Project No. 608930

FP7-SMARTCITIES-2013

# OPtimising Hybrid Energy grids

# for smart citieS

## WP2 Technical, Economical and Social Benefits

## Deliverable 2.1

## Report on Technical, Economical and Social Patterns of Energy Service Provision

D. Schwabeneder[1], H. Auer[1]

[1]TUW-EEG

Version: 1.0
Due Date: 28 Feb 2014
Submission Date: 14 July 2014 / 16 Feb 2015 - revised
Lead Coordinator: TUW-EEG

# Copyright



Consisting of

| | | |
|---|---|---|
| Coordinator | WIP – Renewable Energies (WIP) | Germany |
| Participants | Hochschule Ulm (HSU) | Germany |
| | Stadtwerke Ulm GmbH (SWU) | Germany |
| | Technische Universität Wien (TUW-EEG) | Austria |
| | Austrian Institute of Technology (AIT) | Austria |
| | Deutsches Zentrum für Luft- und Raumfahrt EV (DLR) | Germany |
| | NEC Europe Ltd. (NEC) | UK |
| | Lulea Tekniska Universitet (LTU) | Sweden |
| | Skelleftea Kraft (SKR) | Sweden |

## Deliverable Description

Abstract: This report provides a qualitative description of energy service provision. The historical development of energy networks in dense areas is outlined and various factors determining the patterns of energy distribution grids are demonstrated, investigated and categorized into technological, economic and social influences. Finally several matrices are presented, providing a structure for describing the status quo and outlook of energy service provision in hybrid networks.

Key Words: ICT, smart cities, hybrid energy grid, energy saving,
demonstrations, smart grid, energy control, monitoring

## Document History

| **Version** | **Date** | **Authors** | **Description** |
|---|---|---|---|
| 0.1 | 2013-12-01 | TUW-EEG | D2.1 Draft table of contents of Deliverable 2.1 |
| 0.2 | 2014-02-25 | TUW-EEG | D2.1 Final draft in proper OrPHEuS template format |
| 0.3 | 2014-02-28 | NEC, AIT | Remarks and corrections |
| 0.4 | 2014-02-28 | TUW-EEG | D2.1 Final draft version |
| 1.0 | 2014-07-14 | TUW-EEG | D2.1 Final version |
| 2.0 | 2015-02-13 | TUW-EEG | D2.1 Final revised version (with implementation of comments from EC review meeting) |

## Dissemination Level

| **Dissemination Level** | | |
|---|---|---|
| **PU** | Public | **X** |
| **PP** | Restricted to other programme participants (including the Commission Services) | |
| **RE** | Restricted to a group specified by the Consortium (including the Commission Services) | |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |

# Executive Summary

The OrPHEuS project elaborates a Hybrid Energy Network Control System for Smart Cities implementing novel cooperative local grid and inter-grid control strategies for the optimal interactions between multiple energy grids by enabling simultaneous optimization for individual response requirements, energy efficiencies and energy savings as well as coupled operational, economic and social impacts. Starting from existing system setups in two cities, enhanced operational scenarios are demonstrated for today's market setup, as well as for future market visions.

The main scope of the Deliverable D2.1 (Task 2.1) is the development of several matrices describing in qualitative terms the technical, economic and social patterns of energy service provision in hybrid networks. First, an overview of the gradual historical development of energy grids is given in order to identify the most important factors determining the functionality of European energy provision systems. Then changing patterns such as the availability of new technologies, the liberalisation of the energy markets or the increase of environmental awareness in Europe and related chances and challenges are shown. Additionally, the key technologies for interpreting energy distribution in a hybrid sense are identified. Finally, for each category (technical, economic and social) some matrices are presented, providing a structure for describing the status quo and outlook of energy service provision in hybrid networks.

# Administrative Overview

## Task Description

Task 2.1 investigates the status quo in terms of technical, economic and social patterns of energy service provision in hybrid energy networks in qualitative terms.

## Relation to the Scientific and Technological Objectives

Deliverable D2.1 contributes to STO 1 targeting on Creation of the concept for new Business Models. The results of the work in Task T2.1 provide the basis for the discussion on the techno-economic set-up, aiming later on in WP2 on the definition of the technical needs for business models.

## Relation to activities in the Project

The results of Task 2.1 will be directly used to develop a formal framework in qualitative terms in Task 2.2 and, additionally, they are closely connected to the work in work packages WP3, WP4 and WP5.

# Terminologies

## Definitions

Within the OrPHEuS project facilities enabling the coupling of processes and process chains between different energy grids (e.g. Power-to-Heat-to-Power) in order to overcome deficits in energy efficiencies in a single energy grid (e.g. limitations of integration of high penetration of distributed solar energy supply) are called **coupling points (CP).**

**Supporting points (SP)** mean within this project systems, strategies and measures that do not actually physically connect different energy grids, but support indirectly the coupling of multiple energy domains (e.g. Demand Side Management, Storage Management, etc.).

## Abbreviations

| | |
|---|---|
| MS | Milestone |
| STO | Scientific & Technological Objective |
| CP | Coupling point |
| DSO | Distribution System Operator |
| CCGT | Combined Cycle Gas Turbine |
| CHP | Combined Heat and Power |
| µCHP | Micro-CHP |
| RES | Renewable Energy Sources |
| PV | Photovoltaic |
| TOU | Time Of Use tariff |
| RTP | Real Time Pricing |
| LCOE | Levelized Cost Of Electricity |
| DSM | Demand Side Management |
| SSM | Supply Side Management |

# Table of Contents

# 1 Introduction

The purpose of this document is to give an introduction to the functionality of hybrid energy networks. Due to the liberalisation of the energy markets many constraints have changed, which makes the examination of this topic very complex. While in the past a rather planned and coordinated approach was implemented among several stakeholders, in a competitive environment every market participant focusses on its own objective function and barely anyone keeps an eye on the overall supply chain. In addition, there is a wide range of new technologies available, which constitute great opportunities, but also pose new challenges.

The major objective of this report is to give a comprehensive description in qualitative terms of the technical, economic and social patterns of hybrid energy service provision. Based on the gradual historical development of energy systems and taking into account various influencing factors, technological conditions, economic interdependencies and social implications for end users and "prosumers" are identified and investigated.

**Technical aspects:** For the technological analysis it is crucial, to first detect the key technologies that enable a hybrid interpretation of energy service provision and examine their properties. This means facilities, which allow physical interaction between the energy domains electricity, gas and heat. Within the OrPHEuS project, these facilities are called coupling points (CP). Based on the existing technological portfolio in the project's demonstration sites located in Skellefteå, Sweden, and Ulm, Germany, several use cases will be elaborated later on in Task 2.3 in terms of special interesting aspects of energy service provision.

**Economic aspects:** The economic observations include mainly the breakdown of different regulations as well as objective functions of the various market participants, which are generators, grid operators, retailers and customers, but also possible new actors such as aggregators. In Task 2.2 a formal framework will be developed describing the complex interdependencies between the different stakeholders of the energy supply chain. This framework will be used to initialize the case study analysis in Task 2.4.

**Social aspects:** The social circumstances play a very important role in many parts of the energy supply chain, too. One of the most important coupling points in hybrid energy networks is the end user node and, therefore, the degree of environmental awareness in society, the willingness of customers to change their behaviour, etc. can have a great impact on the future development of the generation portfolio and the overall energy system.

This report is organised as following:

- Chapter 2 explains the gradual historical development of vertically integrated energy systems in dense areas/cities in general.
- Chapter 3 elaborates on the factors having determined energy distribution grid development in the past in particular.
- Chapter 4 describes the changing patterns and challenges for energy distribution grids in unbundled energy systems.
- Chapter 5 provides an introduction on different matrices describing the status quo and an outlook of energy service provision in hybrid energy grid structures.

- Chapter 6 provides some synthesis of lessons learned in previous chapters and concluding remarks.

# 2 Gradual historical development of vertically integrated energy systems in dense areas/cities

The aim of this chapter is to point out some challenges and inefficiencies of energy service provision against the background of the historical development of energy systems, notably in dense areas/cities.

## 2.1 Lack of (partly) coordinated distribution grid infrastructure planning

In the past, in most European cities energy distribution grids (for electricity, heat and gas delivery) have developed in a very complex and uncoordinated way. In general, there was no common strategic planning between the different energy domains. Thus a certain redundancy, especially between gas and heating networks, can be observed in many supply areas in dense areas (e.g. on district level in a municipal city).

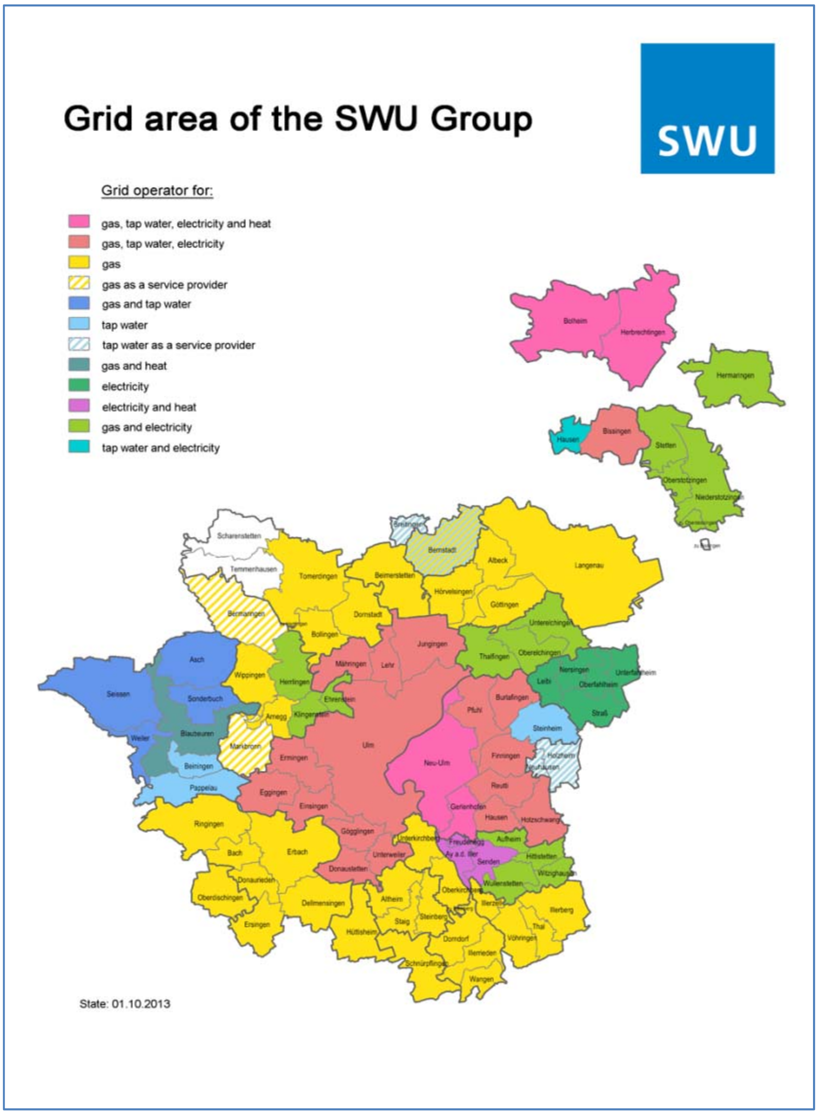



**Figure 1: Energy distribution network of Stadtwerke Ulm in the city of Ulm, Germany. Source: Stadtwerke Ulm (SWU)**

Figure 1 illustrates this heterogeneous energy supply pattern using the example of the city of Ulm in Germany. The image shows a map with the energy distribution grids operated by the local Distribution System Operator (DSO) Stadtwerke Ulm (SWU). The areas coloured in pink in the centre and in the north are supplied with electricity, gas and heat.

