e-HIGHWAY 2050

Modular Development Plan of the Pan-European Transmission System 2050

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WP 3	**Technology portfolio to meet the 2050 scenarios**		
D3.1	**Technology assessment from 2030 to 2050**		

Annex to D3.1 - Technology Assessment Report

Generation Technologies: Combined Heat and Power

Revision	**Organisation**	**Date**
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PU	Public	
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)	X

Document information

General purpose

This document is an annex of deliverable **D3.1** focusing on the technology assessment of combined heat and power generation technologies. It particularly deals with the combined heat and power generation technologies on the time horizon set by the e-Highway2050 project, i.e. from today until 2050 time horizon.

The present document is complemented by an attached Excel file providing the data compiled according to the methodology described in the in the next sections.

Change log

Revision	Date	Changes description	Authors
V1.0	03/03/14	Creation of the document and associated Excel file	IEN
V1.1	10/04/14	Quality pool comments	IEN
V1.3	03/07/14	Comments from WP leader	TECHNOFI
V2.0	25/07/14	Corrections from IEN	IEN
V3.0	29/08/2014	Final version for D3.1	TECHNOFI

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Glossary and acronyms

Acronym	Definition
CHP	Combined heat and power
MSW	Municipal solid waste
Incineration	Waste treatment process that involves the combustion of organic substances contained in waste materials
Gha – giga hectare	Although not strictly a unit of SI, is the only named unit of area that is accepted for use within the SI. 1ha = 10 000 m^2
ICE	Internal combustion engine
CCGT	Combined Cycle Gas Turbine
OECD	Organisation for Economic Co-operation and Development

Table of content

1 Introduction

Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to simultaneously generate electricity and useful heat. Cogeneration is a thermodynamically efficient use of fuel. In separate production of electricity, some energy must be discarded as waste heat, but in cogeneration this thermal energy is put to use.

The primary objective of this deliverable is to establish a uniform, commonly accepted and up-to-date basis for energy planning activities, such as future outlooks, evaluations of security of supply and environmental impacts, climate change evaluations, and technical and economic analyses, e.g. on the framework conditions for the development and deployment of certain classes of technologies.

The main objective of the present document is to provide a collection of information on combined heat and power generation technologies according to a homogeneous methodology developed and used for all generation, demand, transmission and storage technology areas.

Combined heat and power technologies are a small part of bigger piece which is electricity generation. For thermal electricity generation, this topic is comprehensively and deeply covered by the D3.1 annex "e-HIGHWAY2050. Supply Block Generation", prepared by VGB PowerTech. Authors have drawn a clear overview of the basic energy conversion technologies transforming primary energy sources into the electricity energy vector also describing all important power generation technologies. The idea behind the present report on CHP is to focus mainly on the differences between electricity generation in general and specific solutions used in CHP technologies. These differences are mostly the source of primary energy and conversion technologies.

The main added value of this report (as a supplement of the VGB Power Tech report) can be summarized with the following features:

- to document the selection of combined heat and power technologies within the framework of the e-Highway2050 project,
- to define the assumptions set for the data gathering process,
- to provide a list of international references on the subject,
- to appraise trajectories of evolutions of cost and technical parameters for a selection of combined heat and power technologies,
- to contextualize the gathered data, i.e. to fit the data for each of the five e-Highway2050 scenarios.

2 Sources of primary energy for CHP

Sources of primary energy for combined heat and power generation technologies are one of the main two differences between them and conventional heat power plant. In this section, the most commonly used, as well as most promising source of energy in terms of their usefulness for CHP, are described.

2.1 Waste

This sub-section is based upon references [5] and [6].

Incineration, the combustion of organic material such as waste with energy recovery, is the most common waste to energy implementation. The plant is primarily designed for incineration of municipal solid waste and similar non-hazardous wastes from trade and industry. Some types of hazardous wastes may, however, also be incinerated. The waste is delivered by trucks and is normally incinerated in the state in which it arrives. Only bulky items are shredded before being fed into the waste bunker.

Municipal solid waste (MSW) incineration plants tend to be among the most expensive solid waste management options, and they require highly skilled personnel and careful maintenance. For these reasons, incineration tends to be a good choice only when other, simpler, and less expensive choices are not available. Because MSW plants are capital-intensive and require high maintenance costs and comparatively higher technically trained operators, they are commonly adopted by developed countries (high capital and maintenance costs may make MSW incineration out of reach for many of the less developed countries).

Incineration Advantages

Incineration is an efficient way to reduce the waste volume and demand for landfill space. Incineration plants can be located close to waste generation centres, thus reducing the cost of waste transportation. Using the ash from MSW incinerators for environmentally appropriate construction not only provides a low cost aggregate but further reduces the need for landfill capacity. In particular, incineration of waste containing heavy metals should be avoided to maintain a suitable slag quality (however, ordinary household waste does contain small amounts of heavy metals which do not readily leach under field conditions). The slag quality should therefore be verified before it is used. Energy can be recovered for heat or power consumption. All waste disposal alternatives eventually decompose organic materials into simpler carbon molecules such as CO_2 (carbon dioxide) and CH_4 (methane). The balance between these two gases and time frame for the reactions varies by alternative.

Tab. 2.1 Emission factors of different fuels [6]

	Coal	Gas oil	Natural Gas	Waste
CO_2 (kg/GJ)	95	74	57	18
CH_4 (g/GJ)	1,5	1,5	15	0,6
N_2O (g/GJ)	3	2	1	1,5
SO_2 (g/GJ)	45	23	0	23,9
NO_x (g/GJ)	130	52	50	124

Incineration provides the best way to eliminate methane gas emissions from waste management processes. Furthermore, energy from waste projects provides a substitute for fossil fuel combustion. These are two ways incineration helps reduce greenhouse gas emissions. One of the most attractive features of the incineration process is that it can be used to reduce the original volume of combustibles by 80 to 95 percent. Air pollution control remains a major problem in the implementation of incineration of solid waste disposal. In the United States, the cost of best available technology for the incineration facility may be as high as 35 percent of the project cost. The cost of control equipment will, however, depend upon the air pollution regulations existing in a given lesser developing country. Waste incineration may be advantageous when a landfill cannot be sited because of a lack of suitable sites or long haulage distances, which result in high costs.

Incineration Disadvantages

An incineration plant involves heavy investments and high operating costs and requires both local and foreign currency throughout its operation. The resulting increase in waste treatment costs will motivate the waste generators to seek alternatives. Furthermore, waste incineration is only applicable if certain requirements are met. The composition of waste in developing countries is often questionable in terms of its suitability for auto-combustion. The complexity of an incineration plant requires skilled staff. Plus, the residues from the flue gas cleaning can contaminate the environment if not handled appropriately, and must be disposed in controlled and well-operated landfills to prevent ground and surface water pollution.

Incineration Potential

Waste generation depends highly on socio-economic conditions and the degree of urbanization and industrialization. In general, waste generation and composition data cannot be projected from one place to another. In table 2.2 World's waste incineration potential is shown, whereas in Figure 2.1 (next page) distribution of municipal solid waste treatment in EU is presented.

Tab. 2.2 World's Incineration Potential [5]

	Waste generation (kg/cap/year)		Annual growth rate (%)
	Range	Mean	
OECD total	263 - 864	513	1,9
OECD Europe	n.a.	336	1,5
Europe (32 countries)	150 - 624	345	n.a.

Energy recovery

The maximum amount of energy recoverable through MSW incineration depends primarily on the lower calorific value of the waste, but also on the system applied for energy recovery. It is most efficient when both electricity and steam/heat are produced, and the yield is lowest when only electricity is generated and the surplus heat is cooled away, cf. Figure 2.2 next page..

2.2 Biomass

This sub-section is based upon reference [11].

Biomass is biological material derived from living, or recently living organisms. It most often refers to plants or plant-based materials which are specifically called lingo-cellulosic biomass. Today's applications of biomass materials vary from burning wood and agricultural residues as a fuel for cogeneration of steam and electricity in the industrial sector. Biomass is used for power generation in the electricity sector and for space heating in residential and commercial buildings. Biomass can be converted to a liquid form for use as a transportation fuel, and research is being conducted on the production of fuels and chemicals from biomass. Biomass materials can also be used directly in the manufacture of a variety of products. There is no universal definition for types of biomass. A brief description of each type of biomass by the IEA is provided below:

- Agricultural residues are generated after each harvesting cycle of commodity crops. A portion of the remaining stalks and biomass material left on the ground can be collected and used for energy generation purposes. Wheat straw and corn stover make up the majority of crop residues.

