# Publishable summary

### *Introduction and objectives*

To achieve low energy or even energy neutral districts, the share of renewable energy must increase drastically over present levels. However, accommodating a large supplier of renewable energy, such as a wind farm, in the existing energy infrastructure is complicated by the fluctuating character of the energy supply with the result that renewable energy supply may be either too large or too small to cover the instantaneous demand. Both **smart energy management** systems and **energy storage** are essential to meet this challenge.

The objective of the E-hub project is to maximise the amount of renewable energy in a district by matching energy demand and supply, by shifting the demand of heat pumps, refrigerators or white good appliances. Any excess renewable heat can be stored in distributed buffers, advanced Thermo-Chemical Materials (TCMs) or boreholes. An important element is the acceptance of such an advanced energy system by energy suppliers and users alike. Therefore, developing new business models and service concepts that are attractive to all stakeholders is crucial.

The E-hub energy system has been demonstrated in the district of Tweewaters in Leuven, Belgium. In addition, five scenario studies have been carried out to assess the feasibility of an advanced Energy Management System in the districts of Amsterdam (NL), Freiburg (D), Bergamo (It) and Dalian (China) as well as in Tweewaters.

### *Overview of the project and results obtained.*

**WP1 on System Definition, WP2 on Energy Conversion & Storage** and **WP3 Components and Techniques Development** were finished in the second period. In the third (and last) period of the project, the results of these three work packages were used, such as the impact assessment model and the measurements of cogeneration units in WP2, and numerical models of various equipment made in WP3.

An overview of the main tasks in the last period of the E-hub project is given in Figure 1. The elements in the different boxes are discussed below.

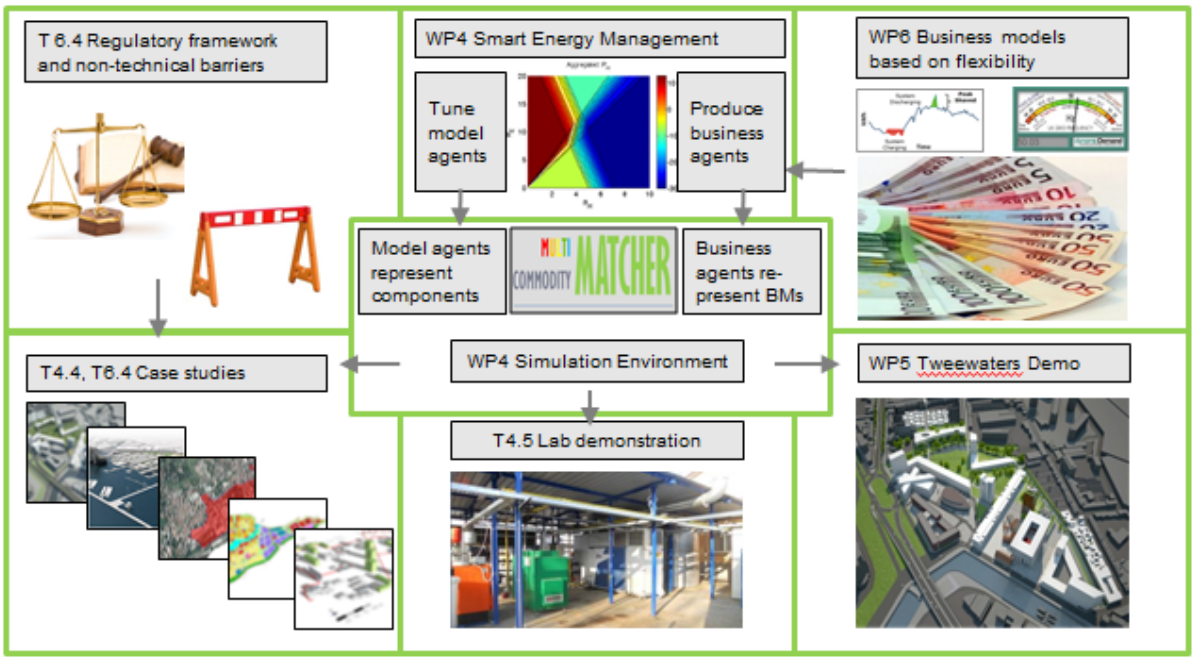


Figure 1: *Overview of the main tasks in the last period of the E-hub project.*

The pivotal work package is **WP4 on Energy Management**, where a simulation environment was developed that includes:

- the implementation of the models of energy generation and storage equipment produced in WP3, represented by model agents,
- a simplified model of aggregated buildings to calculate the space heating demand of the district,
- A heating network and electricity grid connecting them,
- off-line calculation of electricity and DHW demand profiles of the district,
- business agents representing Business models based on flexibility from WP6
- the MCM (Multi Commodity Matcher) control algorithm.

**WP6 on business models** supplied a number of business models /service models to allow specific optimisations for the Energy Management System. For instance, the system could minimise the energy bill for the benefit of end users, shave peaks for the benefit of the DSO (Distribution System Operator)or reduce imbalance for the benefit of the BRP (Balancing Responsible Party). These business models will interact with the Energy Management System through "business agents".

The simulation environment was used in three types of applications. The **first** was to simulate a virtual application of an advanced Energy Management System in a number of case studies: Tweewaters in Belgium, Houthaven in The Netherlands, Bergamo in Italy, Freiburg in Germany and Dalian in China. For each case study three different scenarios were applied:

1. a BAU (Business As Usual) scenario, using a conventional energy supply system
2. a Green or Low carbon scenario, implementing RES (Renewable Energy Sources) and REC (Recovered energy)
3. a Smart scenario, similar to scenario 2 but run with a smart energy management system, making use of the flexibility in demand.

As an illustration, Figure 2 shows the monthly primary energy demand in the 3 scenarios for each of the 5 case studies.