A counter-example for this lack of coordinated planning is the district heating and gas network in Denmark[1]. The development of Danish district heating started in 1903 in Frederiksberg in the western part of Copenhagen with the construction of Denmark's first waste incarnation plant, which led heat in the shape of steam through tunnels to public buildings like a newly built hospital. The following 70 years the centralized form of heat supply grew steadily and large housing areas were also connected to the grid. The energy crisis in 1973/74 severely threatened Denmark's economy, because almost 100% of all fossil fuels required to generate heat were being imported. Thus a number of initiatives were started aiming for an increase of energy efficiency, the development of highly effective distribution pipes and a systematic planning of the heat supply in all areas. One main result was a least cost zoning of gas and heat networks to substitute individual oil boilers. This can be considered as a result of coordinated competition between the two energy domains. Figure 2 shows an example of a least cost zoned area between gas supply in green and heat supply in red.

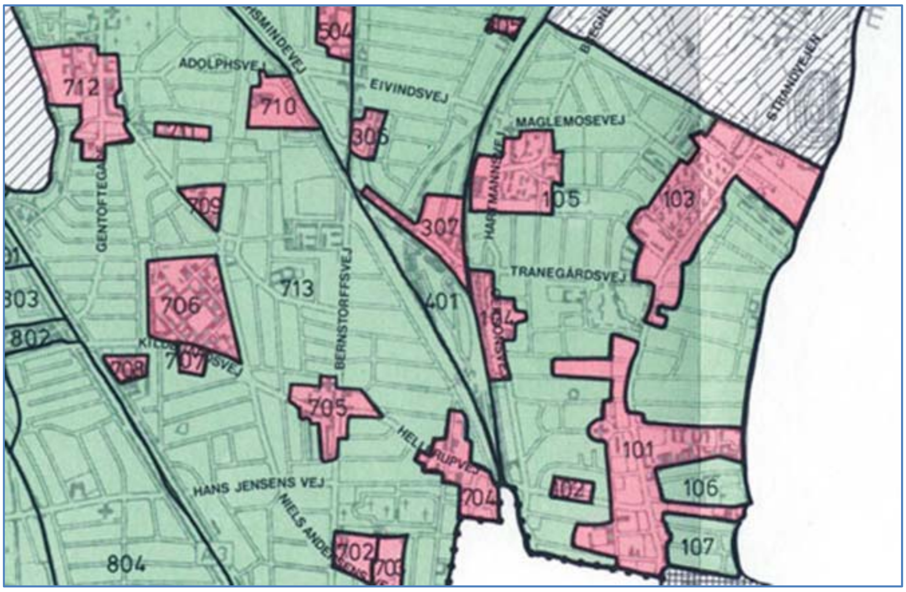



**Figure 2: Least cost zoned area between gas network to small buildings (green) and district heating supply to large buildings (red). Source:** [1]

In general, this redundancy between different energy domains in cities cannot be observed in southern and Mediterranean European countries for different reasons. Figure 3 shows a map of European cities with more than 5000 inhabitants and the corresponding district heating systems. It can be seen that in Greece, in the southern parts of Italy, in Spain and in Portugal barely any district heating systems exist at present. Consequently, in these areas there cannot be any redundancies between gas and district heating networks. The reasons for this pattern are indicated country by country in the following sections for Spain, Italy, Greece, Ireland and Romania.

[1] This paragraph is based on [1]

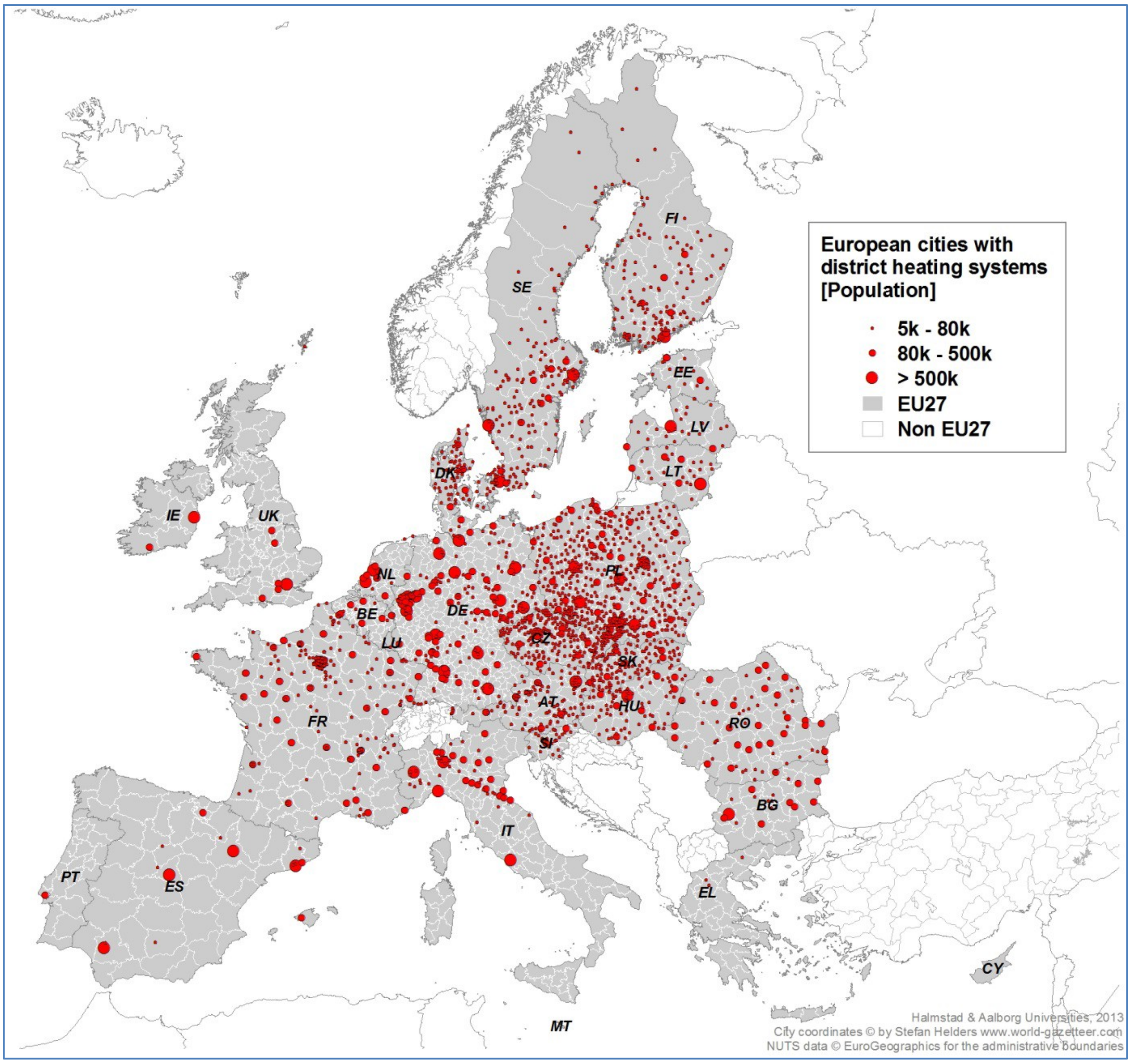



**Figure 3: Cities with district heating systems in EU27 by city size and for cities having more than 5000 inhabitants. Source: [2]**

## Spain

According to [3] the major reasons for the small number of district heating systems in Spain are, on the one hand, the low heat demand due to the mild climatic conditions and, on the other hand, the lack of knowledge and expertise of urban planners, architects and engineers in this field. However, due to the growing interest in energy efficiency, concerns about air pollution in cities and the availability of large scale cooling technologies, there have been several projects addressing the implementation of district heating networks. The *Forum and 22@ District Heating & Cooling Network* [4] in the city of Barcelona is among the most successful projects. Figure 4 shows a map of this district heating network, being supplied by a waste incineration plant, gas boilers and a cold water storage tank.

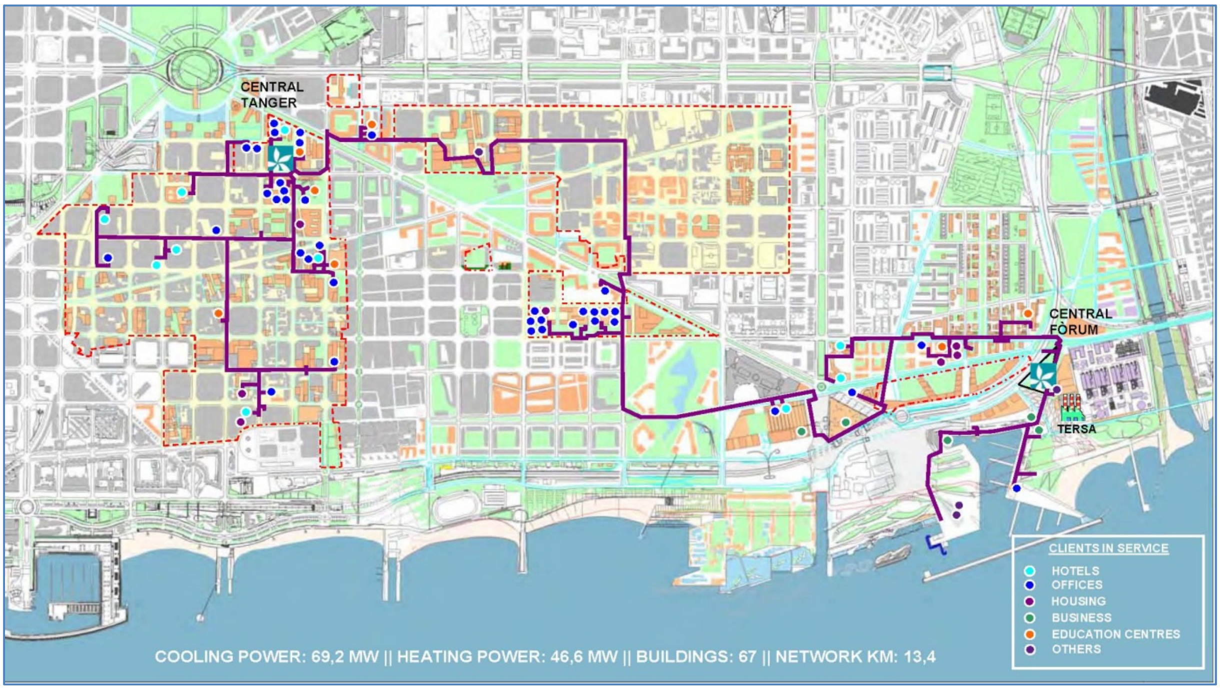



**Figure 4: District Heating and Cooling Network (2012) in Barcelona (Source: [4])**

According to [5] the main barriers for the successful realization of such projects are in the economic context the high investment cost and in the social context public acceptance. Traditionally, individual heating systems are used in Spain and convincing potential customers to switch to a new common system and giving up their independence can be a challenging task.