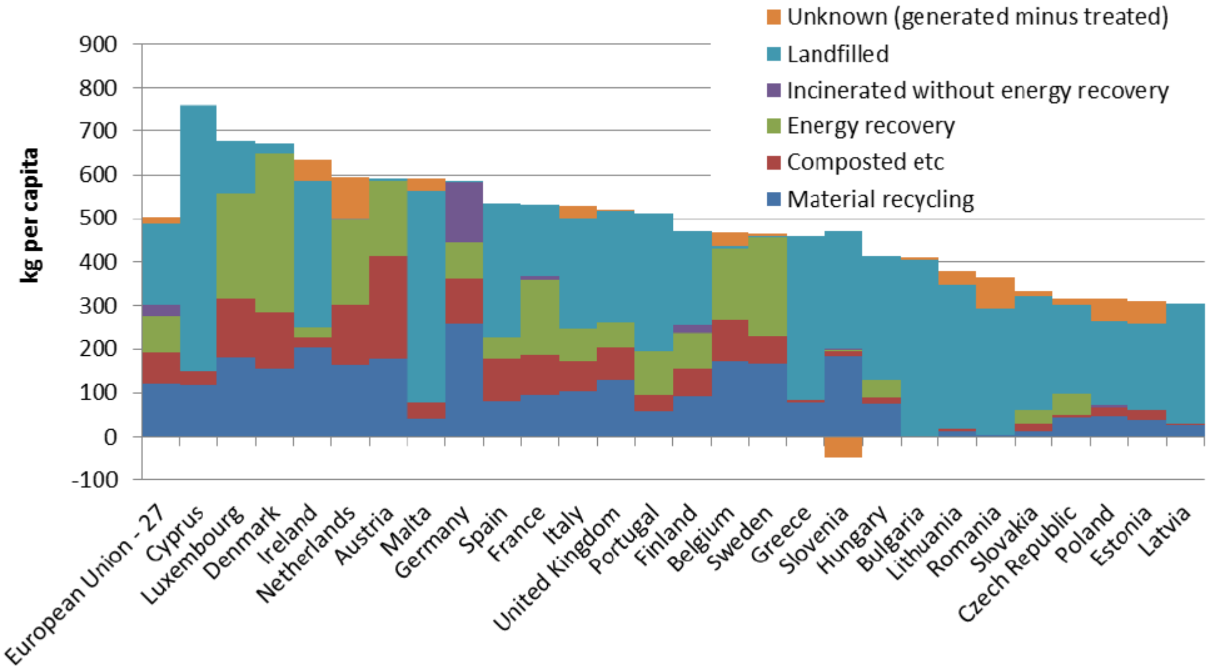

Figure 2.1 Distribution of municipal solid waste treatment in EU27 Member States during 2010 according to the waste hierarchy order categories. [12]

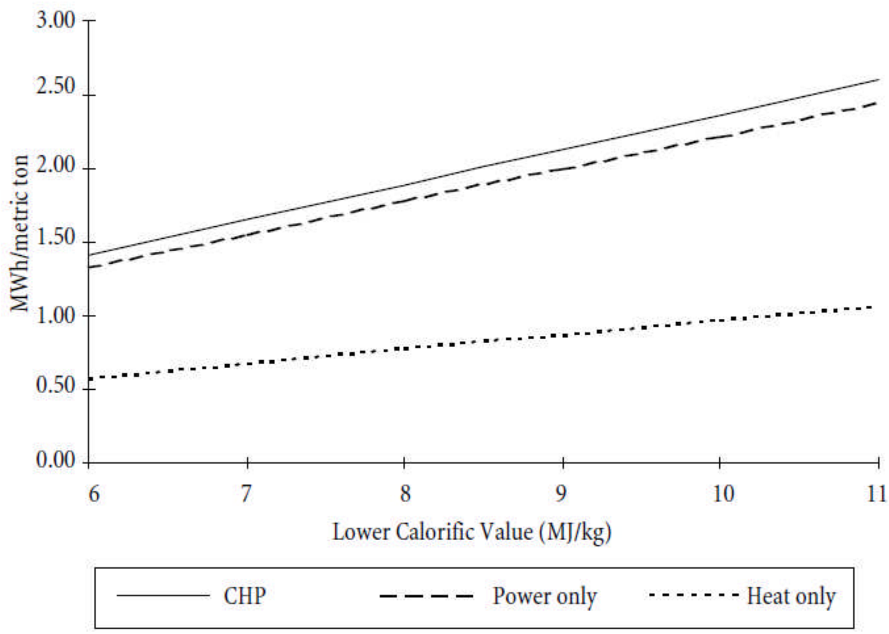

Figure 2.2 Waste energy recovery [5]

- Energy crops are produced solely or primarily for use as feedstock in energy generation processes. Energy crops includes hybrid poplar, hybrid willow, and switch grass, grown on cropland acres currently cropped, idled, or in pasture.
- Forestry residues are the biomass material remaining in forests that have been harvested for timber. Timber harvesting operations do not extract all biomass material, because only timber of certain quality is usable in processing facilities. Therefore, the residual material after a timber harvest is potentially available for energy generation purposes. Forestry residues are composed of logging residues, rough rotten salvageable dead wood, and excess small pole trees.
- Urban wood waste/mill residues are waste woods from manufacturing operations that would otherwise be landfilled. The urban wood waste/mill residue category includes primary mill residues and urban wood such as pallets, construction waste, and demolition debris, which are not otherwise used.

Potential

As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel. Despite the current minor role of bioenergy, biomass has, in the long run, the potential to become a much more significant source of energy in the global energy supply. Numerous studies have been carried out to estimate the potential to harvest energy from biomass. The largest biomass production potential will be in large-scale energy plantations that are located in areas having a favourable climate for maximizing the production of biomass. Table 2.3 gives a summary of the biomass production potential in the light of the latest studies by biomass categories and shows the main assumptions made in the determination of the potentials.

Tab. 2.3 Overview of the global potential bioenergy supply on the long term for a number of categories and the main preconditions and assumptions that determine these potentials [10]

Biomass category	Main assumptions and remarks	Potential bioenergy supply up to 2050, [EJ/yr]
Energy farming on current agricultural land	Potential land surplus: 0-4 Gha (more average: 1-2 Gha). A large surplus requires structural adaptation of intensive agricultural production systems. When this is not feasible, the bioenergy potential could be reduced to zero, as well. On an average, higher yields are likely because of better soil quality: 8-l2 dry tonne/ha*yr is assumed.	0 - 700 (more average development 100 - 300)
Biomass production on marginal lands	On a global scale, a maximum land surface of 1.7 Gha could be involved. Low productivity of 2-5 dry tonne/ha*yr l. The supply could be low or zero due to poor economics or competition with food production.	(0) 60 - 150
Bio-materials	Range of the land area required to meet the additional global demand for bio-materials: 0.2-0.8 Gha. (Average productivity: 5 dry tonnes/ha*yr). This demand should come from categories I and II in case the world's forests are unable to meet the additional demand. If they are, however, the claim on (agricultural) land could be zero.	Minus (0) 40 -150
Residues from agriculture	Estimates from various studies. The potential depends on yield/product ratios and the total agricultural land area as well as the type of production system: Extensive production systems require re-use of residues for maintaining soil fertility. Intensive systems allow for higher utilisation rates of residues.	15 - 70
Forest residues	The (sustainable) energy potential of the world's forests is unclear. Part is natural forest (reserves). The range is based on literature data. Low value: figure for sustainable forest management. High value: technical potential. Figures include processing residues.	(0) 30 - 150
Dung	Use of dried dung. Low estimate based on global current use. High estimate: technical potential. Longer-term utilization (collection) is uncertain.	(0) 5 - 55

Organic wastes	Estimate on basis of literature values. Strongly dependent on economic development, consumption and use of bio-materials. Figures include the organic fraction of municipal solid waste (MSW) and waste wood. Higher values possible by more intensive use of bio-materials.	5 - 50
Total	**Most pessimistic scenario: no land available for energy fanning; only utilization of residues. Most optimistic scenario: intensive agriculture concentrated on better quality soils. (in brackets: more average potential in a world aiming for large scale utilization of bioenergy).**	**40 - 1100 (250 - 500)**

Supply curve uncertainties

Although a significant amount of effort has gone into estimating the available quantities of biomass supply, the following uncertainties still remain:

- the most significant uncertainty is perhaps the value of competing uses of biomass materials. For example, the mulch market consumes large amounts of waste biomass material. Different qualities of mulch are available at different prices. How much mulch and other biomass-derived materials can be diverted from their current markets into electricity generation and the prices at which such reallocations might take place are not well understood,
- in agricultural waste, the significant uncertainty is in the impact of biomass removal on soil quality. A general consensus in the farming community is that more agricultural residues need to be left on the soil to maintain soil quality and this could result in significant losses of biomass for electric power generation purposes,
- in forestry residues, the unknown factor is the impact of changes in forest fire prevention policies on biomass availability. A policy whereby the vegetation in forests is reduced to minimize the potential for forest fires could significantly increase the quantity of forestry residues available.