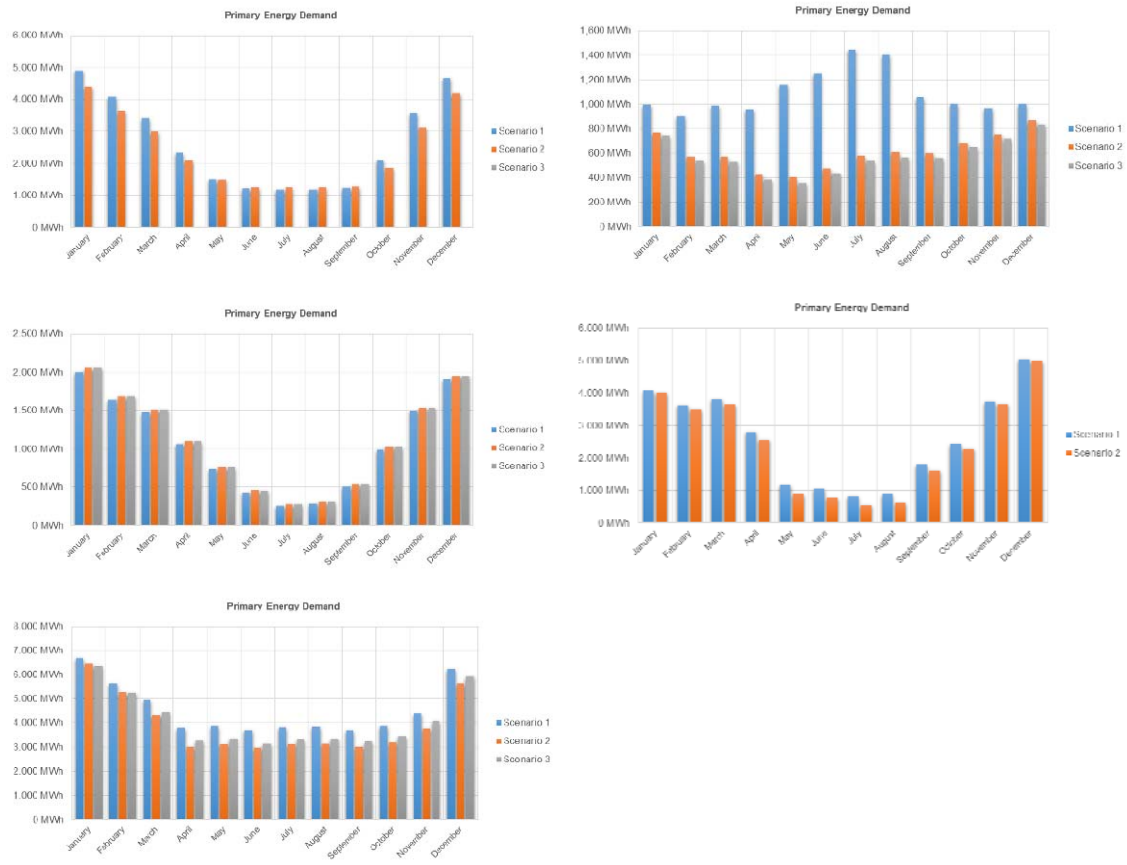


*Figure 2: Monthly primary energy demand in the 3 scenarios for each of the 5 case studies: Tweewaters, Houthaven (top), Bergamo, Freiburg (middle) and Dalian (bottom).*

The introduction of technologies based on Renewable Energy Sources (RES) and/or Recovered Energy (REC) within the district (GREEN/Low Carbon scenario), results in an important decrease in primary energy use and $CO_2$ emissions and leads to more beneficial cash-flows for the studied cases. Moreover, by introducing smart capabilities (SMART scenario) extra savings in costs can be realized. In the SMART scenario the environmental impact may decrease or increase depending on the business case selected.

In addition to the study of technical issues, an overview is made of the regulatory framework and non-technical barriers and practical guidelines for each of these case studies. Barriers identified include: administrative and legal barriers, economic, financial and market barriers and social barriers and acceptance issues that may hamper, in the short term, the application of the E-hub concepts in real life cases.

The **second** application is the demonstration of the Energy Management System in a real lab environment, controlling the operation of several cogeneration units under conflicting demand profiles of heat and electricity, for which the control strategy has to find an optimal solution.

The results of 4 cases were compared:

1. A *simulation*, using the ECoMP (Economic Cogeneration Modular Programme) software, calculating the economic optimal use of different cogeneration units. This is the reference case.
2. A *real test* in the lab with the Zack algorithm controlling the cogeneration units
3. A *real test* in the lab with the MCM (Multi Commodity Matcher) controlling the cogeneration units
4. A *simulation* with the MCM controlling the cogeneration units to check the operation of the MCM

The results of the runs **without** thermal storage are shown in Figure 3 below.