## Italy

There are hardly any district heating networks in the central and southern parts of Italy. Similar to the situation in Spain this can be explained by the mild climatic conditions and the resulting low heat demand. Other reasons for this, stated in [5], are, on the one hand, the excellent territorial coverage of the natural gas network and the high diffusion of efficient gas-driven domestic heating boilers and, on the other hand, the particular urban structure of most old Italian cites and its historical buildings.

However, the number of district heating networks is growing and especially in the northern regions there are several cities with district heating grids showing similar redundancies between natural gas and heating grids like in the city of Ulm. This can be seen for instance in Figure 5 and Figure 6, showing the well-developed natural gas distribution grid of the city of Turin and the district heating network, having been constructed since 1994 [6], respectively.

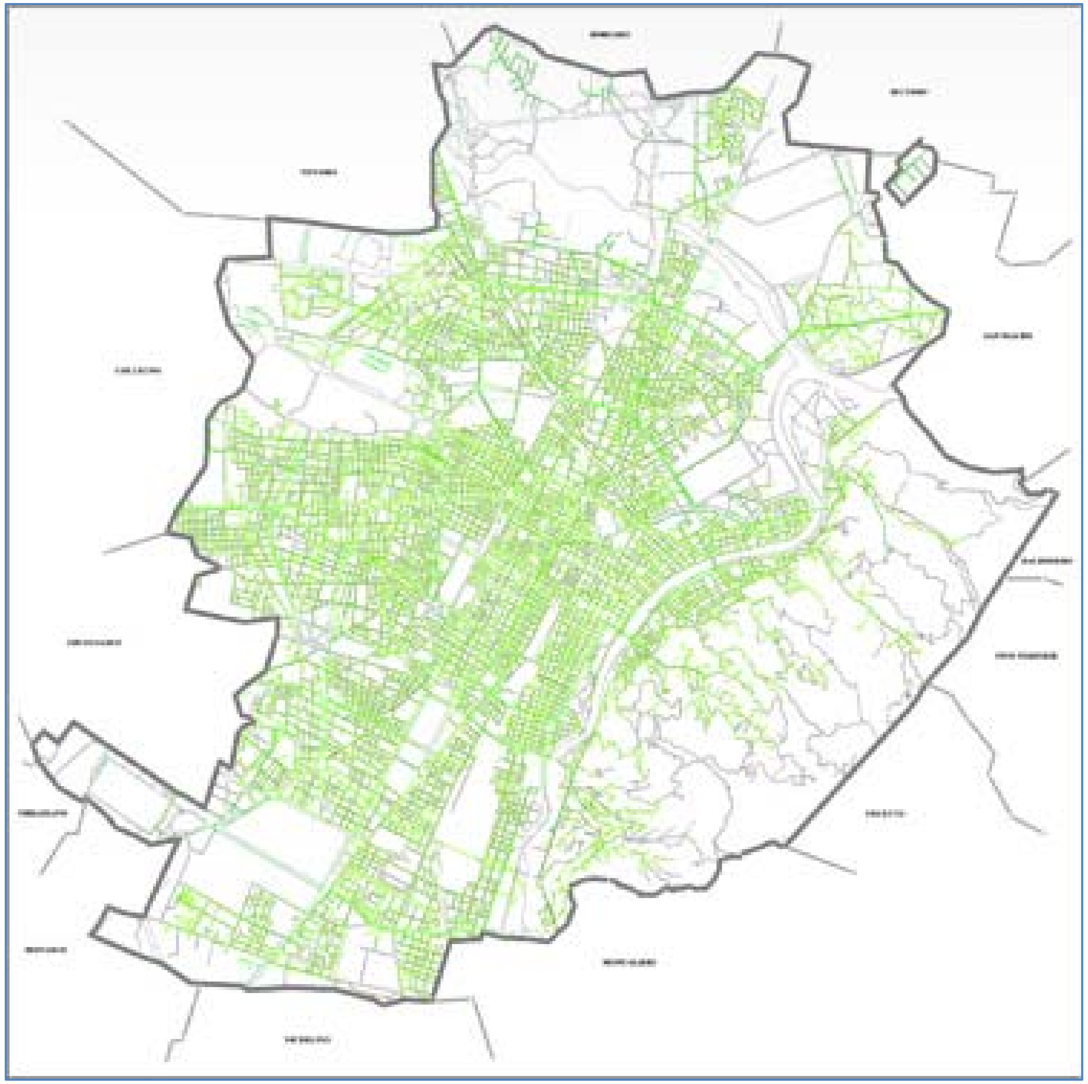


Figure 5: Natural Gas distribution network in Turin (Source: [7])

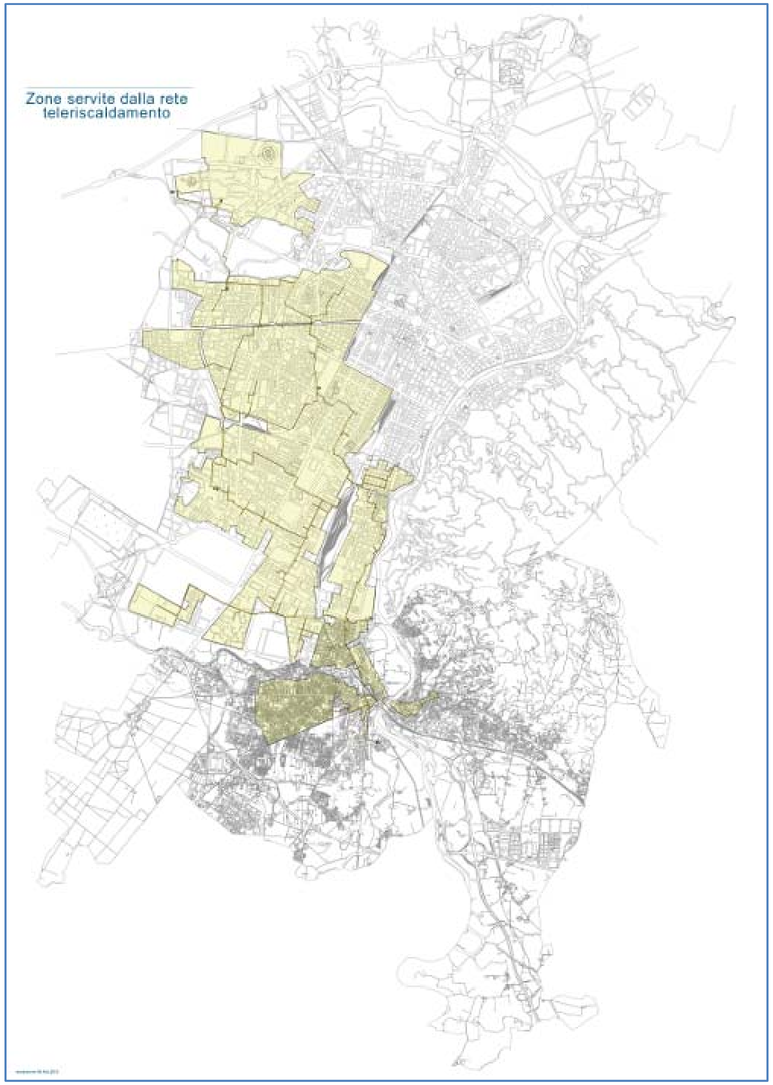



Figure 6: District Heating network in Turin (Source: [8])

### Greece

Similar to Spain and Italy, the climate in Greece is characterized by mild winters and relatively short heating periods compared to other European countries. This results in a low heat demand, which makes the implementation of district heating systems very difficult from an economic point of view, because they are associated with very high investment cost. According to [9] the most popular heating systems in Greece are individual oil-fired boilers.

Nevertheless, in the northern parts of Greece, particularly in the region of West Macedonia, there are some district heating networks in cities which are close to large lignite power plants like Kozani, Ptolemaida, Aminteo, Florina and Megalopoli (cf. [10] and [11]).

### Ireland

The district heating and cooling sector is not very well developed in Ireland. According to [5] the major reasons for this are the lack of knowledge and understanding among the general public and the lack of commitment among policy makers. The major barriers for the development of district heating and cooling systems in Ireland are the trade barriers for surplus electricity from CHPs and regulatory barriers for constructing CHP plants. At present there are no large scale district heating systems in Ireland. However, there are some successful smaller projects, like e.g. the biomass district heating network in the city of Tralee (cf. [12]), as well as some feasibility studies for large-scale district heating networks (cf. [13] and [14]).

### Romania

In Romania (and in other Eastern European countries) many large-scale District Heating networks had been constructed during the days of communist rule. However, according to [15], many of these District Heating networks were struggling with economic, environmental and technical problems because of energy-inefficient technologies, poor maintenance, inadequate management and lack of investments. Thus, during the post-communist transition era District Heating was abandoned in favour of other alternatives for domestic heating. The delay in receiving payments of delivered heat, the low-income population and the age of grid components are mentioned as the major barriers and challenges, for the rehabilitation of District Heating systems in [5].

## 2.2 Lack of active participation and knowledge of customer load profiles

Until liberalisation of the European energy markets in the 1990s the energy supply chain was vertically integrated, i.e. few companies were in charge to operate the entire supply chain, i.e. generation, transmission, distribution and customer supply.

### 2.2.1 Lack of active customer participation

Due to the fact that in the past there was no competition and no end user market, customers did not have any possibility to change their supplier, but they were rather locked to the local energy provision company. Thus the end user was not able to actively participate in the energy market e.g. in the sense of changing the energy supplier.

### 2.2.2 Lack of knowledge of customer load profiles

In the past, only load profiles of big commercial and industrial customers have been measured regularly, whereas small end users were metered once a year only. Thus, energy suppliers and network operators do not have detailed knowledge of the customers' load profiles. Instead they relied on so-called "standardised" load profiles for various different types of customers in their operational and planning processes.