2.3 Coal

Coal technologies for producing electrical energy have been covered in the VGB PowerTech report. All the data presented in the VGB report concerning coal as source of primary energy is also relevant for CHP, as the technological process is the same. The only difference is the overall efficiency, which is one of the main reasons for using CHP. Variations of electrical and CHP efficiencies with useful heat for a coal-fired CHP power station in Denmark are presented in Figure 2.3 below.

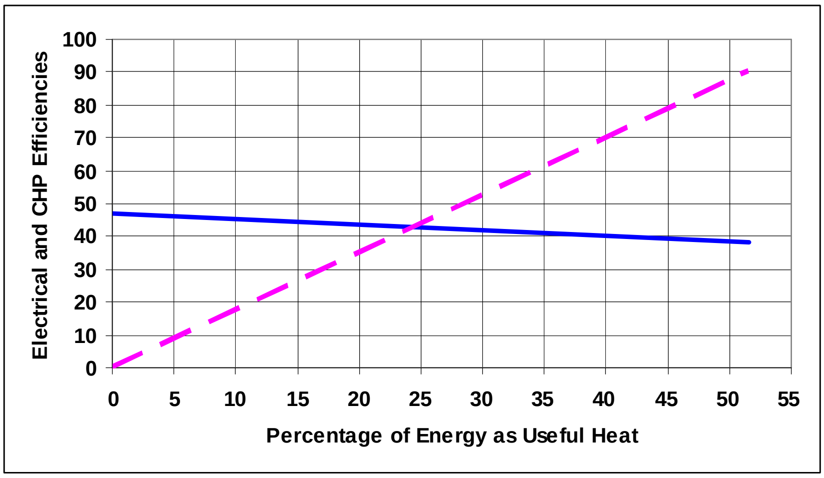

Figure 2.3 Variation of Electrical and CHP Efficiencies with Heat Output at Nordjyllandsværket [1]. In blue: electricity efficiency, in red CHP efficiency.

2.4 Gas

Natural gas technologies for producing electrical energy have been deeply covered in the VGB PowerTech report. All the data presented in the VGB report concerning natural gas as source of primary energy is also relevant for CHP, as the technological process is the same. Again, like in coal technology, the main difference is the overall efficiency, which is one of the main reasons for using CHP. Gas engine combined heat and power systems are measured based upon the efficiency of conversion of the fuel gas to useful outputs. The diagram below illustrates this concept. This diagram and the description assumes usage of internal combustion engine.

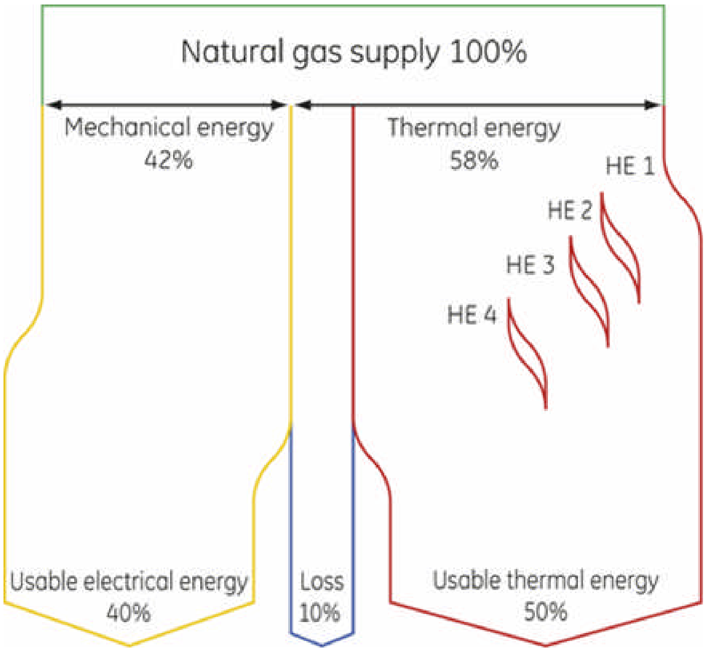

Figure 2.4 Eefficiency conversion of the natural gas to useful outputs by gas fuelled CHP

First, the energy in the fuel gas input is converted into mechanical energy via the combustion of the gas in the engine's cylinders and their resulting action in the turning of the engine's shaft. This mechanical energy is in turn used to turn the engine's alternator in order to produce electricity. The heat from the generator is available in from 4 key areas:

- Engine jacket cooling water [HE1]
- Engine lubrication oil cooling [HE2]
- First stage air intake intercooler [HE3]
- Engine exhaust gases [HE4]

3 Short overview of CHP technologies

3.1 Internal Combustion Engines

Internal Combustion Engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. The best IC engines, running on natural gas, now offer efficiencies in the 38-44 % range. When using IC engines for CHP purposes there is one major advantage, which does result from the way the IC engine operates. The exhaust gas temperature will be in the 700°C region in a non-supercharged engine (for turbocharged it could be as high as 500°C). About half the waste heat from the engine comes in this high temperature form. The exhaust gases pass through a heat exchanger, the reverse side of which carries the water that is used for space heating, or in some cases production of low pressure steam.

3.2 Diesel Engine

The diesel engine has the highest thermal efficiency (up to 50%) of any standard internal or external combustion engine due to its very high compression ratio. The ability to run at compression ratios is the 13-17 ranges, endows the diesel with efficiencies in the 42 to 48% range for the type of unit used in CHP systems. Such engines are usually turbocharged, and the result is that the exhaust temperatures are below 450°C. The higher electrical efficiency will result, of course, in less heat being available, but overall the power plus heat, or “CHP” efficiency, will be similar to natural gas IC engines, at 90-95%.

Nowadays, electricity is far more valuable than heat, in kilowatt hour terms, the price ratio is about 3-4 to 1, and hence even the relatively small increase in electrical efficiency from diesels compared to IC engines is valuable. The major drawback of diesels is that they only operate on liquid fuels.

3.3 Gas Turbines

The gas turbines used in CHP units are variants of the turbojet and turbo prop engines used in aircrafts. Gas turbine, derived from aircraft units, offer a relatively large power output. Typically this will be in the 5-60 MW range, which is often too high for most CHP schemes. The positive aspect of such units is that engine reliability is very good, and times between maintenance are extended. The higher output turbines will offer electrical efficiencies of just over 40%, but a more realistic figure is closer to 30%. The main reason for this is that gas turbines suffer from strong “size effects”; aerodynamic performance decreases as compressor and turbine blades become smaller.

A gas turbine is a machine that works best at above 85% of its nominal rating. It follows that in a typical district heating scheme, where there are big variations during a 24 hour period, gas turbines are not necessarily the optimum choice.

The CHP efficiencies of even the larger gas turbines are mediocre, and not much above 85%. Gas turbine installations suffer from other intrinsic problems. Although there is no vibration, intake and exhaust noise will call for bulky sound proofing and careful location, away from domestic housing. The burners require the fuel gas to be at high pressure, 20-30 bar, which will need a fuel gas compressor. And finally, because the power output from gas turbines suffer from pressure drop effects, the heat exchangers, needed to collect the heat from a gas turbine exhaust have to be big to minimise this effect.

