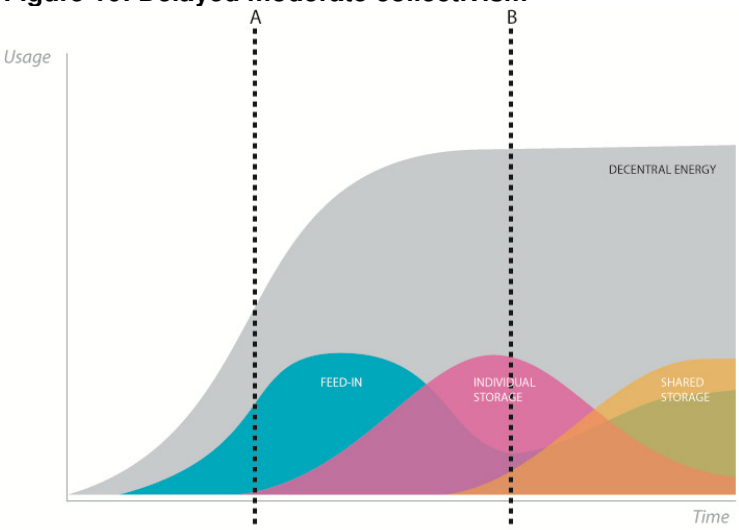
This scenario is characterised by moment A, shown by the dotted line in the figure, when the storage of electrical energy will have the same value for the consumer as feed-in (grid parity). Currently feed-in by domestic householders in the case of normal use and production is subsidised to the extent that the tariff for purchasing and selling electricity for the consumer is the same. In this situation the costs for a storage medium would have to be equal to zero for storage to be financially viable. This arrangement is a subsidy intended to help new technologies get off the ground. It is therefore the intention that when the technology has become mature the subsidy will be reduced or even completely removed. Moment A shows the time when the subsidising of feed-in has dropped to the extent that storage is more advantageous for the consumer/decentral producer. From this point the use of individual storage will rise and feed-in will rise less steeply and even decrease. In a realistic final scenario, the use of individual storage will stabilise, just as the amount of feed-in by individual consumers during periods of imbalance will continue to take place (when the storage medium is fully charged and overproduction is taking place). In this scenario small-scale storage will be used within the built environment (domestic housing or offices). An initial reason for this is that the barrier of conflicting interests will be circumvented due to the minimal amount of cooperation needed. A second reason is that it will be economically attractive for the consumer to start storing electricity.

Figure 9: Moderate collectivism



Future image 3: Moderate collectivism
To make use of storage media within larger collective situations (building complexes/districts) offering economies of scale, governments have influenced the playing field by eliminating the conflicting interests and creating conditions for better cooperation. Here we see a scenario similar to that for the future image Collectivism, where feed-in is the best option for decentral producers, with as extension the organised use of communal storage for building complexes or districts.

Figure 10: Delayed moderate collectivism



Future image 4: Delayed moderate collectivism
A fourth scenario demonstrates a transfer phase from future image Individualism to Moderate collectivism. At moment A the same situation is encountered as in the scenario for Individualism, the moment when the storage of electrical energy for the consumer is just as beneficial as feed-in (grid parity). Developments in the field of storage continue up to a point where economies of scale can be utilised. This point is shown by dotted line B in the figure. As in the future image Moderate collectivism, governments have influenced the playing field by eliminating conflicting interests and

creating conditions for better cooperation, in order to make shared storage cost-effective (cost neutral).

2.4.4 Answer to secondary question 4

What is the state of the playing field for the stakeholders in smart grids and electrical energy storage and what consequences does this have for the feasibility of the storage of electrical energy in the built environment?

What is the state of the playing field?
Many stakeholders are involved in smart grids and the storage of energy. To a greater or lesser degree they all have an interest in the development of smart grids and any storage within them. A characteristic of the playing field is that the stakeholders concerned have partly conflicting interests and goals. For example, traditionally there has been the central producer who does not benefit from decentral production, or the supplier who does benefit from smart grids (more trade) but receives no benefit from decentral storage. The likelihood of fruitful cooperation and the alignment of mutual interests and goals appears at the moment to be non-existent.

And what consequences does this have for the feasibility of the storage of electrical energy in the built environment?
The current network - and certainly with the expected modifications relating to smart grids - does not need decentralised storage in the Netherlands. It is therefore not to be expected that mandatory policies and legislation relating to storage will be introduced. However in spite of this, one reason to choose storage could be economic. The cost effectiveness for the various stakeholders will therefore be decisive. If decentral storage does go ahead then it is probable that the first party for which this storage is profitable will be the consumer/decentral producer.

The consequence of the playing field for the feasibility is that shared (organised) storage will not be used for the time being. It is more likely that one party will start by itself. Within the framework of the scenarios sketched it is probable that if storage does go ahead, in the first instance the scenario Individualism will be at the fore. Storage offers economies of scale and when the smart grid (including storage) is further optimised it is to be expected that shared storage will eventually be utilised. Therefore we anticipate a scenario similar to that in Delayed moderate collectivism.

3 CONCLUSIONS

To what extent is the storage of energy at the building and district levels desirable in the short and longer term taking account of the solutions offered by smart grids?

The need for the storage of (sustainable) electrical energy in the built environment is currently very low. From a technical perspective (capacity), the current and future network in the Netherlands does not need decentralised storage for energy supply. In future the storage of electrical energy in the built environment may well begin, based on the decentralised producer's need to be able to trade more effectively. Therefore the consumer/decentralised producer will be able to store electricity when prices are low and discharge when prices are high.

This need for storage could arise from an increase in decentrally generated electricity. It is expected that European and national policy will contribute to more development and use of decentrally generated electricity. The same applies to trends such as multifunctional land use (integration of residential buildings and energy generation), electrification, downscaling and the tendency towards smart sharing. These are stimuli that could speed up the potential development and implementation of the storage of electrical energy in the built environment.

The emergence of smart grids could reinforce the stimuli mentioned above, but it could also weaken them. Considering the stage of development of the current network (high operational security and the ability to take high loads) and the potential added value of information and communications technology, it is probable that in the short term most developments in the field of optimisation of the existing network will be towards a smart grid. This involves no urgent need for storage.