Compared to the electricity sector, where the standardised load profiles have proven to be a rather good approximation of the actual customer behaviour on an aggregated level, the gas and heating network operators generally have less knowledge of their customers' load profiles. On the one hand, this can be explained by the fact, that it is not as crucial to keep pressure in these networks on an exact default value, as it is in the case for voltage and frequency in the electrical grid. On the other hand, the construction of a district heating grid and a gas network is dominated by very high investment costs and as a result also the customer bill has a high share of fixed costs. This makes the variable use-dependent part of energy delivery less important.

# 3 Factors having determined energy distribution grid development in the past

The purpose of this chapter is to identify and examine various factors that have strongly influenced the development of energy distribution networks in the past. Those factors are sub-divided into four categories:

- Institutional and structural factors
- Technological constraints
- Economic factors
- Social and behavioural factors

Naturally, it is impossible to consider all the influencing parameters in an energy distribution grid, so a few of the major points of each category are presented and investigated exemplarily in the following.

## 3.1 Institutional and structural factors

This category of institutional and structural factors shows some of the constraints from areas like law and politics but also resource-dependent and other conditions, which had a great impact on energy distribution development.

### 3.1.1 Vertically integrated energy supply chain

Historically, the energy supply chain with the elements generation, transmission, distribution and energy supply was integrated vertically and usually operated by public utilities. These circumstances made it very difficult and/or impossible for competitors to contest market shares of incumbent utilities. On the other hand, it was easier to plan and develop an energy system targeting to minimise the total system cost alongside the energy supply chain by exploiting economies of scale of energy service provision.

### 3.1.2 Primary and secondary fuel availability

Another result of the historical development was the construction of large generation plants located near to primary and secondary fuel sources or large industrial customers. The intention was to reduce transportation costs of primary and secondary fuels and to decrease average generation costs. In Germany, for example, there are many coal fired power plants in North-Rhine Westphalia, a region also known for large coal reserves.

### 3.1.3 Security of supply driven energy policy

After the 1973 oil crisis security of energy supply was a main focus in the European energy policy debate. This also explains the above mentioned redundancy between the gas and district heating network in dense areas. In many municipalities across Europe similar redundant distribution grid structures have been implemented like in Ulm, shown in Figure 1 [1].

## 3.2 Technological factors

This section will discuss the two most important technological facts from the past: (i) centralized generation and unidirectional supply and (ii) lack of smart control/metering. Combining these technological aspects, the energy management concept resulted in the energy grid paradigm of today – known as “generation feeds load”. Metering and control entities have been placed near the central generation units and within the transmission lines, leaving the customer side in passive mode. Consequently, the market has not been open to new competing actors on the generation and transmission side.

### 3.2.1 Focus on centralized generation technologies and unidirectional energy supply

In the past, larger generation plants benefited from economies of scale, which means that the average per unit production costs decrease as the quantity of produced MWh increases. As the energy supply chain was vertically integrated and mostly operated by a few public-owned utilities that aimed to minimise the overall production, transmission and distribution costs, they tried to make use of this property and built mainly large central generation plants (e.g. Combined Cycle Gas Turbines (CCGTs)). Naturally, this has also affected the way, energy distribution grids have been planned and constructed. Consequently, they have been designed as a medium to transport energy unidirectional from the big centralised generation plants to the “passive” consumers.

### 3.2.2 Lack of availability of smart control and metering technologies

It has already been mentioned that the distribution grid operators have been lacking detailed knowledge of customer load profiles. A major reason for this is the fact, that smart metering technologies simply were not available. For the electricity domain, for instance, the most common devices for measuring customer’s consumption has been electromechanical meters (called “Ferraris” meters), which only showed the overall kWhs consumed. They had to be read manually. Figure 7 shows a typical Ferraris meter.


Figure 7: Typical Ferraris meter. Source: [16]

## 3.3 Economic factors

Naturally the number of economic factors influencing the development of energy distribution is enormous. Besides market design and regulations having a significant impact also on non-competitive technologies, there are a number of economic determinates having influenced energy distribution grid development in the past. In the following a selection of these economic candidates concentrates on two of the major ones: (i) flat tariffs and (ii) low investment cost technologies.

### 3.3.1 Flat tariffs: Lack of price signals for customers

Customer tariffs were typically flat tariffs, i.e. the price per kWh was the same, regardless when it was purchased. Naturally, this type of tariff does not provide the customer with any information on the overall level of demand for energy at a certain point in time. Consequently, this tariff also does not indicate the effort which is needed to generate and deliver energy. Hence, the customer has no knowledge about the challenges of e.g. production and network operation at peak hours and, therefore, has no incentives to possibly help to overcome those difficulties by e.g. adapting its energy demand accordingly.

### 3.3.2 Implementation of heating technologies with high OPEX/CAPEX-ratio

The construction of district heating and gas networks is linked to high investment costs. Also the connection of a building to the network is rather expensive compared to remote, off-grid alternatives for energy service provision. This property together with the costs for energy efficiency measures in buildings is often reflected in the absolute level of the rent for flats. Thus less expensive flats are often equipped with electric heating systems (low investment costs), which has a much higher OPEX/CAPEX-ratio. This implies that often the socially deprived part of end-users is confronted with high running costs for heating.

## 3.4 Social and behavioural factors

In general, there are numerous social and behavioural factors affecting energy service provision and corresponding energy infrastructure needs. Among others, there are e.g. demographic factors (size of households), life-style factors (occupancy), comfort level expectations, and environmental awareness. In this section two of them are selected and described more in detail on how they affected energy distribution infrastructure development: (i) low comfort level and (ii) no or less environmental awareness.

### 3.4.1 Low comfort level (no or limited central heating systems)

In the past people were not used to high comfort levels that are considered to be standard nowadays in almost all European countries. This topic comprises many areas of everyday life. When it comes to energy distribution, one could for instance point out, that a couple of decades ago it was quite common to heat only one or two rooms regularly, whereas nowadays central heating systems can be regarded as standard.

### 3.4.2 No or less environmental awareness

Another important aspect of social influences on energy distribution development in the past - compared to nowadays - is the absence or weaker manifestation of public environmental awareness. Environmental protection and sustainability have not been that important and a central topic in the public discussions as they are now. Thus other factors like the price played a much bigger role when deciding on the primary energy sources of heating supply. This explains for instance the high share of oil-based heating systems, which are accounted for their heat efficiency value. However, the environmental impacts of oil-based systems are denoted to be negative.

# 4 Changing patterns and challenges for energy distribution grids in unbundled energy systems

The aim of this chapter is to show some of the most crucial changes in terms of energy distribution grid development in a competitive environment and unbundled energy systems. In principle, the structure of this chapter is the same as in the previous chapter, meaning that the following aspects are briefly described: (i) institutional, (ii) technological, (iii) economical and (iv) social and behavioural changes and challenges. Again it is important to note, that the list of changes and challenges presented here is far from complete. It rather targets to describe some of the major issues and tasks of energy provision exemplarily.

## 4.1 Institutional and structural changes and challenges

### 4.1.1 Market-based principles in an unbundled energy supply chain

With the liberalisation of energy markets (mainly gas and electricity) in most European countries in the 1990s and 2000s the previously vertically integrated energy supply chain has been unbundled. This means that grid operation, which meets all properties of a natural monopoly, is the only task in the energy supply chain still being regulated by a public authority. The other segments of the supply chain are deregulated and subject to competition. Thus every customer can freely choose its energy supplier for gas and electricity. On the contrary, the customers are physically still connected to their network operator. Besides connection of customers, the network operator also has to ensure transparent and non-discriminatory third party access to the grid for other market participants such as generators, retailers or aggregators. Figure 8 shows a simplified flowchart of the basic electricity market structure.

The red area indicated in Figure 8 represents the regulated market segment (i.e. the energy networks), whereas the green coloured domains illustrate the competitive segments generation, retail and customer supply business. Basically there are four major clusters of market players illustrated in the flowchart:

- Generator
- Grid operator
- Retailer/Supplier/Aggregator
- Customer

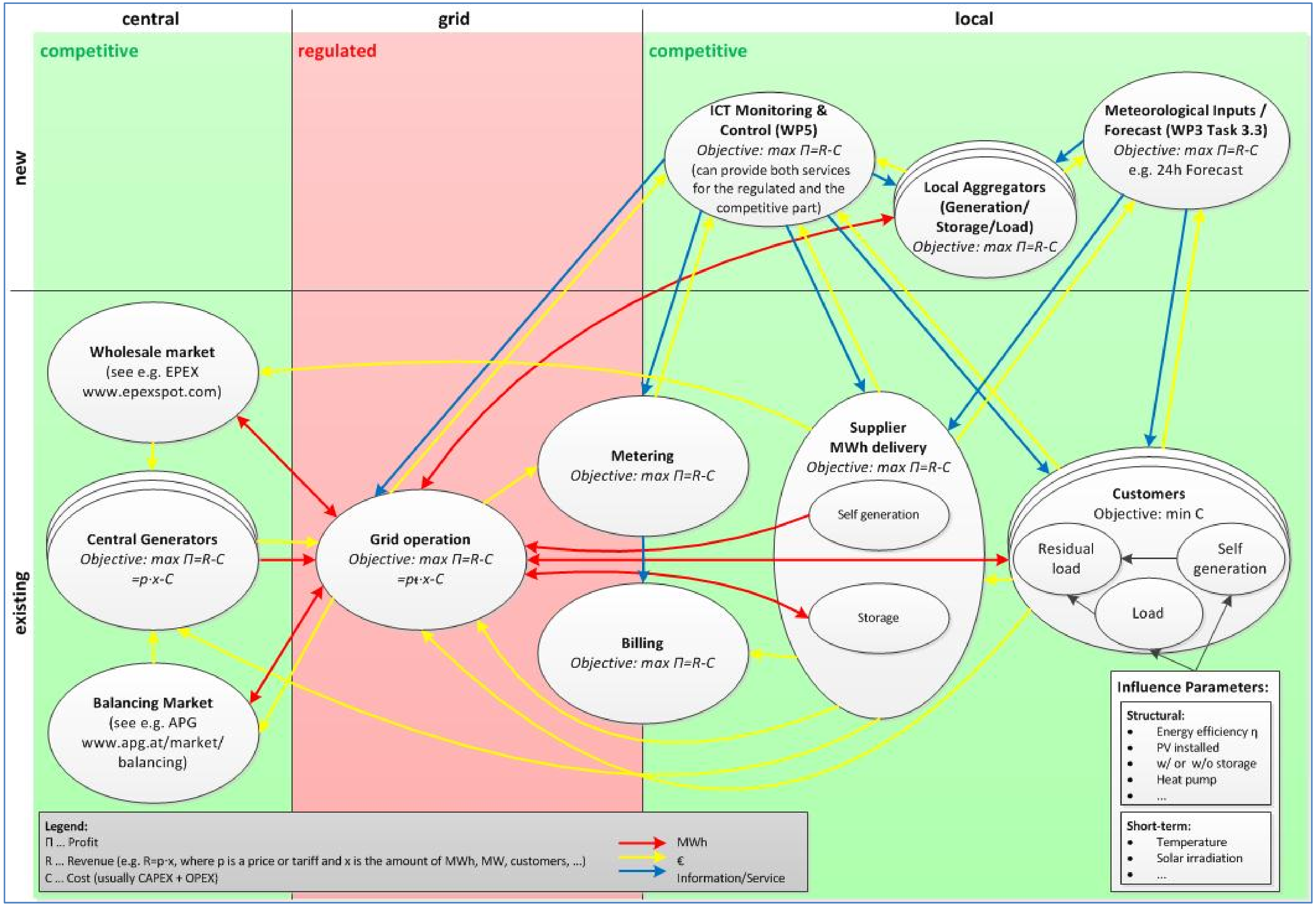



**Figure 8: Simplified flowchart of an unbundled electricity market structure**

The market participants on the right hand side of Figure 8 are the customers. They can meet their electricity load profile either by self-generation or by purchasing from a retailer. It is important to note that, while the end-users physically obtain electricity from the local grid operator, the respective retailer is responsible for energy provision and accounting.