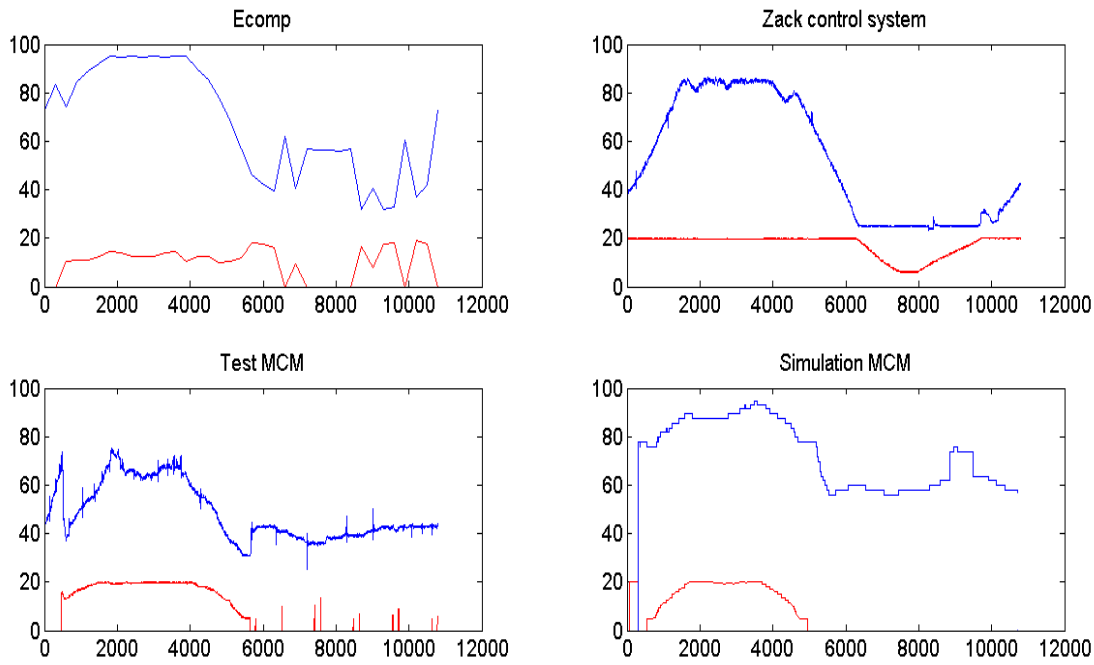


*Figure 3: Results of the 4 runs **without** storage: blue line: output power of the mGT, red line: output power of the ICE.*

The graphs of the MCM test and MCM simulation are similar, showing that in a real lab environment, the MCM performs as expected. In addition, the shape of the curve is similar to that of the economic optimum given by the reference ECoPM simulation.

The **third** application is in **WP5 Demonstration**, where the energy management system (electricity only) was applied in a *full scale demonstration* in the district of Tweewaters in Leuven, Belgium.

Tweewaters is a unique inner-city development which is one of the largest inner-city developments in Belgium. It consists in total of 1,200 dwellings, commercial spaces, offices and other functions covering an area of 11ha in the city centre of Leuven. The district is still under development and the first building completed is the 'Balk van Beel' apartment building, housing 106 families and commercial spaces, shown in Figure 4. A smart energy monitoring and control system was installed in this building.


*Figure 4: Artist's impression of the Tweewaters quarter, of which the 'Balk van Beel' building has been completed. To the right, apartments on top of the grain silos of the former Stella Artois brewery.*

An energy consortium between Ertzberg (developer of the quarter and of the smart control of energy), Dalkia (the energy producer) and Eandis (the distribution system operator for heat and electricity) was set up to supply the district with energy.

Over the summer, Ertzberg conducted interviews and workshops with the tenants, in order to report on client behaviour Privacy issues have been addressed and feedback from the tenants has been reported.

The smart monitoring / management system installed in all 106 dwellings and 9 commercial spaces in the Balk van Beel, allowed us to produce Profiles of DHW (Domestic Hot Water), space heating and electricity. As an illustration, Figure 5 shows a 3D map of the electricity consumption per hour in the month of April 2014.