The playing field within the energy sector is characterised to a degree by stakeholders having conflicting interests and goals. There is currently very little likelihood of fruitful cooperation and a realistic mutual alignment of interests and goals. The levels (house or district) at which there is a need for storage is dependent on the cost structure and on this alignment of interests. If decentralised storage is to take off in the short term, there is a realistic chance that this will be on an individual basis. All in all it can be stated that when storage techniques have further developed, the technology could be a welcome extension of the grid, particularly when this has evolved at least to some extent in the direction of a smart grid.

And which storage methods will be the most feasible for implementation?

Considered from the perspective of the technical selection criteria (power, discharge time, response time and energy capacity) batteries and hydrogen are the most eligible storage methods. Due to its extended storage cycle, hydrogen has disadvantages and its small-scale use is complex. The system that in the short term is likely to be the most suitable for the storage of electrical energy in the built environment is therefore the battery. There are currently many different types of batteries. For bridging short cycles, Lithium-ion batteries would currently appear to be the most favourable, considering their technical specifications and the expected developments in the market for mobile storage. In the longer term, lithium-sulphur and lithium-air batteries are expected to come into use and these are likely to have a wider range of applications. The wide-scale use of batteries will require a (further) drop in their costs.

4 DISCUSSION AND RECOMMENDATIONS

Smart grids, (sustainable) decentral energy production and storage cover three extensive research fields. This exploratory research has given an indication of the relationship between the three. The need for and feasibility of the use of energy storage in the built environment has also been discussed. It was necessary for us to abandon broadening and deepening our investigation on several fronts. It is important to place the findings in perspective. Below are several recommendations for further and more intensive research. Although the three subjects should not be considered as separate fields of research because of their close relationship, for the readability of this chapter it was decided to divide it into decentral generation, smart grids and energy storage.

4.1 Decentral energy production

Development of large-scale central versus small-scale decentral energy generation

The transition towards a sustainable energy supply is already underway, but the world will continue to make use of a mix of conventional and sustainable sources for many years. Conventional energy production will become increasingly more modern, not only in efficiency, but also in flexibility. Coal-fired power stations only have a limited amount of flexibility – they are not constructed to meet rapidly fluctuating demand. Gas-fired power stations can provide a limited degree of flexibility. ECN has indicated that it will focus on research into making gas-fired power stations more flexible (Appendix 4, Congress report). This exploratory research has discussed policy and identified trends that could stimulate decentralised sustainable energy production in the built environment. It did not however establish that this will actually happen. In this light it is important to compare the current strong growth of modern central conventional (and to a lesser extent sustainable) supply of electricity with the expected future growth of decentralised power supply in the Netherlands. This development will certainly influence the degree to which decentralised sustainable generation takes place in the short and longer term. But how big will this influence actually be?

Split incentives: fast trading!

It has been made clear that the playing field within the energy sector is characterised by stakeholders with conflicting interests and goals. Currently there appears to be no chance of fruitful cooperation and a sensible mutual alignment of objectives and goals and this will inhibit further introduction of smart grids and storage. This investigation concluded that the government will need to play a facilitating role in aligning these conflicting interests. This investigation has not gone into detail about the willingness of the government to facilitate this or how the government should do it. Where should the government spend the money it collects from taxation? Which legal frameworks must be modified to make decentralised production and supply easier? Price incentives and pricing control are important options for stimulating stakeholders to invest in more flexibility. The NMa (Dutch Competition Authority) will have to play an active role here to make generation and demand behind the meter more easily possible. Modifications to the tariffs and settlement structures are necessary to enable split incentives to be eliminated. In short how can the interests and objectives within the playing field described actually be brought into alignment?

System variants

Which energy system is desirable in which situation? There are many elements that characterise an energy system at the building or district level. Generation (solar, urban wind, electric cars, heat pumps and micro-CHP), storage methods and types of districts (demographic structure, type of building and demand patterns) are elements that typify a system variant. It is therefore desirable to sketch several individual decentral systems of electricity supply. Working with multiple system variants can offer insight here, as was done in an investigation by Planbureau voor de Leefomgeving (Planning for the Built environment) (Planbureau, 2009).

4.2 Smart Grids

Learning by Interacting: what's going on?

Developments in the field of energy storage and smart grids could be very fast as a considerable amount of work is being carried out in these fields in the Netherlands, Europe and worldwide (particularly in the USA). Further intensification of these activities and dissemination of the knowledge and experience accumulated (research, pilot projects etc) is important to speed up the transition towards the smart grid. Therefore it is desirable to have access to a thorough overview of these activities. When drawing up this type of overview a sub-classification could be made of activities in universities, institutes, companies, consulting bureaus and governments. It could be worthwhile classifying these activities by time to expected market introduction (is it fundamental research, a pilot project or competitive activities?). It is outside the scope of this investigation to include a detailed list of current developments, however a limited summary follows:

- There is a great deal of activity in the United States and particularly in Florida where there are some very interesting developments.
- Smart grids have attracted considerable attention in Europe, see the Seventh Framework Program for Research and Technological Development (FP7)
- In Europe, Kema has carried out pilot projects in several member states with various small-scale storage methods.
- In Germany the E-Energy projects are an interesting example.
- In the Netherlands in 2011 it was possible to apply for subsidies for the project Smart Grid Trials for which the Ministry of Economic Affairs, Agriculture and Innovation made €16 million available.
- In Hoogkerk in the province Groningen in the Netherlands, 25 domestic houses were connected in an experimental setup (FD, 2011)

Similar developments

Developments towards a smart grid are developments in which not just technical aspects play an important role, but social and cultural aspects are certainly also influential. How can we organise that we generate energy (preferably sustainable energy) in an optimum way both centrally and decentrally? And how can we ensure that this energy can be shared for a reasonable price? The parallel with the exceptionally fast growth of the Internet can be helpful here. Indeed, publicly accessible information has traditionally been stored centrally in archives and libraries, and the sharing of information was a time-consuming task. With the advent of the digital age and Internet

we now have both individual data storage options as well as the infrastructure to share it without much effort. Current trends in this area seem to point towards more focus on infrastructure and centralised storage. The manner in which this rapid emergence of information sharing (1990 compared to 2011) is organised could teach us how that we could make the network as we understand it today more intelligent.