This retailer (or also called supply company) can be found left to the customers in Figure 8. They can supply their customers either with self-generated electricity from their own power plants or with electricity they purchased from other generators or the wholesale market. The suppliers have to announce their daily generation and load schedules/profiles to market clearing and settlement agents on the previous day. In case of forecast errors, they have to pay a penalty compensating for balancing services having to be operated by grid operators and other contracted market participants fulfilling the corresponding technical prequalification criteria.

In addition to ensuring non-discriminatory access to the grid, the network operator in the red domain of the flowchart in Figure 8 has to provide the technical requirements for a smooth network operation (i.e. acquisition and operation of balancing energy and services) as well as to maintain security of energy supply.

Last but not least, generators can sell their electricity to retailers, aggregators or the wholesale market. In addition, they can offer balancing energy and/or balancing power to grid operators for activating balancing services.

In this context it is also important to note that it makes a difference between the various energy domains when talking about “liberalisation of energy markets” and implementing competition in the different segments of the energy supply chain. While the structure of the gas market is quite similar (i.e. a bid less complex than the electricity market design described above), the heat market has not yet been legally unbundled. That is due to the fact that heat grids are usually small local networks.

When considering a hybrid energy network containing all three energy domains electricity, gas and heat a flowchart in Figure 9 describes a market structure similar to Figure 8. Here the red area again represents the regulated market segment and the green areas the competitive parts. Figure 9 is divided into the three energy domains. The top left third shows the gas market, the top right the heat market and the bottom triangle the electricity market. Ordered from the outside to the centre of the circles the various market participants are again:

- Generator
- Grid operator
- Retailer/Supplier/Aggregator
- Customer

The different market players can act in different energy domains simultaneously. A Retailer, for instance, can offer electricity, gas and heat, which is indicated by the dashed lines. Hybrid technologies, like a Combined Heat and Power (CHP) plant, can feed into different grids and, therefore, are located at the borders between the respective energy domains. The customers can choose, which of the energy domains they want to use, so they are right in the centre of the flowchart.

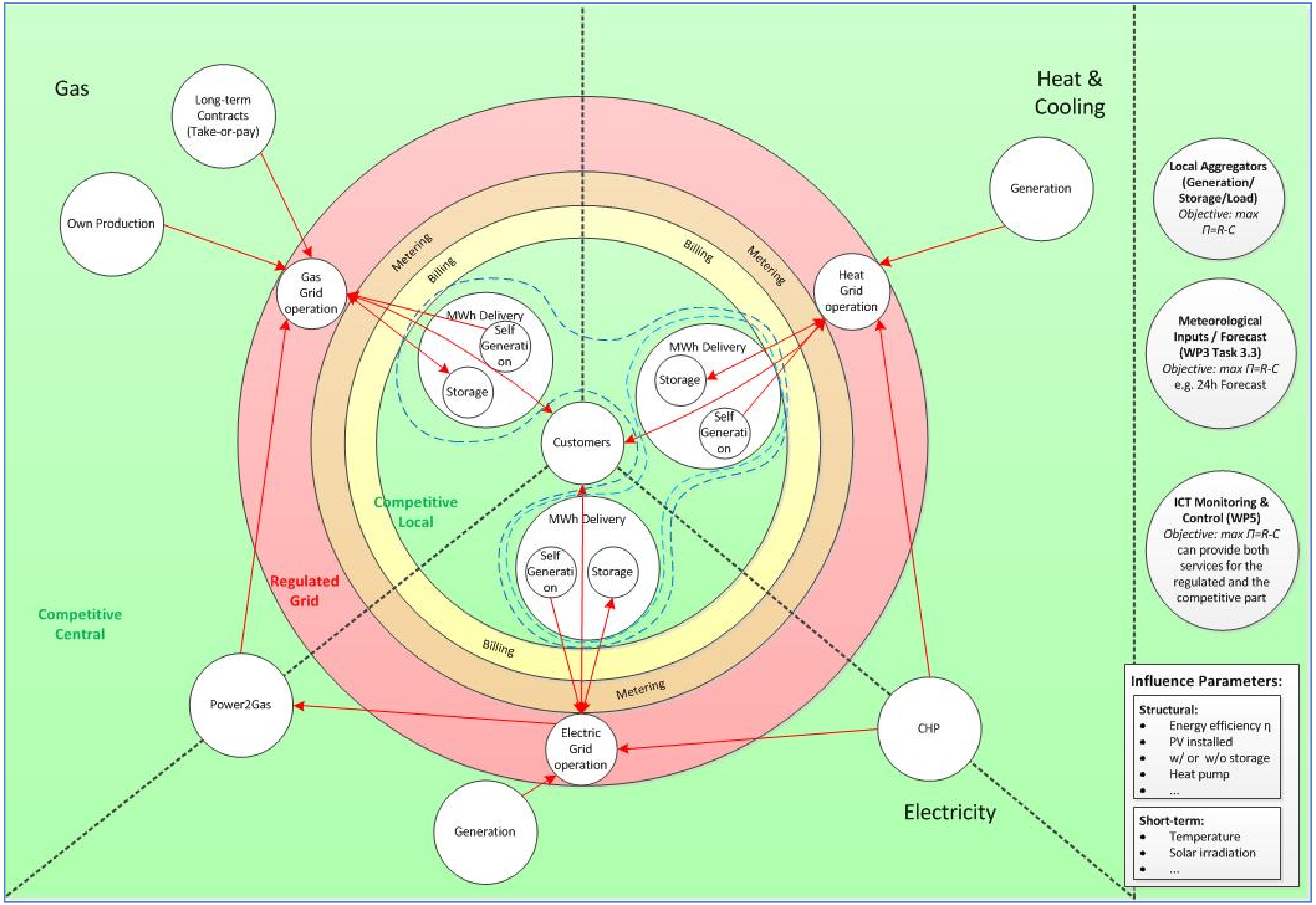



**Figure 9: Simplified flowchart of an unbundled hybrid energy market structure**

### 4.1.2 Financial support for sustainable decentralized technologies and energy efficiency measures

Closely connected to the topic discussed in section 3.4.2 environmental awareness and sustainability has become an important energy policy in recent years. Hence many European policy makers are very interested to support the development of (decentralised) renewable energy technologies (RES) and the promotion of their installation. In Germany, e.g., the Renewable Energy Sources Act[2] (EEG) not only grants priority dispatch for RES, but also guarantees a fixed feed-in tariff for renewable power plants. Another possibility to tackle the issue of environmentalism is to decrease energy consumption. This can be achieved e.g. by improving energy efficiency in many parts of the supply chain (e.g. also in buildings on end-user level). Thus financial support mechanisms for building restoration and many other energy efficiency measures have been developed in various European countries recently.

In the following, support schemes and policy approaches of different European countries for the promotion of energy efficiency, district heating and CHP are described based on the information, provided in [18] and [5]. A table with an overview of CHP support mechanisms for fossil fuel based CHP in the European Union 2007 is provided in Appendix A.

#### Spain

In Spain a Royal Decree has been introduced requiring qualification of buildings in terms of demand for heating and cooling and aiming to promote high efficiency buildings. Furthermore, two Royal Decrees have been introduced within the CHP-directive of the European Commission (EC) aiming to encourage the use of renewable fuels and waste and the sale of electricity from CHPs with tax reductions on input fuels and a generation based feed-in tariff for CHPs, which becomes smaller for plants with higher capacity.

#### Italy

In Italy six EC directives (Energy Performance of Buildings, CHP, Waste, Energy Service, Renewable Energy Sources and Integrated Pollution Prevention Control) have been implemented. CHP plants are granted a feed-in tariff and tax reductions on gas input fuels. Furthermore, small-scale CHPs up to a capacity of 50 kW receive payments to account for the benefits of decentralized generation to the grid. In addition, there is the ReHeat deployment program, promoting renewable heat (biomass boilers, solar thermal collectors and heat pumps in particular), and a Renewable Energy Feed-in Tariff.

#### Greece

In Greece, CHPs and biomass power plants are supported feed-in tariffs. These tariffs cannot be combined for CHPs running on biomass. The tariffs differ according to the location of the power plants. Investment subsidies are available for small-scale CHPs. They vary and can reach 55%.

#### Ireland

[2]see [17]

In Ireland there are building regulations focussing on the energy consumption and emissions of new and existing dwellings. In 2007 the CHP Deployment program has been implemented providing investment grants for small-scale fossil-fired and biomass CHPs (between 50kW and 1MW). Furthermore, financial tax incentives are available through the Accelerated Capital Allowance (ACA), encouraging investments in highly efficient plants.

### Romania

In Romania there is an act on the energy performance of buildings, aiming to reduce the overall energy consumption and especially focussing on demand reduction for heating and warm water by establishing minimal requirements for new and existing buildings. In addition, the CHP-act promotes the development of efficient cogeneration of heat and power by supporting the modernization of old CHPs and the construction of new ones. Grid operators are obliged to connect CHP plants to the grid and to buy electricity from cogeneration with priority over conventional electricity. Furthermore, the Government decision "District Heating 2006-2015 warmth and comfort program" aims to rehabilitate District Heating by different technical investments.

## 4.2 Technological changes and challenges

In the past few decades there has been extensive technological progress and there are already a lot of new, decentralised renewable energy technologies available.