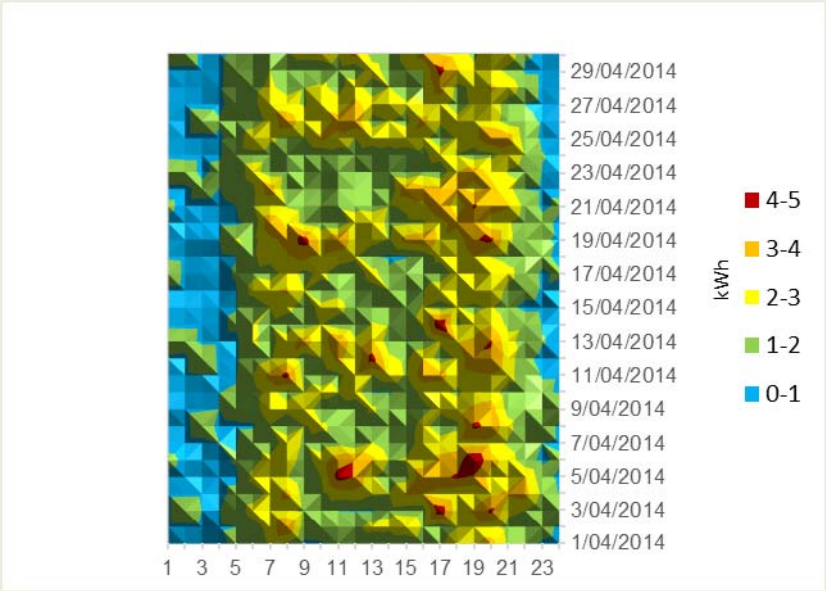


*Figure 5: Three-dimensional representation of the electricity consumption of the 'Balk van Beel' in April 2014 in kWh per hour (kW).*

The map clearly shows low consumption (blue shaded area) between 23:00 and 5:00. It also shows the higher consumption in the weekends (e.g. 5, 6 April)

The energy demand for space heating in the 'Balk van Beel' ranges from 6 to 26 kWh/m$^2$a, with an average of 11 kWh/m$^2$a. This is better than the Passive house standard of 15 kWh/m$^2$a, showing the high quality of the building.

Regarding the potential of shifting the consumption of household appliances, the rather low amount of smart starts allowed by the tenants does not allow us to draw solid conclusions. In the specific case of Tweewaters, a cost reduction of 20% was achieved compared to the reference scenario. However the mean flexibility of 136 min observed in Tweewaters is too low to gain significant electricity cost reductions. For higher profits, the flexibility window should increase to 420 to 460 minutes.

In a simulation, with a smart control of the CHP, operating it at times of high electricity prices, a realistic estimation is that profits from electricity sold to the grid can be raised by 30%. Over a period of one year this results in a profit in the order of 47 € per apartment.

The savings achieved may in themselves not justify the investment in a smart energy system. However, smart control systems are a necessary part of future energy systems to optimally meet all end users' ever increasing energy demands. In the next phases of the development of the Tweewaters quarter, the energy management system will be applied to the other buildings.

In **WP7 Dissemination**, a website was made (http://www.e-hub.org/), containing a public part as well as a restricted part, the latter serving as a database for all project related documents. The website, shown in Figure 6, has been regularly updated.

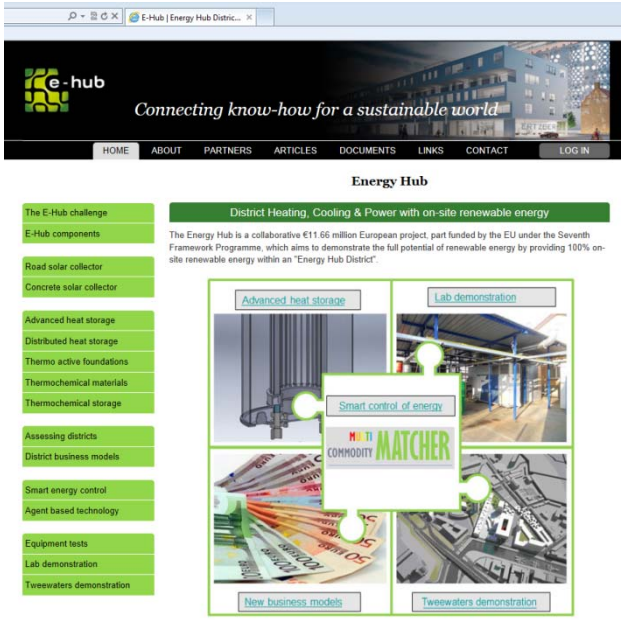


*Figure 6: Home page of the public part of the website.*

A glossy brochure has been produced, giving an overview of the work in the E-hub project and its application to the full scale demonstration in Tweewaters, shown in Figure 7 below.