Solidarity

A political argument against smart grids is the solidarity principle – everyone pays for the energy supplies of everyone else. By setting up a smart grid (and particularly a microgrid) a group shuts itself off from the national grid (often partly). This means that the group pays less tax towards the upkeep of the grid. The consequence is that people who, for whatever reason, cannot or will not participate in a smart/microgrid must pay more towards the national grid. At the same time it is desirable, certainly in the initial phase of the smart/microgrid, that the national grid is available if the smart/microgrid does not work properly. This argument must be taken into account in the political climate of the Netherlands.

4.3 Energy storage

Electric Vehicle as a mobile storage medium

This study has briefly examined the impact of the potential of the large-scale introduction of electric transport on smart grids and storage. This is an important development considering the enormous potential relating to the removal of imbalance in the energy market. Considering the number of vehicles involved, electrical transport could on the one hand result in a much increased demand for electricity and on the other bring a lot of flexibility to the electricity networks. Every electric car is a potential storage medium due to the capacity of it battery. Better insight into the potential large-scale introduction of electric transport and mobile storage media will help give more insight into how far in the future there will be a need for stationary decentralised storage, and also the car being used as a small power station.

The costs of storage

This exploratory research has provided a degree of insight into the costs of storage. The extra costs of storage of decentralised sustainably generated kWh have not been specifically stated. These extra costs will of course be dependent on service life. An insight into the costs and the relationship with the price drop of sustainable energy technology, such as solar panels, is desirable to indicate the likely profitability. This will enable the government to develop improved targeted pricing policies.

The behaviour of early adopters

This exploratory investigation has largely provided an overall picture rather than a detailed problem analysis. This has limited the attention paid to aspects that influence the actual purchase of a storage system. Indeed, if a storage system is economically viable for the user this will not per definition lead to its purchase and use. More insight into the aspects that influence adoption is important. Therefore in addition to cost considerations, key aspects that relate to: relative advantage (including price and

perception of sustainability), compatibility, complexity, trailability and observability are relevant (Rogers, 1995).

Large-scale consumers

Large-scale consumers could be interested in storage due to security of supply issues. Power cuts can have disastrous consequences for a number of sectors (e.g. hospitals and continuously operating companies) and are therefore a large risk. In many cases such organisations have an emergency generator. This investigation has not examined the situations of large-scale users and storage on this scale. This deserves consideration for potential future research into storage in a broader context, e.g. considering emergency electricity needs. Systems that make use of hydrogen are expected to be of more interest in this context.

Sustainability of storage media

The origin of the interest in the development of energy storage in relation to smart grids came from the requirement to make energy supplies more sustainable. A summary of the impact on sustainability in terms of various criteria (including scarcity of materials, toxicity, safety and service life) is highlighted per storage medium. Additional investigation into the sustainability of storage media will provide insight into the degree to which the potential use of storage media is desirable. Reusability of materials and corporate social responsibility are also relevant here.

5 RECOMMENDATIONS FOR TVVL

Given the mission of TVVL we can say that decentral generation, smart grids and energy storage are particularly relevant subjects for the platform. TVVL is already active in the field of smart grids. Several workshops have been organised, investigations (including this one) are being carried out into smart grids, and members of TVVL have given presentations to congresses and symposia. In the context of smart grids and storage TVVL is already fulfilling the following parts of its mission:

- *Gathering, compiling and developing knowledge.*
- *Transferring knowledge within the context of public debate, daily events and adjacent sciences.*

The question is which concrete steps TVVL should take next to meet the remaining parts of its mission:

- *The influence on people and their functioning.*
- *The translation of knowledge into innovative technological solutions.*
- *The organisation of practical guidelines and tools.*
- *The development and implementation of the technology of building related facilities.*

When establishing follow-up steps relating to smart grids and the storage of (electrical) energy it is important for TVVL to be clearly focused on its ambitions and capabilities (how much influence can be exerted?). Will TVVL focus mainly on the technical aspects of building facilities or can and will TVVL widen its scope? As indicated by this exploratory research, decentral generation, smart grids and energy storage are subjects that cannot be seen separately from developments outside building technology and the building related playing field. The role model (Royal Haskoning, 2008) can be helpful in resolving this issue. The role model describes the following steps:

- *Step 1: Choose position and role*
  The position of TVVL is determined based on defining the ambitions and the possible sphere of influence of the organisation.
- *Step 2: Define the bandwidth*
  From the chosen role the ambitions and potential sphere of influence can be specified more accurately. The target groups, the instruments available to TVVL, the personnel capacity available and the financial means are important criteria here.
- *Step 3: Formulate or check the actions*
  Once the role has been chosen and the role definition specified, new actions can be formulated or existing actions checked.
- *Step 4: Explore the competencies*
  This step provides insight into the strengths and weaknesses of the competencies available within TVVL. This will make it clear which competencies still have to be developed to give substance to the chosen role.
- *Step 5: Evaluate the choices*
  Progressing through the first four steps brings consistency to the position, role, activities and competencies of TVVL in relation to its ambitions. The steps can be run through once again to provide a consistent role for TVVL in practice.

After following steps 1 and 2, new actions can be formulated in step 3. The discussion points and potential issues for subsequent research stated in the previous chapter may be taken into consideration in step 3.

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19 April 2012

Appendix 1
Outline of methods for the storage of electrical energy

Flywheel

A flywheel is a body that rotates round an axis. Excess energy can be used to rotate a flywheel using an electric motor and in this way store the energy in the form of kinetic energy. The moment of inertia is the most important property concerned and basically it indicates the degree to which an object opposes change of speed of rotation about its own axis. The greater the moment of inertia, the more difficult it is to get the flywheel started and the greater the moment of inertia, the more energy you must use to get the wheel to turn faster and therefore the more energy you store in the system.

In modern flywheel-based energy storage systems the flywheel is set up in a vacuum to prevent friction with air. The flywheel can be simply driven by an electric motor and the energy returned using a dynamo.

Extensive materials research has been carried out into the development of flywheels and new composite materials give considerably improved performance at a lower cost.