### 4.2.1 Availability of sustainable decentralized technologies

The first field that greatly advanced recently in technological terms is the development of sustainable distributed generation plants such as photovoltaic (PV), solar thermal systems or small combined heat and power plants (µCHP). These technologies have become more efficient and also more economical in the recent past. Therefore, they have been implemented as decentralised power stations. This furthermore is regarded as a great opportunity for carbon dioxide reduction and security of energy supply for European countries, but it also poses some challenges in terms of network integration and smooth network operation as there are e.g. lower utilization of networks due to local self-generation, bidirectional energy flows in networks in case of local excess generation, etc.

### 4.2.2 Availability of smart ICT technologies

One possible strategy to tackle the challenge of integrating more decentralised generation plants into existing energy grids is the use of smart ICT technologies to control operation schedules in order to ensure optimal hybrid energy grid use. This area of research has also advanced considerably in recent years and raises various opportunities and challenges (e.g. privacy questions) as well.

## 4.3 Economic changes and challenges

Unbundling of the energy supply chain and the liberalisation of the energy markets has already been discussed briefly in section 4.1.1. It is straightforward that unbundling has important consequences for several economic aspects of several market participants in the supply chain.

### 4.3.1 Optimization of individual objective function for each market participant in the unbundled supply chain

Because the energy supply chain has been unbundled (notably for electricity and gas, but also to a large extent already for the heat market) in general any new stakeholder can try to enter the market. Thus economic analysis has become substantially more complex and it is important to examine each market participant and its respective objective function in order to develop a fitting analytical model.

If we consider e.g. customers, their objective is most likely to minimise their costs. Let us assume that they have a PV system installed and that they have to pay $p_{grid}$ to the network operator and $p_{supply}$ to the retailer for each MWh they obtain from the grid in $EUR/MWh$. In order to compare these tariffs with the cost of self-generated energy, one can compute the levelized cost of electricity (LCOE) for the PV system subject to investment cost, economic life-time, produced energy etc.[3] $LCOE_{PV}$. If we assume a fixed feed-in tariff $p_{feed}$ and denote by $q_{gen}(t)$ the self-generated energy, by $q(t)$ the purchased energy and by $q_{feed}(t)$ the energy fed into the grid at time $t$, then a simplified representation of a customer's optimisation problem could look like

$$\min \sum_{n=1}^{T} \frac{1}{(1+i)^n} \{\sum_{t=1}^{8760} [(p_{supply} + p_{grid} + p_{taxes/fees}) \cdot q_{grid}(t) + LCOE_{gen} \cdot q_{gen}(t) - p_{feed} \cdot q_{feed}(t)] + c_{fix}\}$$

$$\text{s.t.} \quad q_{grid}(t) + q_{gen}(t) - q_{feed}(t) = d(t),$$
$$q_{grid}(t) \geq 0, q_{gen}(t) \geq 0, q_{feed}(t) \geq 0,$$

where $d(t)$ is their demand at time $t$, $T$ is the life-time of the PV system in years, $i$ is the annual interest rate and $c_{fix}$ are fixed costs. In order to consider variable tariffs the items $p_{supply}, p_{grid}$ and $p_{feed}$ could also depend on time $t$.

This simple example only takes account of the electricity network and of course it has to be extended also considering additional heat or gas demand.

Similarly objective functions and optimisation problems for other market players can be elaborated and of course extended maximising their profit. For details in this context it is referred to the formal framework describing several market participants in the energy supply chain in Deliverable D2.2 ("Report on a multi-dimensional framework for smart hybrid energy network analyses") of the OrPHEuS project.

### 4.3.2 Smart metering and billing based on market price signals

Another economic challenge for energy service provision and distribution grid charging is to overcome the lack of correct price signals for end users (already briefly discussed in section 3.3.1). The large-scale usage of time-of-use (TOU) or real-time-pricing (RTP) tariffs could help reducing peaks in customers' load profiles and consequently decreasing generators' peak generation capacity

[3] See e.g. [19]

needs.[4] They could also contribute to avoid or postpone network operators' needs for grid expansion. Of course this requires adequate metering devices and other infrastructure components (like so called set-points in substations).

## 4.4 Social and behavioural changes and challenges

### 4.4.1 Higher comfort level without changes of consumer behaviour

Fortunately, in the last decades society has been able to continuously increase its energy service level. In almost all European countries there are also some measures and policy instruments implemented to protect also the socially deprived and to enable a certain level of energy comfort in their residences. The objective for the future shall be to further increase this comfort level without any need of changing consumer behaviour by implementing novel ICT technologies into the energy system.

Additionally, in recent decades a certain degree of environmental awareness has emerged throughout European society. But at the same time – when it comes to the individuals contributing to implement environmentally friendly technologies – a certain reluctance can be observed (and also in terms of change of consumer behaviour). Those changes in behaviour could be important means to exploit the full benefits of new and renewable energy sources and technologies.

### 4.4.2 Active participation and choice of consumer

The liberalisation of the energy markets has given the consumers the opportunity to freely choose their supplier. This means, that also the demand-side customers can actively participate in the energy market and influence the technology portfolios to be used to generate, distribute and to use energy. In addition, the consumers also can implement local generation and storage technologies, so they become increasingly so-called "prosumers". This means that they not only influence the generation technology portfolio, but also the power plant portfolio and its structure (i.e. centralised versus decentralised and local generation). In addition, "prosumers" are also increasingly changing the market organisation and they also influence the business models for several market participants involved in the energy supply chain.

---

[4] Although there exist some pilot studies in terms of TOU-Tariffs and Real-Time-Pricing, only the large-scale implementation can trigger some visible effects for the energy systems and, subsequently, for decision making in energy infrastructure planning by the different stakeholders.

# 5 Matrices describing the status quo and outlook of energy service provision in hybrid energy grid structures

In this chapter the first results of aiming to develop a well-structured systematic method to describe the status quo and outlook of hybrid energy service provision in qualitative terms are presented. At the beginning a way is shown, how several crucial technologies can be categorized. Based on that, several matrices describing various important technological, economic and social aspects of energy service provision are introduced.

## 5.1 Categorization

In order to be able to use several possible synergies of the three different energy domains electricity, gas and heat as one hybrid network, there have to be some facilities allowing physical interaction between the grids, i.e. some coupling points (CP) that enable conversion from one energy domain into another.

Figure 10 below indicates the basic elements of a hybrid energy network and the possible coupling points between the different energy domains.

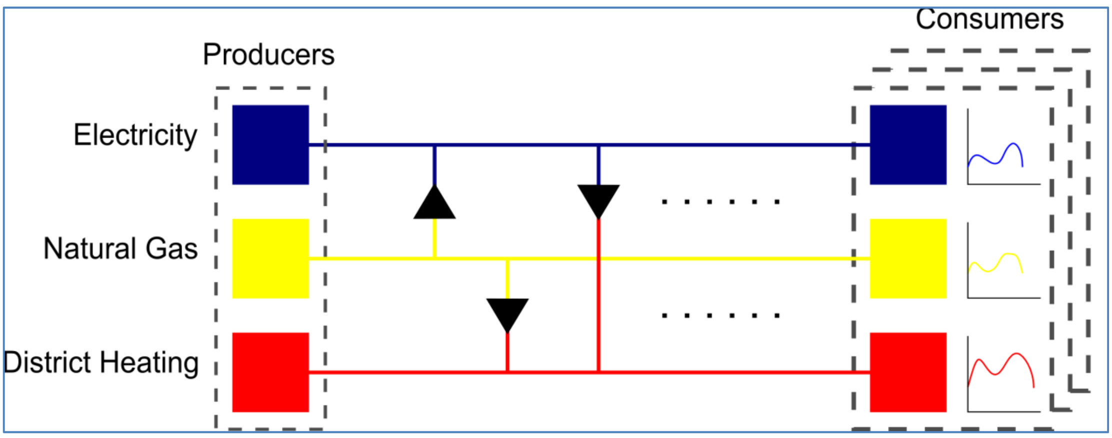



Figure 10: Basic elements of a hybrid energy network including possible coupling points.

Figure 11 finally shows an implementation example of the structure indicated above in the simplest form in the modelling tool “eTransport” having already been used for corresponding analyses of different hybrid energy systems (see e.g. [5] and [6]).

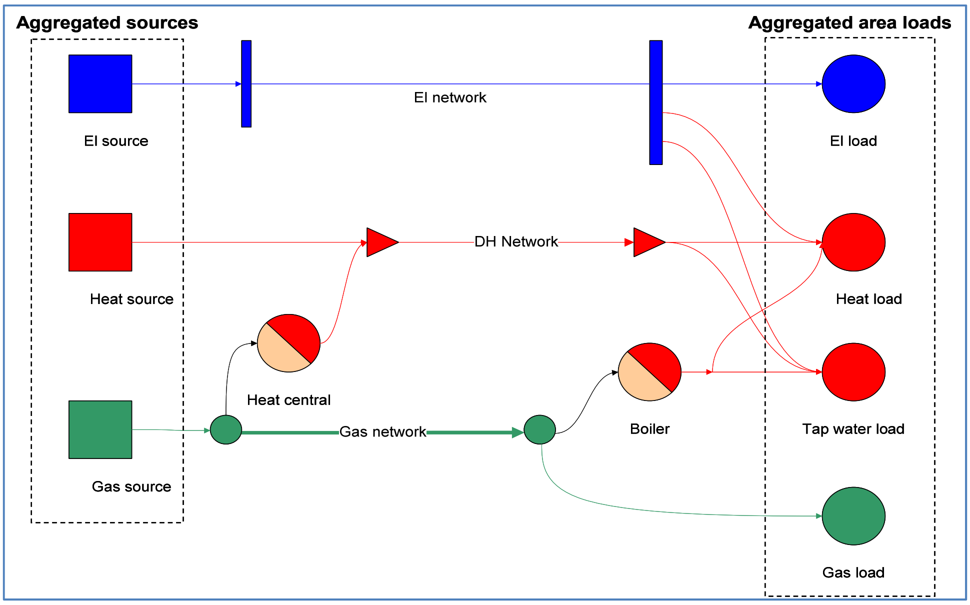



Figure 11: Basic elements of the eTransport[5] modelling tool (used in the FP7 project SUSPLAN[5])

At those coupling points the key technologies are allocated to enable energy service provision to the different end-user nodes in a hybrid sense. Table 1 indicates a list of coupling technologies classified by (i) energy domain connection and (ii) central versus distributed/local generation.