3.4 Coal-Fired Steam Plant with Cogeneration

A steam turbine plant requires a boiler to provide the steam, heated by coal, oil or natural gas. After passing through the turbine, the steam is condensed, and the water is sent back to the boiler to produce more steam. In practice the circulation of steam and water is far more complex than this. A key development in the improvement of electrical efficiency was the extraction of a portion of the steam from the turbines which is used to preheat the water before it reaches the boiler. Obviously power is reduced, but even with one extraction point, efficiency is increased by 2-3%.

The extraction technique is also used on some types of CHP systems. Here, instead of the low pressure extracted steam being used to preheat boiler water, it is passed through a heat exchanger to give heat to the water in the CHP system. Quite a small amount of steam can provide a great deal of heat, with only a small loss in electrical output. Furthermore, one big advantage of extracted steam turbine CHP, is that, if heat is not needed, the extraction valves are closed and all the steam is used to produce electricity.

The other approach, in using steam for CHP, is to use the back pressure type of steam turbine. Here, all the steam passes through the turbine, apart from that used for feed preheating. The difference between a back pressure turbine and one of the conventional type, is that with the conventional type, the steam is condensed after it has reached a very low temperature and pressure. Typical values would be 35°C, 0.05 bar pressure (i.e. near vacuum). This is great for maximising power, but useless for heating, since the cooling water, after it leaves the power station, will be in the 15-30°C range. The back pressure turbine, in contrast, takes all the steam from the back end of a steam turbine, at a pressure of about 1 bar and 100°C. The steam passes over the CHP system heat exchanger, which acts as a high temperature condenser. The condensed steam, in the form of hot water at about 80-90°C, is then pumped back to the boiler. The water going into the district heating systems will range in temperature from 70° to about 120°C. But many back pressure steam turbine units can only operate in the true CHP mode, since the heat exchanger condenser is designed for operation at about 100°C. The power to heat ratio of such units is more or less fixed.

3.5 CCGT with Cogeneration

The CCGT (Combined Cycle Gas Turbine) is the most efficient method for converting the fuel energy (gas) into electrical energy. Nowadays, efficiencies have levelled out at just under 60%. The CCGT, consists of a gas turbine which produces about two thirds of the power. The waste heat in the exhaust system from the gas turbine is used to produce steam which powers a set of steam turbines, producing the remaining third. It is only the steam system which can be used for cogeneration duties, so a CCGT is not as efficient as a steam power plant for CHP applications. This fact is well recognised and most industrial scale CCGTs utilise an ancillary burner, situated after the gas turbine exhaust, which is used to raise extra process steam. In such cases this is not true cogeneration.

The heat exchangers for evaporating water and superheating the steam in a CCGT are referred to as the HRSGs (Heat Recovery Steam Generators) and are situated in the exhaust duct of the gas turbine. For various reasons steam has to be raised at two or more different pressures, typically 60-90 bar and 5-10 bar. The high pressure steam is fed to high pressure turbines, and the exhaust steam from the HP turbine is used to link with low pressure steam before it enters the low pressure turbine.

In a conventional CCGT the exhaust from the low pressure turbine would be at about 0.5-0.7 bar, but in cogeneration mode some of the steam could be extracted from the LP turbine for district heating. Because the steam section of the plant provides only a relatively small amount of power, and because the stack losses in CCGT are high, the amount of useful heat that can be obtained from a CCGT is limited. If the steam turbine units were shut down completely in a typical plant, only 50-55% of the heat energy in the fuel would be available for district heating purposes. But electrical efficiency would fall to around 37%.

3.6 Nuclear Cogeneration

There are some places in Eastern Europe where a small amount of useful heat is used for local heating of nearby buildings, but the idea of using nuclear energy for cogeneration seems impractical.

A modern nuclear power plant of the PWR (Pressurised Water Reactor) type generates about 2 GW of electricity, but converts only 32% of the heat from the nuclear reactions into electricity. Steam temperatures, at about 260°C, are too low. If modified to produce cogeneration heat, output would probably drop to about 1-1.5 GW, and the amount of useful heat is likely to be in the 2-3 GW range.

3.7 Micro CHP

A micro-CHP system is a small heat engine (power plant) which provides all the power for an individual building; heating, ventilation, air conditioning and electric power. It is a smaller-scale version of cogeneration schemes which have been described above.

Three separate forms of micro CHP have been promoted. The higher output, up to about 100 kW, relies on modified car engines or small recuperative gas turbines. The car engine approach suffers from the need for high maintenance. The micro gas turbine, although using a recuperator, has quite a low electrical efficiency. And as noted earlier, the CHP efficiency tends to be low because of the large excess air required by the unit. Since these units would be intended for small business or apartment blocks, electrical efficiency is fairly important: 30% at both high and low loads is possible target which has not been reached so far;

Also a home fuel cells, as a residential-scaled energy system are becoming more popular. A home fuel cell is an alternative energy technology that increases efficiency by simultaneously generating power and heat from one unit, on-site within a home. They have demonstrated superior efficiency for years in industrial plants, universities, hotels and hospitals. Residential and small-scale commercial fuel cells are now becoming available to fulfil both electricity and heat demand from one system. Fuel cell technology (see section 3.8 below) in a compact system converts natural gas, propane, and eventually biofuels—into both electricity and heat, producing carbon dioxide (and small amounts of NOx) as exhaust.

Micro-CHP engine systems are currently based on several different technologies:

- Internal combustion engines
- Stirling engines
- Steam engines (using either the traditional water or organic chemicals such as refrigerants)
- Microturbines
- Fuel cells

There are many types of fuels and sources of heat that may be considered for micro-CHP, just as for regular CHP installations. The properties of these sources vary in terms of system cost, heat cost, environmental effects, convenience, ease of transportation and storage, system maintenance, and system life. Some of the heat sources and fuels that are being considered for use with micro-CHP include: biomass, LPG, vegetable oil (such as rapeseed oil), wood gas, solar thermal, and natural gas, as well as multi-fuel systems.

3.8 Fuel cells

Fuel cells are an emerging small-scale power generation technology, mostly under 1 MW although larger applications do exist. Although fuel cells were first designed as purely electric generators, there are mainly developed for transportation applications today. Fuel cells primarily used for power generation, such as Phosphoric Acid, Solid Oxide, and Molten Carbonate fuel cells, are generally not suited for transportation use.

Fuel cells require hydrogen for operation: hydrogen must be extracted from other hydrogen-rich sources such as gasoline or natural gas. Cost effective, efficient fuel reformers that can convert various fuels to hydrogen are necessary to allow fuel cells increased flexibility and better economics. Fuel cells have very low levels of NOx and CO emissions, all resulting from the reforming process.

Using gasifiers to produce hydrogen fuel from sources such as biomass could help to increase flexibility and market share of fuel cells.

Fuel cell can be used in two different types of industrial cogeneration applications: to produce hot water at around 60°C, or to produce hot water at around 60°C and low temperature steam at 120°C. Overall efficiency for both is around 80-85 %.

This technology is not mature yet, thus it is not covered in the following Excel spreadsheets, because of lack of reliable data. Fuel cells are an emerging technology with few manufacturers offering commercial units. Fuel cells themselves have a high degree of reliability and availability due to their lack of moving parts, but are limited by the reliability of support systems such as pumps and fans needed for operation. Future research and development into turbine/fuel cell hybrids is also expected.

4 Technology performance characteristics

4.1 Variables selected

Tab. 4.1 Variables describing the technology performance characteristics

Data type : *technology performance characteristics*	Unit	Definition
Electrical rated power	MW	Maximum rated electrical power of a single unit
Technical minimum	%	Percentage of nominal (rated) power
Total efficiency net	%	Including thermal and electrical efficiency
Thermal efficiency net	%	
Electricity efficiency net	%	
Time for warm start-up	hours	Time for start-up when the boiler is pressurized (water temperature in the evaporator above 100°C)
Forced outage	%	Weighted percentage of forced outage hours (hours caused by unplanned outages, weighted according to how much capacity was out).
Planned outage	weeks per year	
Outage rate	%	Total percentage of operating time lost due to outages
Operation hours (base load)	h/year	Maximum number of operating hours available annually taking outages into account
Availability	%	Percentage of time available to deliver heat/electricity

4.2 Underlying assumptions

CHP plants' basic technical parameters can be characterized by a set of variables describing their technology performance, related to electrical (and thermal) efficiency, rated power and availability, cf. Table 4.1. Numerical value are displayed in the attached Excel sheet.