Facts:

- Power: approximately 3 kW–20 MW (KEMA, 2007)
- Response time: ~ 10–15 min.
- Efficiency: maximum 95% (Makarov, 2008)
- Service life: approximately 20 years.
- Stage of development: A proven technology that is used on a small-scale; considerable further development is possible.

Advantages:

- Efficient conversion.
- Long service life.
- High energy density (energy per unit volume)
- Fast response time and fast charge/discharge cycle.

Disadvantages:

- Needs a relatively large amount of maintenance.
- High initial costs.
- Difficult to use at the building/district level due to safety issues (mechanical flywheel explosions)

Water pump

Excess electrical energy can be used to pump water from a low lying reservoir to a reservoir at a higher location. In this case the energy is stored in the form of potential energy. When there is a demand for energy the water is directed to flow back down to the lower reservoir through a turbine, thus generating electricity.

The height difference is usually dictated by the geology of the area. Developments in pump technology have enabled a wider range of locations to be used.

Facts:

- Power: approximately 200 MW–2 GW.
- Response time: ~ 10–15 minutes.
- Efficiency: ~75%.
- Service life: approximately 50 years.
- Stage of development: A proven and used technology that is used for large-scale applications.

Advantages:

- Low-costs.
- High reliability and long service life.
- High-power.
- Moderate response time.
- Efficiency around 75%.

Disadvantages:

- Specific geological conditions are needed (difficult to use in the built environment)
- Potentially adverse effects on the prevailing ecosystem. The construction of a large water basin (whether or not in the form of a reservoir) introduces new elements into the prevailing ecosystem or the existing environment.

Compressed Air Energy Storage (CAES)

A series of compressors can be used to compress air which is stored underground. The energy can be released when required by passing the compressed air through a turbine. The compression of air generates a lot of heat and the decompression uses heat. For the efficient use of this type of system it is essential that this heat is effectively stored or used (Advanced Adiabatic CAES: AA-CAES).

Facts:

- Power: approximately 25 MW-2.7 GW (Linden, 2002)
- Response time: ~ 10-15 minutes.
- Efficiency: ~ 70% (without making useful use of heat generated, as in AA-CAES)
- Service life: maximum 50 years.
- Stage of development: Proven and used technology.

Advantages:

- Long storage periods without energy loss are possible, assuming the storage medium is airtight.
- High-power.
- Reasonable response time.

Disadvantages:

- Specific geological conditions are needed (not always usable in the built environment)
- High costs for the underground storage.

Electrochemical energy storage in batteries

We are used to using batteries and rechargeable batteries for small-scale applications (mobile telephones, cameras etc). Batteries can also be used on a large scale. There are there are different types of batteries with varying properties. The current technologies are listed below:

- Lead-acid
- Lithium-ion
- Redox flow
- Sodium-sulphur

Potential future technologies:

- Sodium-water
- Lithium-sulphur
- Lithium-air

The principle of these batteries is the same - electrical energy is stored electrochemically. There is currently a great deal of development taking place in the field of battery technology. Lithium–ion batteries in particular have been the subject of extensive research due to their large-scale use in mobile consumer electronics and the expected rise in use of electric cars. The facts about current and potential future variants follow:

Existing batteries

Lead-acid:

Facts:

- Power: From the order of kilowatts to approximately 50 MW.
- Response time: A few seconds.
- Efficiency: 70-80% (Wagemaker, 2011)
- Service life: 500-800 cycles (Wagemaker, 2011)
- Stage of development: Proven and used technology.

Advantages:

- Inexpensive.
- Many possible applications (scalable from small to large)
- Very short response time.
- Efficiency around 80%.

Disadvantages:

- Short service life.
- Low energy density.
- High self-discharge (lose charge when not in use)
- Sensitive to environmental conditions (temperature)
- Storage capacity reduces when not fully charged/discharged.
- Contain toxic materials (such as lead) which have potential environmental consequences.

Lithium-ion:
Facts:
- Power: In the order of kW to approximately 50 MW.
- Response time: A few seconds.
- Efficiency: 90-98% (Wagemaker, 2011)
- Service life: 1000-10,000 cycles (Wagemaker, 2011)
- Stage of development: Proven and used technology; a good deal of development still possible.

Advantages:
- Many possible applications (usable from small to large-scale)
- Very short response time.
- Little energy loss.
- Efficiency up to 98%.
- High energy density.

Disadvantages:
- Sensitive to environmental conditions (temperature))
- Expensive technology. The development of the electrical car may enable production costs to reduce due to upscaling (Mulder, 2011)

Redox Flow:
Facts:
- Power: maximum 1 MW.
- Efficiency: 65-80% (Wagemaker, 2011)
- Service life: 2000-15,000 cycles (Wagemaker, 2011)
- Stage of development: Demonstration and a few commercial projects completed.

Advantages:
- Instantaneously refillable by replacing electrolyte.
- Inexpensive.
- Long service life.

Disadvantages:
- Corrosion problems because sensors and pumps are necessary.
- Average efficiency.
- Low energy density.

Sodium – sulphur:
Facts:
- Power: in the order of kW to approximately 350 MW.
- Response time: A few seconds.
- Efficiency: 80-90% (Wagemaker, 2011)
- Service life: 2500-4500 cycles (Wagemaker, 2011)
- Stage of development: Used commercially on a small-scale.

Advantages:

- Large-scale possible.
- Relatively inexpensive.
- Little energy loss (almost no self-discharge)
- Efficiency up to 90%.
- High energy density.

Disadvantages:

- Corrosion problems (with sodium polysulphides)
- Sodium dendrite formation (growth of sodium crystals)
- Works at high temperatures.

Potential future batteries

Sodium-water:

Facts:

- Response time: A few seconds.
- Efficiency: > 90% (Wagemaker, 2011)
- Service life: > 5000 cycles (Wagemaker, 2011)
- Stage of development: Test phase; start of production 2012 (Wagemaker, 2011)

Advantages:

- Inexpensive.
- Little energy loss.
- Efficiency more than 90%.
- Long service life.
- Environmentally friendly materials.

Disadvantages:

- Low energy density.
- Decreasing voltage during discharge.