Table 1: Coupling points classified by energy domain connection and central versus distributed/local

| Energy Domains | | Technology | Input Domain | Output Domain |
|---|---|---|---|---|
| **Electricity, Heat & Gas** | **central** | Gas fired CHP | Gas | Heat & Electricity |
| | **local** | Gas fired µCHP | Gas | Heat & Electricity |
| **Electricity & Heat** | **central** | CHP | Gas or other fuels | Heat & Electricity |
| | | Heat Pump / Electric Heater | Electricity | Heat |
| | **local** | µCHP | Gas or other fuels | Heat & Electricity |
| | | Heat Pump / Electric Heater | Electricity | Heat |
| **Electricity & Gas** | **central** | Power2Gas | Electricity | Gas |
| | | Gas fired power plant | Gas | Power |
| | **local** | Power2Gas | Electricity | Gas |
| | | Gas fired power plant | Gas | Power |
| **Gas & Heat** | **central** | Gas driven Heat Pump / Boiler | Gas | Heat |
| | **local** | Gas driven Heat Pump / Boiler | Gas | Heat |

[5] See [20] and [21]

In addition to coupling points there are other measures and strategies available that can help improving the operation of a hybrid energy network. We call them supporting points (SP) and some examples are:

- Supply Side Management (SSM; e.g. *Virtual Power Plants* or *Supply Temperature Control*)
- Demand Side Management (DSM)
- Storage Management

## 5.2 Selected technological matrices

In this section selected tables are presented that qualitatively show the impact of certain coupling points or supporting points on different market participants in technological and economic terms respectively.

The technological key parameters for evaluating the effects of coupling points and supporting points on several stakeholders are efficiency for generators and customers, impact on the load factor, flexibility and predictability for grid operators and retailers. In Table 2 some technological aspects of heat pumps and electric boilers are presented.

**Table 2: Technological aspects of heat pumps / electric heaters**

| | | Technology | Generator | Grid Operator | Retailer | Customer | Aggregator |
|---|---|---|---|---|---|---|---|
| **Power & Heat** | **central** | **Heat Pump / Electric Heater** | Low primary energy efficiency (compared to CHP) | Possibility to relieve stressed electric grid | | | |
| | **local** | **Heat Pump / Electric Heater** | | | Higher electric load profile and smaller thermal load profile | Lower primary energy efficiency (compared to µCHP) | |

Due to the fact that it is almost impossible to clearly separate technological from economic properties of coupling points, it makes sense also to consider the economic implications of the different coupling points for the various market participants. As an example, Table 3 below shows the economic implications and interdependences of a centralized gas fired CHP plant and a local gas fired micro-CHP (µCHP) operated by a customer or a small community on the various stakeholders.

Table 3: Economical implications and interdependences of gas fired CHPs

| | | Technology | Generator | Grid Operator | Retailer | Customer | Aggregator |
|---|---|---|---|---|---|---|---|
| Power, Heat & Gas | central | **Gas fired CHP** (Gas to Heat & Power) | Shared fixed costs for electricity and heat gen.; Generation costs depend on gas price; | | + (more kWhs to sell) | | |
| | local | **Gas fired µCHP** (Gas to Heat & Power) | Lower efficiency but higher flexibility than big scale plants | | - (less kWhs to sell) | Shared fixed costs for electricity and heat gen.; Generation costs depend on gas price; Electricity produced is proportional to heat demand | |

## 5.3 Selected economical matrices

For the qualitative description of economic interdependences of energy service provision in hybrid networks some of the key parameters for the different stakeholders are listed in Table 4, notably those relevant for the electricity sector (the gas sector is similar, the heat sector has some further particularities not shown in detail in Table 4 below).

Table 4: Economic aspects of hybrid energy service provision

| | Generator | Grid Operator | Retailer | Customer | Aggregator |
|---|---|---|---|---|---|
| **regulated vs. competitive** | competitive | regulated | competitive | competitive | competitive |
| **price / tariff** | marginal cost pricing, spot market | 1-part or 2-part tariff | usually flat tariff | | |
| **asset management** | yes | yes | no / yes (smart meters) | no / yes (in case of self-generation) | |
| **financial support instruments** | yes (for renewable energy sources) | no | no | yes | yes |
| **environmental taxes** | yes | no | yes | yes | yes |
| **…** | | | | | |

Explanations to Table 4:

- A 1-part tariff is a tariff that depends on the amount of delivered energy only, whereas a 2-part tariff has an energy (EUR/kWh) and power (EUR/kW) component.
- The marginal cost depends on the quantity of a produced commodity and is the cost of producing one more unit– in this case one more kWh on energy.

## 5.4 Selected social matrices

For the development of social matrices the customers are divided into the following groups:

- Tertiary sector (public buildings, schools, hospitals, etc.)
- Industrial and commercial sector (big industries, small and medium sized enterprises, etc.)
- Private sector (single family houses, multi-family houses, etc.)

Exemplarily, in the following Table 5 the different customer groups' incentives and degrees of freedom are compared in terms of a selection of a few criteria being relevant in energy service provision in hybrid energy systems: (i) decision making potential, (ii) incentives and willingness to invest in eco-friendly technologies and (iii) incentives for behavioural changes.

Table 5: Social aspects of hybrid energy service provision

| | Tertiary | Industrial and commercial | Private | |
|---|---|---|---|---|
| | | | Single-family buildings | Multi-family buildings |
| **Decision making potential of individuals** | - | +/- | + | - |
| **Incentives to invest** | economic / bureaucratic criteria | economic / marketing criteria | economic / ideological criteria | economic / ideological criteria |
| **Willingness to invest in eco-friendly technologies** | - | +/- (see explanation below) | + | +/- |
| **Incentives for behavioral changes** | - | +/- | + | +/- |

Legend: +…positive, -…negative, +/- ...positive or negative (depends which individual has the power to decide)

@ Willingness to invest in eco-friendly technologies (industrial and commercial customers):
Many industrial and commercial areas already have to fulfill environmental constraints in many countries and, therefore, incentives to invest in sustainable technologies exist. In general, however it always depends on the constraints/regulations and the economics of an investment. In terms of economics also marketing aspects may play a significant role, at least implicitly (in case companies that like to advertise how green they are to attract a corresponding customer segment).

# 6 Conclusions

Summing up the main insights of this report, it has become apparent that describing the technical, economic and social patterns of energy service provision in hybrid networks is a very complex topic. On the one hand, this is due to the particular historical development explained in the chapters 2 and 3. On the other hand, it is because of the multitude of factors influencing the operation and control of hybrid energy grids by different stakeholders trying to optimize their individual objective function (see e.g. Figure 12 where the interdependencies between the various stakeholders are presented).

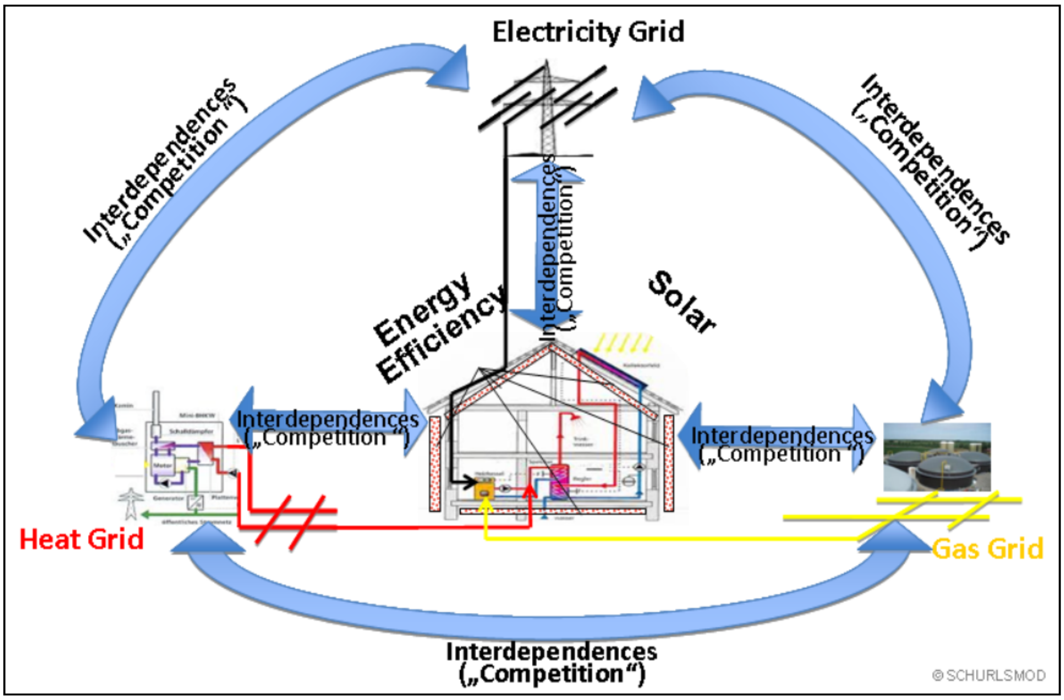



Figure 12: Interdependencies and competition between the energy domains and the customers. Source: EEG

Figure 12 shows, how the energy domains electricity, gas and heat are competing for the end users' load profile (or at least congesting each other's market shares in case of end-user heat system changes, implementation of new components at the end-user like wall insulation, solar energy technologies for local heat and/or electricity generation, etc.). Furthermore, due to the manifold technological advances in terms of standardized, decentralized generation technologies and also due to the increasing degree of environmental awareness among society, many customers have developed from passive consumers to active participants in the energy supply chain (e.g. due to local self-generation). Thus, the three energy domains not only have to compete with each other, but also with the end users energy efficiency measures or with possibly installed self-generation, like photovoltaic or solar thermal systems.

To better illustrate this competitive situation, Figure 13 exemplarily shows the impact of energy efficiency implementation in the medium to long term and the corresponding choice of the preferred heating strategy[6].

| Preferable Heating Strategies Depending on End-use Efficiency Ambition up to 2050 | | | Expected End-use Efficiency Implementation 2030 - 2050 | |
|---|---|---|---|---|
| | | | Low | High |
| Stand Alone | Non grid connected RES-H (e.g. stand alone biomass in less dense & rural areas,Solar thermal collectors) | | O | + |
| Network Infrastructure | Electricity Distribution Grid | Direct electric heating (e.g. Norway) | O | - |
| | | „Innovative" electric heating (e.g. heat pumps) | - | + |
| | Heat Distribution Grid | CHP-based RES-H (e.g. Biomass / Biogas in dense areas / municipalities) | + | -/o |
| | | District heating (e.g. various fuels in dense areas / municipalities) | + | -/o |
| | Gas Distribution Grid | RES-G fed into gas distribution grid | + | - |
| | | Natural gas and LNG fed into gas distribution grid | + | - |

+...Preferable Strategy O...Indifferent -...Non Preferable Strategy

Source: Auer (2010)

**Figure 13: Preferable heating strategies depending on the end-use energy efficiency ambition in the heating sector up to 2050**

In general, it can be stated that in order to mitigate at least parts of the $CO_2$ emission problem in the heating sector it is expected that in a medium to long term perspective the development will be characterized by much more ambitious end-use efficiency strategies than today. The effects of policies like that on the different heating strategies are indicated in the far right column in Figure 13 which is explained in detail in the following:

- In general, several grid connected technologies and technology combinations are increasingly confronted with significant challenges (notably heat and gas distribution grids); except electricity grids supplying innovative technologies like heat pumps (on the contrary to direct electric heating which is supposed to be the worst technology solution in a sustainable energy world)[7].
- In general, high energy efficiency standards are, furthermore, also favoring innovative stand-alone solutions like biomass (chips) and/or pellets in combination with solar thermal collectors in less dense and rural areas.