In the literature, different values can be found depending on the technologies and the time horizons. For some variables such as the electrical rated power, it has been assumed that the values will not significantly change within the foreseen time horizon, partly due to the requirement of profitability.

The efficiency values have been found in differing formats, either separately regarding electrical and thermal efficiency or covering the total efficiency of heat and electricity generation. The presented values (cf. Excel sheet) refer to continuous operation of a new unit at full load. Operating the unit at partial load usually means the efficiency is decreased, but no quantitative data regarding this aspect (e. g. concerning efficiency at minimum load level) have been found. The same problem holds for the availability data, presented as a percentage of operating time lost due to unplanned outages or, alternatively, in terms of length of planned outages in weeks per year, or both types of outages presented separately or as a total availability regardless of the outage type. In general, the values for availability are also difficult to assess for the long-term forecasts and they should probably be taken as constant as the technologies are rather mature (this assumption has been made in the VGB report).

5 Possible implementation constraints

5.1 Variables selected

Tab. 5.1 Variables describing possible implementation constraints

Data type : *possible implementation constraints*	Unit	Definition
Construction time	years	From financial closure (financing and all permits secured) until commissioning

5.2 Underlying assumptions

Possible implementation constraints of CHP plants have been characterized by a single variable, which estimates the total time needed for constructing a new unit. The construction time represents the period from the moment when financing has been secured and all necessary permits are at hand until the completion of commissioning and the possibility to start commercial operation.

The data has been found only for a few technologies. The future evolutions of this variable are difficult to grasp and probably the best estimation is to assume a constant value within the foreseen time horizon.

6 Costs

6.1 Variables selected

Tab. 6.1 Variables describing costs

Data type : *costs*[1]	Unit	Definition
Specific investment	€/MW	In several cases given in €/kW; for waste-to-energy CHP also given in €/tonne/hour, as electricity generation is secondary to waste incineration in this case
Total O&M	%/year	Percentage of the total investment value per year of operation. For waste-to-energy given in €/tonne of waste
Fixed O&M	€/MW/year	All costs independent of how much energy the plant generates (reinvestments within the scheduled lifetime also included)
Variable O&M	€/MWh	Fuel costs not included
Lifespan	years	

6.2 Underlying assumptions

Factors such as market environment changes, supply of resources (especially fossil fuels) or technology gaining maturity, all of which could heavily influence the financial data, cannot be reliably taken into account in the context of a nearly 40-year perspective. In particular, the change of market conditions (e.g. due to political factors) can have a very significant impact on projected data.

The investment costs as defined in the present report include all equipment, infrastructure and construction costs, but not pre-development costs, such as consultancy, land purchase, site preparation, obtaining approvals and permissions, etc. The cost of dismantlement has not been included either.

All the financial data for waste- and biomass-fired CHP plants are for fixed 2011 price level. For some technologies (e.g. medium scale straw-fired CHP), there was no data found on future projected values of financial parameters.

For some of the analysed technologies, a separate cost (investment and O&M) estimation has been provided for various modification of standard installations - units equipped with CCS (Carbon Capture and Storage) or with biomass co-firing.

[1] Most sources for power and energy cost in US$.

7 Environmental impact and public acceptance

7.1 Variables selected

Tab. 7.1 Variables describing environmental impact and public acceptance

Data type : *environmental impact and public acceptance*	Unit	Definition
SO_2 (degree of desulphurisation)	%	Given only for waste-to-energy
SO_2 content	g/GJ fuel	This value, and all below, depict emissions in grams per GJ of fuel input or kWh of electricity production (for coal- and gas-fired CHP)
NO_x content	g/GJ fuel	Includes NO and NO_2
N_2O content	g/GJ fuel	
UHC (unburned hydrocarbon)	g/GJ fuel	
CH_4 content	g/GJ fuel	
CO_2 content	g/kWh	

7.2 Underlying assumptions

Environmental impact has been characterized by a set of variables describing the level of emissions resulting from energy generation.

For coal- and gas-fired CHPs the values are given separately for “standard” units and units equipped with CCS (Carbon Capture and Storage) equipment. For hard coal-fired CHPs, the values considering biomass co-firing have also been provided.

The values for the above variables (cf. table 7.1) have not been found for all technologies and all time horizons. In some cases, the values result from a predicted estimate for a given technology reaching commercial maturity at a given time horizon.

8 Dynamic performance of technology

8.1 Variables selected

Tab. 8.1 Variables describing dynamic performance of the technology

Data type : *dynamic performance of the technology*	Unit	Definition
Ramp rate	%/min	Percentage of maximum load
Regulation speed	MW/min	The ability to regulate when already in operation

8.2 Underlying assumptions

The dynamic performance of a given generation technology can be characterized by a set of variables differing between technologies.

In case of various types of CHP units, only values describing the ability to provide a spinning reserve have been found. It has been assumed that these values should remain constant.

9 Technological break-through

As mentioned earlier in the document, the CCGT (Combined Cycle Gas Turbine) is the most efficient method for converting the fuel energy (gas) into electrical energy. The efficiency and low capital cost of CCGT makes this particular technology interesting for technological progress in terms of CHPs. CCGTs, at the present time, are basically a very simple concept: gas turbine based on aircraft technology is not the best choice. There are more sophisticated gas turbines, in which, by optimizing the thermodynamics, and by improving the turbine and hot section cooling techniques, one could offer machines which would have a significant increase in thermal efficiency. The various concept include:

- reheat or two stage combustion in the turbines;
- intercooling of the compressor;
- steam cooled turbine blades;
- steam cooled hot section;
- cooling of compressor air used for disc and bearing cooling.

Putting together all these ideas should result in electrical efficiency up to 70-75% (with a gas turbine efficiency of 50%).

The main problem of current designs of CCGT is the excessive stack due to a huge amount of excess air to control combustion temperatures and to cool critical components. Fortunately, all of the innovations listed above will reduce the excess air requirement. Up to 95% of the fuel could be used for energy production instead of 80-90% in today's units. It will then be possible to maintain steam plant output, despite the fact that more energy in the fuel is taken up by the gas turbine. As a result, an advanced CCGT, when operating in cogeneration mode, could supply 55-60% of the fuel energy as electricity, and 35-40% as useful heat. Such a unit could supply only electricity during summer, running at up to 75% electrical efficiency.

10 Contextualization

Data contextualization aims to allocate, for a given technology, typical values to key variables descriptive of this technology, at the 2050 time horizon, and this for each of the five considered scenarios [13]. The diagram shown in Figure 10.1 presents the step by step approach implemented in this report in order to obtain contextualized data.

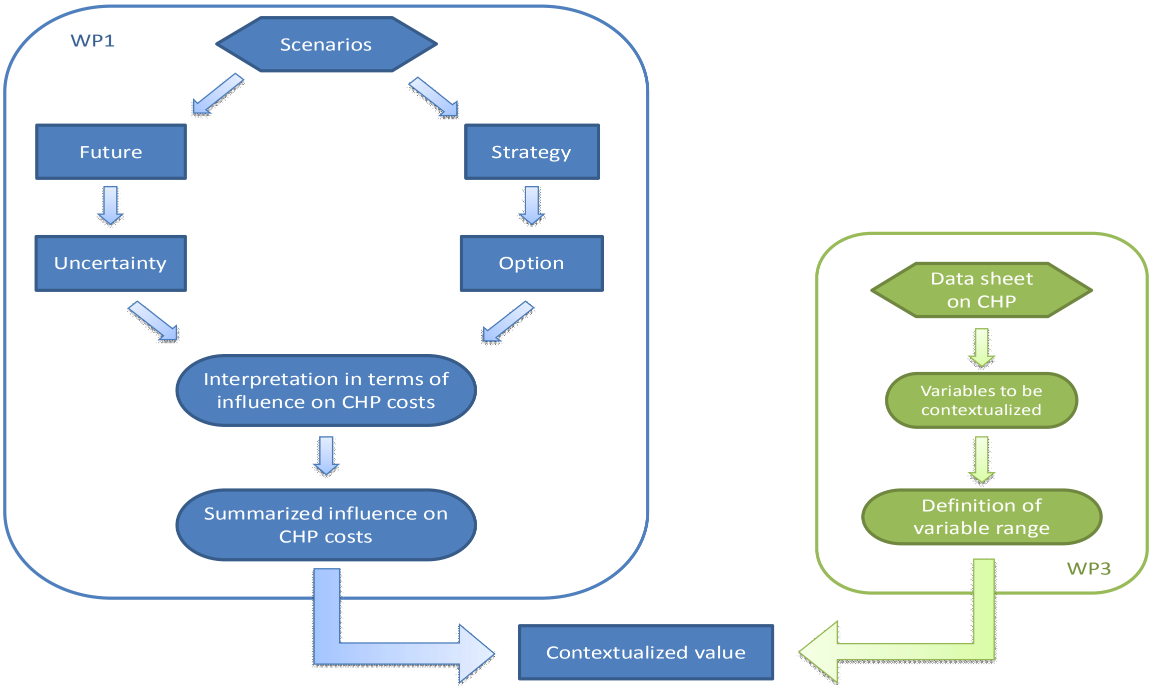

Figure 10.1 Contextualization process

The first stage of the contextualization process was to determine the degree of influence of individual factors (uncertainties as defined for each "future" and options as defined for each "strategy") on variables selected to be contextualized. **Only the variables regarding investment and O&M (total) costs were contextualized**. Other variables, such as those regarding emissions or technical parameters, cannot be reliably contextualized and they are assumed to remain for each scenario.