Lithium–sulphur and Lithium–air:

Research is being carried out into lithium–sulphur and lithium–air batteries. These technologies are still very much at the early stage, but the lithium–sulphur battery is considered to be one of the most promising storage systems. (Wagemaker, 2011; Zhang, 2011)

The stated benefits:

- Low costs.
- Non-toxic and environmentally friendly.
- Wide operating temperature range.
- Long service life.

Wagemaker has detected the following potential issues with these batteries [Wagemeker, 2011]:

- The reactivity of the electrolyte that results in a loss of active material and a reduction in service life (Zang, 2011)

- The formation of crystals (dendrites) of lithium resulting in a reduction in service life.

Lithium–sulphur and lithium–air batteries are particularly interesting for mobile applications. Due to the influence of multiple design parameters these techniques are capable of realising an energy density (in Watt hour/kg) of 2 to 3.5 times more than the current generation of lithium–ion batteries. (Wagemaker, 2011).

Hydrogen

The high energy density of hydrogen makes it particularly attractive as an energy carrier. Before use it must first be produced and production for use in an energy storage system (district/ building level) is possible using the electrolysis of water. In a complete system the hydrogen can subsequently be stored as follows:

- In gas form under high pressure.
- As a liquid at -253°C.
- In solid materials:
    - Metal hydrides (compounds in which hydrogen atoms are bound to metals, e.g. MgH_2, LiH, $NaALH_4$)
    - In porous materials (Valk,2010)

When there is a demand for energy the hydrogen can be converted into electricity by reaction with oxygen in a fuel cell. There are many different types of fuel cells with widely varying properties.

For a large-scale energy storage system the hydrogen can also be stored in the form of ammonia (Mulder, 2011). The large-scale is required here because of the toxic nature of ammonia and the consequent safety requirements (the distance within which no buildings may be located). Because the storage of ammonia is extremely simple (liquid at room temperature), a large quantity of energy can be stored for long periods. If the demand for energy is high, ammonia can be converted to nitrogen and hydrogen (relatively simply), and the latter is used for conversion to electrical energy using a fuel cell. This method of storage would even allow the season cycle to be bridged.

Facts: (for a system at building and district levels):

- Power: In the order of kW to approximately 2.8 MW, operating temperature 650°C (FC-Energy, 2011)
- Response time: a few seconds (FC-Application, 2011)
- Efficiency: 40-70%[4]
- The service life depends on the type of production of hydrogen, the type of storage and the type of fuel cell used.
- Stage of development: Technology proven on a small scale; considerable development potential.

Advantages:

- High energy density.
- Short response time.
- The stored energy in the form of hydrogen is relatively easy to transport.

[4] Using a combined heat and power (CHP) system.

Disadvantages:

- Efficiency drops back when demand is high (>30% of the maximum power)
- Relatively high price because as yet there is no mass production.
- Three system steps are needed: production, storage and conversion. Each of these steps results in the reduction of efficiency and also introduces limitations.

Super/Ultra capacitors

Another method for storing electrical energy is storage in an electric field between two electrodes. The principle of the capacitor has been known for at least two centuries, but the development of new materials has made it possible to continuously improve performance. Improved dielectric properties enable higher voltages, as well as an increase in storage capacity. Dielectric materials are materials in which polarisation plays a dominant role compared to electrical conductivity and magnetisation. Energy can be stored in this form. In addition to the improvement by means of the dielectric properties, nanotechnology has made it possible for increasingly fine structures to be manufactured having a large internal area, enabling the energy density of capacitors to be increased.

Facts:

- Power: Up to 150 kW.
- Response time: Maximum one second.
- Efficiency: Up to 98% (capacitor only); up to 70% including transducer (Zdenek, 2004)
- Service life: At least 10 years.
- Stage of development: Technology has been used on a very small-scale; still plenty of development possible.

Advantages:

- Very short response time.
- Many cycles possible with relatively little maintenance.

Disadvantages:

- High costs.
- The technology is not yet far enough advanced to enable it to compete with other storage methods.

Appendix 2
Report of interview with Prof F.M. Mulder

Interview report

To	:	F. Lippmann, S. Lemain
From	:	S. Valk
Date	:	17 October 2011
Copy	:	Prof. F.M. Mulder
Our reference	:	9W5041/M0001/904644/Rott
Re	**:**	**Interview report**

Interviewee: Professor F.M. Mulder of the Department of Fundamental Aspects of Materials and Energy (FAME) at the Faculty of Radiation, Radio nuclides & Reactors (R3), Delft University of Technology.
Interviewer: S. Valk.
Date of meeting: 4 October 2011, Delft.

Introduction
A building is not just a consumer of energy; it can also be used for the storage and generation of energy. In this context TVVL (Platform for People and Technology) would like to obtain more insight into ways in which sustainably generated energy could be stored in the built environment. Demand and supply of sustainably generated energy could in that case be brought into better in balance by the storage of excess energy. The stored energy could be used at the moment that demand exceeds supply. The development of sustainable energy (in the form of wind and solar energy) is being used on an increasingly larger scale. In most cases this involves decentral generation of energy. The balancing of the supply and demand of electrical energy is very important in this respect. Also when the supply of electricity is greater than the demand overloading (and damage to) the electricity network can occur.

Questions

1. To what extent is there a need for the storage of electrical energy in the built environment, now and in the future? (This with a view to the supply and demand of energy and overloading of the electricity grid by the decentralised generation of sustainable electricity).

- Currently the proportion of sustainably generated energy is still relatively small. This proportion will rise in the future. As this sustainably generated energy will not be generated on a continuous basis storage will be necessary to prevent energy losses or overloading of the grid.
- The storage of (electrical) energy can also help reduce transmission losses. In Groningen (in the North of the Netherlands) for example wind energy is generated while in Limburg (in the south of the country) there is a high demand for energy. In that case the energy has to be transmitted over a long distance. Local storage and smart grids will reduce energy losses because transmission distances will be made shorter. Increasing transmission distances also increases transmission losses.
- Heating demands a great deal of energy, however the storage of heat is relatively simple and this should be a possibility for many households. A great deal of the energy demand can be buffered in this way.