[6] The results and the graphic are taken from the FP7 project "SUSPLAN" [21].

[7] When talking about sustainable energy systems, one strong argument against direct electric heating is the fact that electricity is the energy carrier with the highest degree of refinement. Furthermore, with the exception of hydro-power, wind and PV dominated electricity supply systems another strong opposing argument is the low total efficiency (and, subsequently, negative environmental balance) of the chain of conversions from primary energy to end-use energy services.

- In particular, conditions for *gas distribution grids* (supplying the residential and tertiary sector) may become increasingly difficult in many regions. They are simply not needed any more in the long-term. So already at present a further extension of gas distribution grids for domestic consumption may be an ambiguous strategy in many cases. At this point it is important to note, however, that corresponding gas infrastructures supplying the industrial and power generation sector are not included in this assumption.
- *District heating* also faces many challenges in the future. On the one hand, competitors like energy efficiency, solar thermal collectors and others contest market shares of heat loads in areas with medium/average density but, on the other hand, district heating is supposed to be still the first best solution in dense areas like cities and bigger municipalities.

Last but not least, it is important to note that several of the arguments mentioned above in the individual case also have to consider further important aspects as there are e.g.

- various implementation problems of energy efficiency measures in buildings (e.g. tenant/owner problem in decision making, monument protection and/or cost intensive retrofitting of historical buildings, etc.)
- space limitations on the customer side for heat pumps and electrical/thermal storages
- limited resources for heat pumps, especially in dense urban areas
- security of supply aspects favoring/hampering a particular solution
- others

Finally, several of the aspects mentioned above have to be considered in subsequent tasks and work packages in the OrPHEuS projects when trying to find cooperative control strategies of hybrid network operation in general and in the two test sites Ulm (Germany) and Skellefteå (Sweden) in particular.

# 7 References

[1] DBDH: District heating history. [January 17, 2014]; Available from: http://dbdh.dk/district-heating-history/.

[2] Connolly D, Mathiesen BV, Østergaard PA, Möller B, Nielsen S, Lund H et al. Heat Roadmap Europe 2050: Second pre-study for the EU27; 2013.

[3] Eguaras-Martínez M. District Energy Systems Development: The Spanish Case. 14th International Symposium on District Heating and Cooling 2014.

[4] Forum/ 22@ District Heating & Cooling Network. [November 26, 2014]; Available from: http://81.47.175.201/project-protocol/index.php/forum-22-district-heating-cooling-network.

[5] EcoHeat4.eu / Country-by-country db / Overview. [November 26, 2014]; Available from: http://ecoheat4.eu/en/Country-by-country-db/Overview/.

[6] Storia. [November 27, 2014]; Available from: http://www.irenenergia.it/ChiSiamo/ChiSiamo/Storia.html.

[7] La rete di distribuzione | AES Torino. [November 27, 2014]; Available from: http://www.aes.torino.it/aes-il-gas/la-rete-di-distribuzione.

[8] Piano di Sviluppo. [November 27, 2014]; Available from: http://www.irenenergia.it/ChiSiamo/Attivita/Teleriscaldamento_Torino/piano_sviluppo.html.

[9] Papadopoulos AM, Oxizidis S, Papandritsas G. Energy, economic and environmental performance of heating systems in Greek buildings. Energy and Buildings 2008;40(3):224–30.

[10] Markogiannakis G, Giakoumi A, Kara F. Feasibility Analysis: District Heating Network in Ptolemaida, Greece.

[11] ΑΝΑΠΤΥΞΙΑΚΗ ΔΥΤΙΚΗΣ ΜΑΚΕΔΟΝΙΑΣ Α.Ε. [November 28, 2014]; Available from: http://www.anko.gr/.

[12] The_Mitchels_Boherbee_Regeneration_Project. [January 07, 2015]; Available from: http://www.seai.ie/Publications/Renewables_Publications_/Bioenergy/The_Mitchels_Boherbee_Regeneration_Project.pdf.

[13] District Heating for Dublin Feasibility Study. [January 07, 2015]; Available from: http://www.dublinwastetoenergy.ie/uploads/archive/files/FeasibilityStudyMainReport29-09-2008.pdf.

[14] Cork Docklands high level district heating feasibility study. [January 07, 2015]; Available from: http://www.corkcity.ie/services/docklands/sustainability/districtheatingfeasibilitystudy/District%20Heating%20Feasibility%20Study.pdf.

[15] Poputoaia D, Bouzarovski S. Regulating district heating in Romania: Legislative challenges and energy efficiency barriers. Energy Policy 2010;38(7):3820–9.

[16] Wikimedia Commons: File:Drehstromzähler l&g hochkant.jpg. [January 22, 2014]; Available from: http://commons.wikimedia.org/wiki/File:Drehstromz%C3%A4hler_l%26g_hochkant.jpg.

[17] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit BMU, www.bmu.de. Gesetz für den Vorrang Erneuerbarer Energien (Erneuerbare-Energien-Gesetz - EEG).

[18] European Summary Report on CHP support schemes: a comparison of 27 national support mechanisms. CODE project report. [January 09, 2015]; Available from: http://www.code-

project.eu/wp-content/uploads/2011/02/231210-European-Summary-Report-on-CHP-support-schemes.pdf.

[19] Branker K, Pathak M, Pearce JM. A review of solar photovoltaic levelized cost of electricity. Renewable and Sustainable Energy Reviews 2011;15(9):4470–82.

[20] eTransport - SINTEF. [February 25, 2014]; Available from: http://www.sintef.no/etransport.

[21] SUSPLAN - EU project. [February 25, 2014]; Available from: http://www.susplan.eu/.Auer (2010).

[22] Hybridnetze für die Energiewende – Forschungsfragen aus der Sicht der IKT, acatech Materialien, Berlin, 2012.

# 9 Disclaimer

The OrPHEuS project is co-funded by the European Commission under the 7th Framework Programme "Smart Cities" 2013.

The sole responsibility for the content of this publication lies with the authors. It does not necessarily reflect the opinion of the European Commission.

The European Commission is not responsible for any use that may be made of the information contained therein.

# 10 Contacts

### Project coordinator

Ingrid Weiss & Silvia Caneva @ WIP – Renewable Energies

Sylvensteinstrasse 2, Munich, Germany

Email: Ingrid.weiss@wip-munich.de / Telephone: 0049 (0) 720 12 742

Email: silvia.caneva@wip-munich.de / Telephone: 0049 (0) 720 12 733

### WP Leader

Hans Auer @ TUW-EEG

Vienna University of Technology

Institute of Energy Systems and Electrical Drives

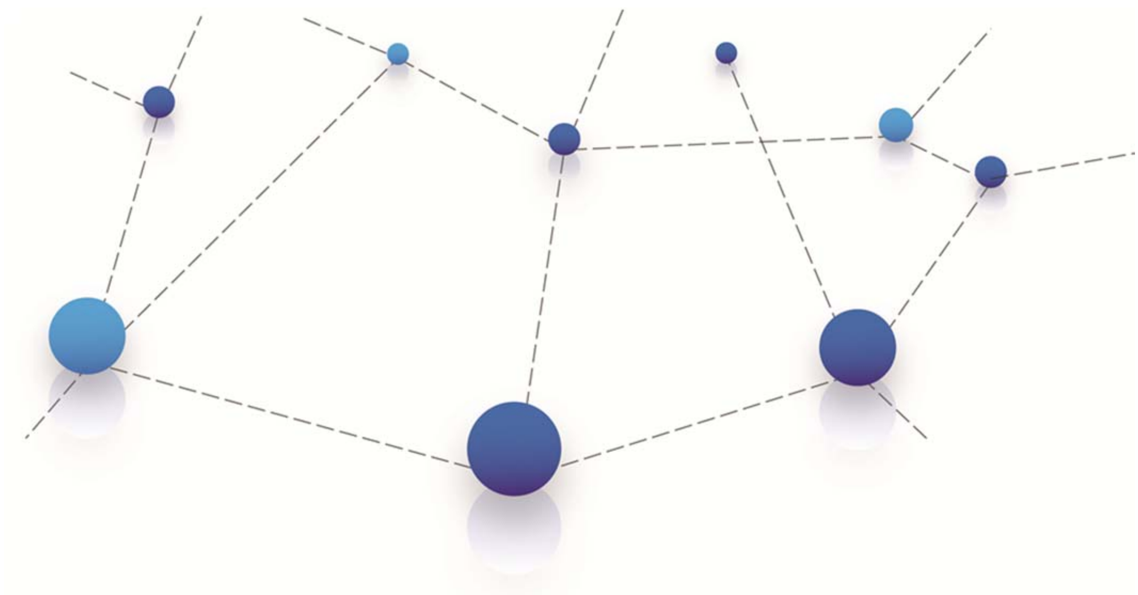
Energy Economics Group (EEG)

Gusshausstrasse 25-29/E370-3

A - 1040 Vienna

Austria

Email: auer@eeg.tuwien.ac.at / Telephone: 0043 (0) 1 58801 370357



# A Overview of CHP support mechanisms across Europe

Table 6: Overview of CHP support mechanisms for fossil fuel based CHP in the European Union 2007. Source: [18]

| Country | Tax Support | Feed-in Tariff | Certificate Scheme | Capital grant |
|---|---|---|---|---|
| Austria | | ✓ | | |
| Belgium – Flanders | ✓ | | ✓ | |
| Bulgaria | | ✓ | | |
| Cyprus | | | | |
| Czech Republic | | ✓ | | |
| Denmark | | | | |
| Estonia | | | | |
| Finland | | | | ✓ |
| France | | ✓ | | |
| Germany | | ✓ | | |
| Greece | ✓ | ✓ | | |
| Hungary | | ✓ | | |
| Ireland | | | | |
| Italy | ✓ | ✓ | | ✓ |
| Latvia | | ✓ | | |
| Lithuania | | ✓ | | |
| Luxembourg | ✓ | | | |
| Malta | ✓ | | | |
| Netherlands | ✓ | ✓ | | ✓ |
| Poland | | | ✓ | |
| Portugal | | | | ✓ |
| Romania | | ✓ | | ✓ |
| Slovakia | | ✓ | | |
| Slovenia | | ✓ | | |
| Spain | ✓ | ✓ | | |
| Sweden | | | | ✓ |
| United Kingdom | ✓ | ✓ | | ✓ |