The analyzed technologies have been grouped into four categories, for each of which the impact of individual factors has been assessed. The categories are: waste to energy, biomass-fired, coal-fired and gas fired CHP plants.

In tables 10.1 to 10.8 (next pages), a summary of the assessed influence of impact factors on the projected level of costs for the above categories of CHP technologies is presented. The impact has been assessed as one of the following values: ++ (major impact), + (minor impact), - (negligible or no impact).

Tab. 10.1 Impact of future uncertainties on costs: waste to energy CHP

Future: Uncertainty	Impact on:	
	Investment costs	O&M costs
International Climate Agreement	+	-
Dependency on fossil fuels from outside Europe	+	-
Joint transnational initiatives	-	-
Fuel costs	++	-
CO2 costs	+	++
Storage technology maturity	-	-
CCS maturity	+	-
Electrification in transport, heating, industry	++	-
Demographic change	+	-
GDP growth in EU	-	-
Public perceptions to RES	-	-
Public perceptions to nuclear	-	-
Public perceptions to shale gas	++	-
Shift towards greener behaviours	++	-

Tab. 10.2 Impact of strategy options on costs: waste to energy CHP

Strategy: Option	Impact on:	
	Investment costs	O&M costs
Deployment of centralized RES	-	-
Deployment of de-centralized RES (including CHP and biomass)	++	-
Deployment of centralized storage	-	-
Deployment of de-centralized storage	-	-
Deployment of nuclear plants	-	-
Deployment of fossil fuel plants with CCS	-	-
Deployment of fossil fuel plants without CCS	-	-
Increase of energy efficiency (include DSM and flexibility)	-	+
Increase of funds and better coordination of RDD activities (at EU level)	++	+
Electricity imports from outside Europe	-	-
Permitting framework (including EU nature legislation)	++	+

Tab. 10.3 Impact of future uncertainties on costs: biomass-fired CHP

Future: Uncertainty	Impact on:	
	Investment costs	O&M costs
International Climate Agreement	+	-
Dependency on fossil fuels from outside Europe	+	-
Joint transnational initiatives	-	-
Fuel costs	++	-
CO2 costs	+	++
Storage technology maturity	-	-
CCS maturity	+	-
Electrification in transport, heating, industry	++	-
Demographic change	+	-
GDP growth in EU	-	-
Public perceptions to RES	++	-
Public perceptions to nuclear	-	-
Public perceptions to shale gas	++	-
Shift towards greener behaviours	++	-

Tab. 10.4 Impact of strategy options on costs: biomass-fired CHP

Strategy: Option	Impact on:	
	Investment costs	O&M costs
Deployment of centralized RES	-	-
Deployment of de-centralized RES (including CHP and biomass)	++	-
Deployment of centralized storage	-	-
Deployment of de-centralized storage	-	-
Deployment of nuclear plants	-	-
Deployment of fossil fuel plants with CCS	-	-
Deployment of fossil fuel plants without CCS	-	-
Increase of energy efficiency (include DSM and flexibility)	-	+
Increase of funds and better coordination of RDD activities (at EU level)	++	+
Electricity imports from outside Europe	-	-
Permitting framework (including EU nature legislation)	++	+

Tab. 10.5 Impact of future uncertainties on costs: coal-fired CHP

Future: Uncertainty	Impact on:	
	Investment costs	O&M costs
International Climate Agreement	++	-
Dependency on fossil fuels from outside Europe	++	-
Joint transnational initiatives	-	-
Fuel costs	++	-
CO2 costs	++	++
Storage technology maturity	-	-
CCS maturity	++	-
Electrification in transport, heating, industry	++	-
Demographic change	+	-
GDP growth in EU	-	-
Public perceptions to RES	+	-
Public perceptions to nuclear	-	-
Public perceptions to shale gas	++	-
Shift towards greener behaviours	++	-

Tab. 10.6 Impact of strategy options on costs: coal-fired CHP

Strategy: Option	Impact on:	
	Investment costs	O&M costs
Deployment of centralized RES	-	-
Deployment of de-centralized RES (including CHP and biomass)	++	-
Deployment of centralized storage	-	-
Deployment of de-centralized storage	-	-
Deployment of nuclear plants	-	-
Deployment of fossil fuel plants with CCS	++	+
Deployment of fossil fuel plants without CCS	++	+
Increase of energy efficiency (include DSM and flexibility)	-	+
Increase of funds and better coordination of RDD activities (at EU level)	+	+
Electricity imports from outside Europe	-	-
Permitting framework (including EU nature legislation)	++	++

Tab. 10.7 Impact of future uncertainties on costs: gas-fired CHP

Future: Uncertainty	Impact on:	
	Investment costs	O&M costs
International Climate Agreement	++	-
Dependency on fossil fuels from outside Europe	++	-
Joint transnational initiatives	-	-
Fuel costs	++	-
CO2 costs	+	+
Storage technology maturity	-	-
CCS maturity	+	-
Electrification in transport, heating, industry	++	-
Demographic change	+	-
GDP growth in EU	-	-
Public perceptions to RES	+	-
Public perceptions to nuclear	-	-
Public perceptions to shale gas	++	-
Shift towards greener behaviours	+	-

Tab. 10.8 Impact of strategy options on costs: gas-fired CHP

Strategy: Option	Impact on:	
	Investment costs	O&M costs
Deployment of centralized RES	-	-
Deployment of de-centralized RES (including CHP and biomass)	++	-
Deployment of centralized storage	-	-
Deployment of de-centralized storage	-	-
Deployment of nuclear plants	-	-
Deployment of fossil fuel plants with CCS	+	+
Deployment of fossil fuel plants without CCS	+	+
Increase of energy efficiency (include DSM and flexibility)	-	+
Increase of funds and better coordination of RDD activities (at EU level)	++	+
Electricity imports from outside Europe	-	-
Permitting framework (including EU nature legislation)	++	+

Each of the selected scenario parameter (future uncertainty or strategy option) has then been analyzed in order to determine its impact on potential incentive to develop a given technology and its investment and O&M costs. It has been assumed that a greater incentive to develop a given technology (and hence a potentially larger penetration of this technology) will result in lowering the overall investment costs and vice versa. Based on the impact of each parameter's value, a final assessment of the projected level of both types of costs was assigned to each scenario and each technology category, cf. Table 10.9 to 10.12 next pages.