2. Which methods of electrical energy storage of could be considered at the building and district levels?

- Heat:
  - Water basin/groundwater.
  - Salts that solidify/melt around 60℃ which release/absorb a lot of energy.
- Electrical:
  - Flywheel: Too expensive and too little/non-constant power.
  - Water pump: Geographical limitations and too low an energy density.
  - CAES: Excessive energy losses due to the heating up of the gas and safety hazards.
  - Batteries: Expensive; a possibility on a small scale.
  - Hydrogen: High energy density, difficult to use on a small scale.
  - Super/Ultra capacitor: Too expensive. Non-constant power and too low energy density.

3. Is hydrogen a promising medium for energy storage?

- Yes, particularly in the form of NH_3 on a large-scale (central). At the building/district level (decentral) there are too many disadvantages (particularly toxicity). The energy density of hydrogen is extremely high. The production of NH_3 and conversion to nitrogen and hydrogen are mature and efficient techniques.
- An installation using electrolysis for small-scale storage (at high pressures or in a solid material) and a fuel cell results in excessive losses (efficiency ~25%)

4. What are the current developments in the field of batteries and particularly lithium batteries?

- Batteries are an effective method of storing electrical energy. They have a high efficiency (~95%) and supply constant power. However, batteries are expensive and particularly for large capacity installations the price rises very quickly. Batteries are therefore suitable for decentral storage for a short buffer period (day/night cycle for solar panels). Capturing the seasonal cycle using batteries is currently not feasible.

5. Taking account of the use of smart grids and various stages of the development of this concept, which systems for the storage of sustainable energy in the built environment do you think are the most promising?
   The most promising appear to be:
   - Technical feasibility (this is where the focus is for this aspect)
   - Economic feasibility.
   - Environmental effectiveness.
   - Social feasibility, where the following aspects could be highlighted:
     - Market situation.
     - Acceptance by society (including safety)
     - Policy, legislative and regulatory/legal feasibility.
     - Organisational feasibility/ collaboration between relevant stakeholders.

- On a small scale (decentral), batteries are the most useful from technological, environmental and economic feasibility perspectives; however certainly only for short buffer periods.
- On a large scale (central) hydrogen (particularly in the form of ammonia) from technological, environmental and economic feasibility perspectives is the most useful.
- The market for batteries is strong (growing exponentially) due to the rise in the use of electric cars. This will make the first step towards batteries for energy storage simple. Once the proportion of sustainably generated energy becomes larger, a larger storage capacity will be needed. In this case hydrogen will become a major contender.

6. Do you happen to know any projects or pilot projects where research has been done into the storage of energy or sustainably generated energy?

- In glasshouses heat is often stored in the summer and used for heating in the winter.
- DenLab in Delft is extensively researching sustainable energy, but not specifically its storage. It is possible that they have some information on other projects where the storage of sustainably generated energy has been investigated.

Primary question:
To what extent is the storage of energy in buildings and districts needed in the short and longer term, taking account of solutions offered by smart grids and which storage methods are the most feasible for implementation?
The storage of energy will always be necessary. A smart grid with worldwide coverage is not possible from technical, economic and social (safety) perspectives. The use of hydrogen is promising, but only at large-scale (centrally). Batteries are a good first step for the decentralised storage of sustainably generated energy. This is partly due to the market situation. Their capacity is really too small for buffering seasonal cycles, but certainly sufficient for day/night cycles.

Appendix 3
Attendance list for the Congress on decentralised energy production and storage 26 and 27 October 2011

Decentrale Energieproductie en –Opslag
26 & 27 oktober 2011, Conferentiecentrum Woudschoten in Zeist

Registrant	Job Title	Company Name
Arendonk, R.J. van	Consultant	Alliander N.V.
Barendse, P.N.M.	Ontwikkelingsmanager	Ceres projecten (onderdeel van Vestia)
Besjes, M.	Senior Productmanager	Rabo Groen Bank BV
Boer, P.D.M. de	Consultant	KEMA Nederland B.V.
Bokhoven, T.	Voorzitter	Duurzame Energie Koepel
Bongaerts, M.	Manager Innovatie & Voorzitter projectgroep Smart Grids	Liander Assetmanagement & Netbeheer Nederland
Braaksma, A.S.	Business Analyst	GasTerra B.V.
Chatelin, M.	Advocaat & Partner	Eversheds Faassen
Donders, R.	Specialist Asset Management	Endinet BV
Duijnmayer, D.	Redacteur	Energeia
Geradts, F.	Marktinnovator Energietransitie	Enexis
Haytema, A.P.	Product Manager	NEDAP Energy Systems
Heijmans, A.	Directeur Utilities en Telecom	Realworld Systems BV
Hoekstra, A.E.	Senior Program Manager Sustainable Mobility	Stichting Urgenda
Hotke, T.	Adviseur Milieucommunicatie	Gemeente Amersfoort
Hovius, P.	Senior Consultant	Looije Agro Technics
Jablonska, B.	Wetenschappelijk onderzoeker	ECN Energieonderzoek Centrum Nederland
Kolstee, G.J.	Projectleider	Animal Sciences Group van Wageningen UR
Korf, D.	Initiatiefnemer	FreeEnergy4All
Kuijlaars, I.C.A.	Business Consultant	Realworld Systems BV
Kwast, R.P.	Adviseur Duurzaamheid, Energie en Conceptontwikkeling	Herman de Groot Ingenieurs
Lemain, S.O.	Consultant	Royal Haskoning
Leys, T.	Projectmanager Innovations	Electrawinds NV
Man, G. de	Director ELES Management	Essent Local Energy Solutions (ELES)
Molendijk, W.O.	Adjunct-directeur	Raadgevend Ingenieursbureau Lievense
Müller, F.	Senior Specialist Marktoperaties	Stedin Netbeheer BV
Nieuwenhout, F.D.J.	Smart Grids and Electricity Storage	ECN
Pelt, R. van	Business Director	Greenchoice
Philipsen, W.J.M.	Bestuurslid	CCI Consult
Pieterse, C.W.	Adviseur Duurzaamheid, Energie en Conceptontwikkeling	Herman de Groot Ingenieurs
Raadschelders, J.	Principal Consultant Energy Storage	KEMA Nederland B.V.
Rouwenhorst , H.	Productmanager	Rabo Groen Bank BV
Schoen, A.J.N.	Adviseur	New Energy Works
Slootweg, H.	Deeltijd Hoogleraar Smart Grids & Manager Innovatie	TU Eindhoven & Enexis
Slot, D.A. van 't	Energieadviseur	DWA installatie- en energieadvies
Smits, I.M.	Consultant	Alliander N.V.
Snellen, S.W.	President; CEO	IHaveMyOwnEnergy
Staal, H.	Adviseur Gebiedsontwikkeling	Agentschap NL
Terbijhe, A.	Projectleider	PPO-AGV
Timmerman, W.H.	Onderzoeker-docent	Energie Kenniscentrum Hanzehogeschool Groningen
Urlings, M.	Architect	LSWA Architecten
Vercauteren, T.C.	Project developer Sustainable Energy	HEJA Projectontwikkeling Woningcorporatie B.V.
Wagemaker, M.	Assistant Professor	Technische Universiteit Delft
Waters, D.	Marketing Manager	Energeia
Werf, M.C.I. van der	Kamerlid	Tweede Kamer der Staten-Generaal