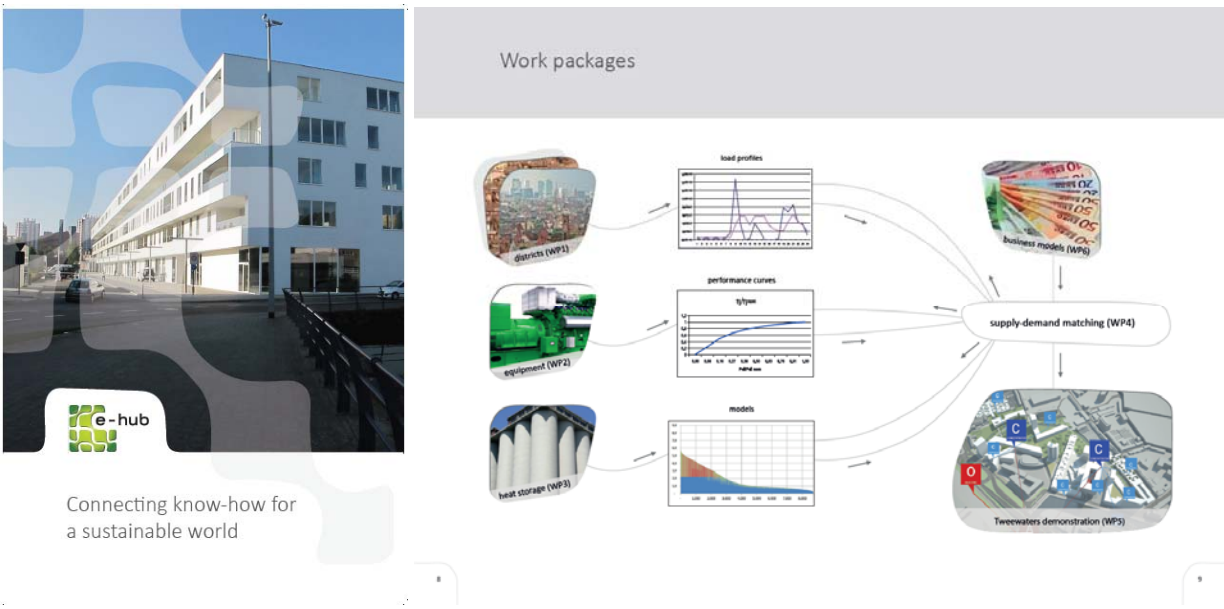


*Figure 7: Front page and pages 8/9 of E-hub Glossy Brochure.*

In the four years of the project, 6 peer reviewed publications were submitted to scientific journals, 23 papers were written and presented at international conferences, 14 presentations were made in other forums and 9 workshops were carried out on various topics in the E-hub project.

TNO is actively involved in the foundation of the 'Flexible Power Alliance' with stakeholders in an attempt to set the Powermatcher and Multi Commodity Matcher as the standard for smart control in smart grids.

### *Impact*

Due to finite stocks of fossil fuels and an increasing demand for energy, in the long run, energy prices will inevitably rise. Considering also increasing public awareness of the effects of greenhouse gas emissions and stricter regulation, future energy supply systems will change considerably.

The share of renewable energy from wind, biomass and solar energy is expected to grow substantially. Application of short term and long term **energy buffers** and intelligent **energy management** systems are essential to match demand and supply of energy to deal with the fluctuating nature of renewable energy supply.

Thermal storage is sometimes called 'the holy grail' of energy neutral buildings. The consortium made good progress in improving several types of thermal storage (Thermo-Active foundations, Thermo-Chemical storage and distributed storage)

Energy, being an increasingly scarce commodity, is expected to be subject to a price differentiation which will replace the flat rate in use today. Energy will be more expensive in times of shortages of supply and cheaper in times of abundant supply. Powermatcher ® and Multi Commodity Matcher software, the latter developed in the E-hub project, use a pricing mechanism - presently using artificial prices - to match the supply and demand of energy. These control algorithms are therefore well prepared for future price differentiation mechanisms.

Using the simulation tool that was developed in the project, the consortium can provide consulting services e.g. to municipalities in configuring energy neutral/energy efficient districts.

Finally, the consortium set a best practice with the full scale demonstration of high quality building equipped with a smart energy management system in the district of Tweewaters.

*Part of the team at the final review meeting in Genoa with the PTA.*