Tab. 10.9 - Contextualisation of cost variables - waste to energy CHP

	Scenario X5	Scenario X7	Scenario X10	Scenario X13	Scenario X16
	Large scale RES & no emissions	100% RES	Big & Market	Large fossil fuel with CCS & Nuc	Small and local
Future	2		4		5
International Climate Agreement	EU alone: prices relatively stable		Global agreement: no available cheaper installations from outside EU, demand exceeding supply leading to higher prices		EU alone: prices relatively stable
Dependency on fossil fuels from outside Europe	Low: low incentive to build waste CHP		Medium: higher incentive to build waste CHP		Medium: higher incentive to build waste CHP
Fuel costs	High: Very high incentive for new waste CHP		Low: low incentive to build waste CHP		High: Very high incentive for new waste CHP
CO2 costs	High: leads to increasing O&M costs		High: leads to increasing O&M costs		Low: no significant change
CCS maturity	No: higher prices of CCS installations		Yes: lower prices of CCS installations		No: higher prices of CCS installations
Electrification in heating	All: very low incentive to build waste CHP		Large scale (commercial etc.): no significant change		Residential: low incentive to build waste CHP
Demographic change	Growth: more demand for heat		Growth: more demand for heat		Migration only: no significant change
Public perceptions to shale gas	Negative: other fuels (e.g. waste) necessary		Positive: available gas will lower the incentive for other technologies		Negative: other fuels (e.g. waste) necessary
Shift towards greener behaviours	Major: lack of public support for waste CHP		Minor: no significant change		Major: lack of public support for waste CHP
Strategy	2	4	1	5	3
Deployment of de-centralized RES (including CHP and biomass)	Low	High	Medium	Low	High
Increase of energy efficiency (include DSM and flexibility)	Low: higher O&M costs due to frequent need of regulation	High: lower O&M costs due to low need of regulation	Medium: no significant impact	Low: higher O&M costs due to frequent need of regulation	High: lower O&M costs due to low need of regulation

	Scenario X5	Scenario X7	Scenario X10	Scenario X13	Scenario X16
Increase of funds and better coordination of RDD activities (at EU level)	High: technology may become cheaper	High: technology may become cheaper	Medium: prices at medium level	Medium: prices at medium level	Low: higher technology prices
Permitting framework (including EU nature legislation)	Convergent and strong framework: lowering investment costs	Convergent and strong framework: lowering investment costs	Convergent and strong framework: lowering investment costs	Heterogenous framework at EU level: possibly higher investment costs	Heterogenous framework at EU level: possibly higher investment costs
Resulting scenario for costs					
Investment	medium	low	high	high	Medium
O&M	high	medium	high	high	Medium

Tab. 10.10 - Contextualisation of cost variables - biomass-fired CHP

	Scenario X5	Scenario X7	Scenario X10	Scenario X13	Scenario X16
	Large scale RES & no emissions	100% RES	Big & Market	Large fossil fuel with CCS & Nuc	Small and local
Future	2		4		5
International Climate Agreement	EU alone: prices relatively stable		Global agreement: no available cheaper installations from outside EU, demand exceeding supply leading to higher prices		EU alone: prices relatively stable
Dependency on fossil fuels from outside Europe	Low: low incentive to build biomass CHP		Medium: higher incentive to build biomass CHP		Medium: higher incentive to build biomass CHP
Fuel costs	High: Very high incentive for new biomass CHP		Low: low incentive to build biomass CHP		High: Very high incentive for new biomass CHP
CO2 costs	High: leads to increasing O&M costs		High: leads to increasing O&M costs		Low: no significant change
CCS maturity	No: higher prices of CCS installations		Yes: lower prices of CCS installations		No: higher prices of CCS installations
Electrification in heating	All: very low incentive to build biomass CHP		Large scale (commercial etc.): no significant change		Residential: low incentive to build biomass CHP
Demographic change	Growth: more demand for heat		Growth: more demand for heat		Migration only: no significant change
Public perceptions to RES	Positive: high incentive for biomass CHP		Indifferent: no significant change		Positive: high incentive for biomass CHP
Public perceptions to shale gas	Negative: other fuels (e.g. biomass) necessary		Positive: available gas will lower the incentive for other technologies		Negative: other fuels (e.g. biomass) necessary
Shift towards greener behaviour	Major: higher incentive for biomass CHP		Minor: no significant change		Major: higher incentive for biomass CHP
Strategy	2	4	1	5	3
Deployment of de-centralized RES (including CHP and biomass)	Low	High	Medium	Low	High

	Scenario X5	Scenario X7	Scenario X10	Scenario X13	Scenario X16
Increase of energy efficiency (include DSM and flexibility)	Low: higher O&M costs due to frequent need of regulation	High: lower O&M costs due to low need of regulation	Medium: no significant impact	Low: higher O&M costs due to frequent need of regulation	High: lower O&M costs due to low need of regulation
Increase of funds and better coordination of RDD activities (at EU level)	High: technology may become cheaper	High: technology may become cheaper	Medium: prices at medium level	Medium: prices at medium level	Low: higher technology prices
Permitting framework (including EU nature legislation)	Convergent and strong framework: lowering investment costs	Convergent and strong framework: lowering investment costs	Convergent and strong framework: lowering investment costs	Heterogenous framework at EU level: possibly higher investment costs	Heterogenous framework at EU level: possibly higher investment costs
Resulting scenario for costs					
Investment	low	low	high	high	low
O&M	high	medium	high	high	medium

Tab. 10.11 - Contextualisation of cost variables - coal-fired CHP

	Scenario X5	Scenario X7	Scenario X10	Scenario X13	Scenario X16
	Large scale RES & no emissions	100% RES	Big & Market	Large fossil fuel with CCS & Nuc	Small and local
Future	2		4		5
International Climate Agreement	EU alone: prices relatively stable		Global agreement: no available cheaper installations from outside EU, demand exceeding supply leading to higher prices		EU alone: prices relatively stable
Dependency on fossil fuels from outside Europe	Low: no significant impact		Medium: lower incentive to build coal CHP		Medium: lower incentive to build coal CHP
Fuel costs	High: very low incentive for new coal CHP		Low: high incentive for new coal CHP		High: very low incentive for new coal CHP
CO2 costs	High: leads to increasing O&M costs		High: leads to increasing O&M costs		Low: no significant change
CCS maturity	No: higher prices of CCS installations		Yes: lower prices of CCS installations		No: higher prices of CCS installations
Electrification in heating	All: very low incentive to build coal CHP		Large scale (commercial etc.): no significant change		Residential: low incentive to build coal CHP
Demographic change	Growth: more demand for heat		Growth: more demand for heat		Migration only: no significant change
Public perceptions to RES	Positive: low incentive for coal CHP		Indifferent: no significant change		Positive: low incentive for CHP
Public perceptions to shale gas	Negative: other fuels (e.g. coal) necessary		Positive: available gas will lower the incentive for other technologies		Negative: other fuels (e.g. coal) necessary
Shift towards greener behaviour	Major: lack of public support for coal CHP		Minor: no significant change		Major: lack of public support for coal CHP
Strategy	2	4	1	5	3
Deployment of de-centralized RES (including CHP and biomass)	Low	High	Medium	Low	High

	Scenario X5	Scenario X7	Scenario X10	Scenario X13	Scenario X16
Deployment of fossil fuel plants with CCS	No CCS	No CCS	Medium	High	No CCS
Deployment of fossil fuel plants without CCS	Low	No	Medium	Low	Low
Increase of energy efficiency (include DSM and flexibility)	Low: higher O&M costs due to frequent need of regulation	High: lower O&M costs due to low need of regulation	Medium: no significant impact	Low: higher O&M costs due to frequent need of regulation	High: lower O&M costs due to low need of regulation
Increase of funds and better coordination of RDD activities (at EU level)	High: technology may become cheaper	High: technology may become cheaper	Medium: prices at medium level	Medium: prices at medium level	Low: higher technology prices
Permitting framework (including EU nature legislation)	Convergent and strong framework: lowering investment costs	Convergent and strong framework: lowering investment costs	Convergent and strong framework: lowering investment costs	Heterogenous framework at EU level: possibly higher investment costs	Heterogenous framework at EU level: possibly higher investment costs
Resulting scenario for costs					
Investment	high	N/A	medium	high	high
O&M	medium	N/A	high	high	low