Appendix 4
Congress report
Decentral energy production and storage
26 and 27 October 2011

Congress Summary
Decentral energy production and storage
Woudschoten conference centre, Zeist
26 and 27 October 2011

Mr Jillis Raadschelders, KEMA, principal energy storage consultant, *chair*
Mr Raadschelders commented that solar energy is currently more advantageous in the Netherlands than in Germany because the German feed-in tariff is not linked to the market price of electricity. In the Netherlands, feed-in is currently 100% balanced & settled, at least up to 5000 kWh. At KEMA Mr Raadschelders had carried out several studies into storage facilities, particularly in the USA. These ranged from large-scale (multi-megawatt) to small-scale community level, 25 kW). These were Li-ion batteries and flywheels.

Mr Michel Chatelin, Eversheds Faassen, lawyer and partner; *legislation presentation*
Mr Chatelin gave a presentation about gaps in the law. 'If any exist, use should be made of the opportunities they offer', commented Mr Chatelin. The most important concern at the moment is that there are laws relating to energy (Heat Act & Gas Act) that protect the small-scale consumer. This means that as a supplier you have to meet certain requirements (including security of supply). Just selling power to your neighbours is prohibited by this act (unless you do this within a closed community). It can certainly be expected that changes will take place in this area.

Another concern is that a maximum price has been set for heat. This could well stand in the way of sustainable production, because it may well be possible to sell sustainably produced energy at a higher price.

Mr Chatelin mentioned the existence of Energy Service Companies (ESCOs). These companies guarantee a reduction in energy consumption and in exchange for this take either a fixed sum per year or for example the difference in the energy bill.

Balancing & settlement was discussed, this is settling feed-in to the grid against the energy bill. When settling is set at 100%, the price for supply is the same as the price for consumption. If you pay 22 ct/kWh to consume, then you also receive 22 ct/kWh when you supply. This is a subsidy from the government and the energy supplier. The cost price of energy in the market is only a maximum of around 7 ct/kWh. This eventually becomes 22 ct/kWh for the consumer due to taxation and transmission costs. The settlement is thus a form of subsidy, or a promotion for energy suppliers. Settlement does have a limit. Often only the first 5000 kWh is offset, after that you only receive 7 ct/kWh. There are however parties who offset 100%, and even 100+, in other words when the consumer is actually a net producer. NB: If the Netherlands is eventually packed with solar panels it can be expected that the offsetting regulation will stop; the government and energy suppliers will have to get their money from somewhere.
Contact Mr Chatelin: +31 20 5600651

Conclusions for smart grids: Legislation is almost always one step behind what is actually happening. The energy market is no exception. Currently the climate is favourable for the consumer to install solar panels. This will result in a rise in the proportion of decentralised generation, and the smart grid will be a consequence of this.
Conclusions for storage: No conclusions can be drawn about storage.

Mr Frans Nieuwenhout, ECN, Smart grids and electricity storage; *European vision presentation*

Mr Nieuwenhout has a background in sustainable energy in developing countries. Where there is no grid, storage is almost always essential. From a European Union perspective, sustainable energy is almost always considered to be electricity (possibly because electricity can be marketed and distributed on a European scale). Europe has a good grid; Mr Nieuwenhout would not say that it was 'over-dimensioned' but certainly getting close to it. This grid is much more stable than in the United States for example (where there is more request for storage for stabilising the grid).

Mr Nieuwenhout saw a number of issues that must be handled to optimise the grid to transform it into a smart grid. First he saw **further integration of the European grid and the European market**. The objective of the European Union is to have a single European electricity market in 2014. Mr Nieuwenhout considered this to be somewhat ambitious, but at least it was moving in the right direction. Mr Nieuwenhout showed an illustration from AEA (American Energy Storage) that indicated the price per delivered kWh per storage medium. From this figure (said to be out of date, but no date was stated) it appeared that only pumped hydroelectric came anywhere near the standard price for energy. All other techniques were way above this. If you have to be profitable using storage then pumped hydroelectric is currently the only option. They are very good at this in Norway. For the Netherlands it is more profitable to lay a good cable to Norway and store energy there, rather than trying to develop something in the Netherlands. It is worth examining the options outside the borders of your country; because that's the way we are going in Europe according to Mr Nieuwenhout.

Therefore we can expect that during at least the next two decades we will have an energy mix that will continue to contain fossil fuels. As an answer to imbalance Mr Nieuwenhout predicted **flexible conventional installations** (gas). In his list of five successive points, storage was the last to be mentioned, i.e. the least urgent.

The 20/20/20 goal at European Union level will probably be achieved, but that will be due to countries such as Germany and Spain. The required CO_2 reduction will probably be solved by capture and storage (CCS), although there are still some issues involved with this technology.

Relating to governmental support: Wind energy is only viable in a few locations without subsidy, as is solar energy stated Mr Nieuwenhout. At least two decades support will be necessary for new techniques in sustainable energy (such as solar and wind). Whether subsidy is the correct course of action is open to discussion. In countries such as Germany and Spain for example it will keep the cost of solar panels artificially high.

Priority for sustainable energy is already regulated by law in the EU and in the Netherlands. The catch is that it has not been determined when 'congestion' will occur. France is convinced that we will go electric. Biomass to bio-diesel is very much under discussion. In the day-ahead EU energy market you pay approximately 4 ct/kWh.

The PowerMatcher is an apparatus that has been developed partly by ECN to match supply and demand at the decentral scale. There is a PowerMatcher for house, district and

municipality levels. Experiments are now taking place in a district in Brabant. The apparatus is reminiscent of the Qbox from Qurrent.

Conclusions for smart grids: For the time being the smart grid will mainly be formed by further integration and added flexibility.

Conclusions for storage: This will only be viable on a large-scale, e.g. pumped hydroelectric. On a small-scale, the only potential for storage will be in the event of capacity problems with the grid. Mueller from Stedin did not expect these capacity problems to arise.

Mr Waldo Molendijk, deputy director, Lievense consulting engineers; *Water Island Business Case presentation*

Mr Molendijk gave a presentation about a project that was conceived as long ago as the 1980s - an artificial island off the coast in which pumped hydroelectric facilities could be operated. The business case never got off the ground, because the construction would have been too expensive. It is more cost-effective to make use of locations where there is a natural fall as in Norway for example. The rise and fall of tides in the Netherlands is also too small to be useful.

Mr Molendijk stated that currently wind energy was responsible for more CO_2 emission than would have been the case if all required energy was produced using coal, because the imbalance is being compensated by large CO_2 consuming actions. He cited C Lepair, 2011 as source. Mr Frans Nieuwenhout of ECN stated that this was completely at odds with his findings.

Mr Molendijk considered that the future of storage would be mainly decentral, because central storage would require excessively high investments. (NB: Mr Molendijk's comments did appear to be limited to the Netherlands). In addition Mr Molendijk summarised a number of arguments in favour of the storage of energy. This was the list that we are familiar with, particularly from American Energy Storage. Here in the Netherlands at the present time there appear to be few relevant arguments in favour of storage.
Conclusions for a smart grid: Is not present; the future will be storage driven.

Conclusions for storage: Not on a large-scale in the Netherlands. What the solution will be for small-scale situations was not stated.

Mr Richard van Pelt, business director, Greenchoice; presentation of Greenchoice Business Model

The focus of Greenchoice is 100% on sustainable energy, particularly decentral, but they also find central wind energy interesting, i.e. solar panels in the Netherlands or wind offshore. Greenchoice is involved in a number of initiatives, such as Zonvast and Easystreet. Greenchoice guarantees 100+% settlement, therefore also for net producers.

Mr Van Pelt believed in 'the grid as storage'. They would like to see themselves as administrators - a company that could earn its money doing that. That the consumer will become a producer was not considered a problem, but someone will have to administer it. They are therefore also focused on the grid being a 'storage medium'; otherwise no administration would be necessary. If power from your solar panel goes straight into your car battery no third party will be involved. In this respect storage is therefore not part of

Greenchoice's business model. Mr Van Pelt told me that this is indeed the case, because storage alone will not always be sufficient and the grid will always be needed. Greenchoice is also working on remote settlement. This will be needed when a solar panel for example is not located on your own roof but on the roof of your block of flats, or perhaps if you are a participant in your district's windmills in the polder.

Zonvast installs solar panels on consumers' roofs free of charge and the consumers pay a fixed amount of 23 ct/kWh for 20 or 30 years after which the panels belong to the consumer. Easystreet is an experiment in Breda where a mini-smart grid with solar panels has been installed in a street.

Mr Van Pelt also commented on the **reliability of the grid**, and the **settlement** that currently takes place in the Netherlands as being the reasons that **storage is not being used in the Netherlands**. If these are abandoned then it could suddenly become relevant, but we're not there yet.

Conclusions for smart grids: If this party has its way there will be a smart grid, but preferably without storage or decentral storage.

Conclusions for storage: Will not come into use for the time being.

Mr Paul Hovius, senior consultant, Looije Agro Technics; The business case for CHP in horticulture

The bottom line is that there should be more CHP that is **heat controlled**. This company is therefore a non-regulated electricity producer.

Conclusions: None. CHP for horticulture is not very relevant for this project.

Mr Peter Barendse, development manager, Vestia (Ceres projects); *Discussion*

Mr Barendse explained that their energy activities are focused on heat. They are therefore not really involved with smart grids. They are involved with smart links between industry and for example district heating (Snowworld Zoetermeer was given as an example).

They are involved with installation (energy-saving), synergy with industry where possible, and geothermal heating. With its 90,000 houses Vestia is the largest housing corporation in the Netherlands. They see that energy prices are rising and would like to try and stop the energy cost becoming higher than the cost of renting a property. Investing in energy saving in the case of social housing is an issue, as it is not always possible to retrieve the costs involved from the customer, because there is a legal maximum rent.

Mr Han Slootweg, Enexis, TU/e

Mr Slootweg saw grid capacity as the most important driver for the use of smart grids. The current grid capacity was constructed for the theoretically highest peak loading plus a margin/redundancy. In practice this means that most of the time the grid is loaded to less than 50%. The grid capacity is therefore not necessarily insufficient; it is however important how this is utilised. Smart grids and the demand control options that they allow can play an important role here. According to Mr Slootweg three developments were necessary for the success/usefulness of smart grids:

- Electrification of the market (electric cars and heat pumps)
- More decentralised/sustainable generation.

- • Loading flexibility (e.g. electric cars charged at night)

Other and discussion

Mr Martijn van Liander thought that in five years everybody would be purchasing viable solar panels at the local DIY supermarket. He also considered that everyone will have a storage medium and will live in a self-sufficient manner. The energy and storage installation will be a standard part of the house. The grid will then become redundant, and only be used as insurance. Mr Nieuwenhout of ECN did not agree with this. The grid is highly suitable as a 'storage medium' that in addition will continue to play a role in handling the base load.

According to the majority present solar energy will begin to play a more important role over the next five years. Not particularly due to the gain in efficiency, but more due to the dropping costs of such systems.