Tab. 10.12 - Contextualisation of cost variables - gas-fired CHP

	Scenario X5	Scenario X7	Scenario X10	Scenario X13	Scenario X16
	Large scale RES & no emissions	100% RES	Big & Market	Large fossil fuel with CCS & Nuc	Small and local
Future	2		4		5
International Climate Agreement	EU alone: prices relatively stable		Global agreement: no available cheaper installations from outside EU, demand exceeding supply leading to higher prices		EU alone: prices relatively stable
Dependency on fossil fuels from outside Europe	Low: no significant impact		Medium: lower incentive to build coal CHP		Medium: lower incentive to build coal CHP
Fuel costs	High: very low incentive for new coal CHP		Low: high incentive for new coal CHP		High: very low incentive for new coal CHP
CO2 costs	High: leads to increasing O&M costs		High: leads to increasing O&M costs		Low: no significant change
CCS maturity	No: higher prices of CCS installations		Yes: lower prices of CCS installations		No: higher prices of CCS installations
Electrification in heating	All: very low incentive to build coal CHP		Large scale (commercial etc.): no significant change		Residential: low incentive to build coal CHP
Demographic change	Growth: more demand for heat		Growth: more demand for heat		Migration only: no significant change
Public perceptions to RES	Positive: low incentive for coal CHP		Indifferent: no significant change		Positive: low incentive for CHP
Public perceptions to shale gas	Negative: other fuels (e.g. coal) necessary		Positive: available gas will lower the incentive for other technologies		Negative: other fuels (e.g. coal) necessary
Shift towards greener behaviour	Major: lack of public support for coal CHP		Minor: no significant change		Major: lack of public support for coal CHP
Strategy	2	4	1	5	3
Deployment of de-centralized RES (including CHP and biomass)	Low	High	Medium	Low	High

	Scenario X5	Scenario X7	Scenario X10	Scenario X13	Scenario X16
Deployment of fossil fuel plants with CCS	No CCS	No CCS	Medium	High	No CCS
Deployment of fossil fuel plants without CCS	Low	No	Medium	Low	Low
Increase of energy efficiency (include DSM and flexibility)	Low: higher O&M costs due to frequent need of regulation	High: lower O&M costs due to low need of regulation	Medium: no significant impact	Low: higher O&M costs due to frequent need of regulation	High: lower O&M costs due to low need of regulation
Increase of funds and better coordination of RDD activities (at EU level)	High: technology may become cheaper	High: technology may become cheaper	Medium: prices at medium level	Medium: prices at medium level	Low: higher technology prices
Permitting framework (including EU nature legislation)	Convergent and strong framework: lowering investment costs	Convergent and strong framework: lowering investment costs	Convergent and strong framework: lowering investment costs	Heterogenous framework at EU level: possibly higher investment costs	Heterogenous framework at EU level: possibly higher investment costs
Resulting scenario for costs					
Investment	high	N/A	medium	high	high
O&M	medium	N/A	high	high	low

Finally, the values of selected variables have been allocated to individual scenarios and technologies. The allocation has been performed based on assessment of final marks to adequate technology groups in a given scenario and the range of values for the selected variable. The values for three defined levels of final marks for selected variables have been defined as follows:

- In case a range of values is available for a given variable (see Excel spreadsheet), the low end value of the range is assigned to the "low" final mark, the high end value of the range is attached to the "high" final mark, while the "medium" final mark is attached an arithmetical mean of low and high end values of the range.
- In case only a single value of the variable is available, it is assumed to correspond to the "medium" final mark. The values for "low" and "high" final marks are then calculated using the assumption that they differ respectively by -12,5% and +12,5% from the available "medium" value. This approach is arbitrary due to a lack of better data, but in case of variables for which a range of values is available, the difference between low and high end values for the range is approximately 25%, therefore the mean value ±12,5%.

In the following tables, the allocation of values of selected variables to individual scenarios and technologies has been presented.

Tab. 10.13 Contextualized values for CHP - scenario X5

Technology	Time horizon				
	2015	2020	2030	2040	2050
Investment costs [mln €]					
Waste	8,5	8,5	8,5	8,5	8,5
Woodchips biomass, medium	2,2	2,2	2,2	2,2	2,2
Woodchips biomass, small	3,6	3	3	3	3
Straw biomass, medium	3,5	3,5	3,5	3,5	3,5
Straw biomass, small	4,5	4	4	4	4
Hard coal	1,45	1,45	1,45	1,45	1,45
Hard coal, biomass co-firing	1,55	1,55	1,45	1,45	1,45
Hard coal, with CCS	N/A	N/A	N/A	N/A	N/A
Lignite	1,55	1,55	1,55	1,55	1,55
Lignite, with CCS	N/A	N/A	N/A	N/A	N/A
OCGT	0,75	0,75	0,75	0,75	0,75
CCGT	0,95	0,95	0,87	0,85	0,82
CCGT, with CCS	N/A	N/A	N/A	N/A	N/A
O&M costs [% of investment/year]					
Waste [€/tonne]	60	60	60	60	60
Woodchips biomass	4	4	4	4	4
Straw biomass	4,5	4,5	4,5	4,5	4,5
Hard coal	2	2	2	2	2
Hard coal, biomass co-firing	2	2	2	2	2
Hard coal, with CCS	N/A	N/A	N/A	N/A	N/A
Lignite	2	2	2	2	2
OCGT	3	3	3	3	3
CCGT	2,5	2,5	2,5	2,5	2,5

Tab. 10.14 Contextualized values for CHP - scenario X7

Technology	Time horizon				
	2015	2020	2030	2040	2050
Investment costs [mln €]					
Waste	7	7	7	7	7
Woodchips biomass, medium	2,2	2,2	2,2	2,2	2,2
Woodchips biomass, small	3,6	3	3	3	3
Straw biomass, medium	3,5	3,5	3,5	3,5	3,5
Straw biomass, small	4,5	4	4	4	4
Hard coal	N/A	N/A	N/A	N/A	N/A
Hard coal, biomass co-firing	N/A	N/A	N/A	N/A	N/A
Hard coal, with CCS	N/A	N/A	N/A	N/A	N/A
Lignite	N/A	N/A	N/A	N/A	N/A
Lignite, with CCS	N/A	N/A	N/A	N/A	N/A
OCGT	N/A	N/A	N/A	N/A	N/A
CCGT	N/A	N/A	N/A	N/A	N/A
CCGT, with CCS	N/A	N/A	N/A	N/A	N/A
O&M costs [% of investment/year]					
Waste [€/tonne]	53	53	53	53	53
Woodchips biomass	3,5	3,5	3,5	3,5	3,5
Straw biomass	4	4	4	4	4
Hard coal	N/A	N/A	N/A	N/A	N/A
Hard coal, biomass co-firing	N/A	N/A	N/A	N/A	N/A
Hard coal, with CCS	N/A	N/A	N/A	N/A	N/A
Lignite	N/A	N/A	N/A	N/A	N/A
OCGT	N/A	N/A	N/A	N/A	N/A
CCGT	N/A	N/A	N/A	N/A	N/A

Tab. 10.15 Contextualized values for CHP - scenario X10

Technology	Time horizon				
	2015	2020	2030	2040	2050
Investment costs [mln €]					
Waste	10	10	10	10	10
Woodchips biomass, medium	2,9	2,9	2,9	2,9	2,9
Woodchips biomass, small	4,9	4	4	4	4
Straw biomass, medium	4,5	4,5	4,5	4,5	4,5
Straw biomass, small	5,8	5,2	5,2	5,2	5,2
Hard coal	1,3	1,3	1,3	1,3	1,3
Hard coal, biomass co-firing	1,39	1,39	1,3	1,3	1,3
Hard coal, with CCS	N/A	N/A	3	2,85	2,7
Lignite	1,4	1,4	1,4	1,4	1,4
Lignite, with CCS	N/A	N/A	3	2,85	2,7
OCGT	0,55	0,55	0,55	0,55	0,55
CCGT	0,75	0,75	0,68	0,66	0,64
CCGT, with CCS	N/A	N/A	1,5	1,5	1,5
O&M costs [% of investment/year]					
Waste [€/tonne]	60	60	60	60	60
Woodchips biomass	4	4	4	4	4

Straw biomass	4,5	4,5	4,5	4,5	4,5
Hard coal	2,2	2,2	2,2	2,2	2,2
Hard coal, biomass co-firing	2,2	2,2	2,2	2,2	2,2
Hard coal, with CCS	N/A	N/A	2,2	2,2	2,2
Lignite	2,2	2,2	2,2	2,2	2,2
OCGT	3	3	3	3	3
CCGT	2,5	2,5	2,5	2,5	2,5

Tab. 10.16 Contextualized values for CHP - scenario X13

Technology	Time horizon				
	2015	2020	2030	2040	2050
Investment costs [mln €]					
Waste	10	10	10	10	10
Woodchips biomass, medium	2,9	2,9	2,9	2,9	2,9
Woodchips biomass, small	4,9	4	4	4	4
Straw biomass, medium	4,5	4,5	4,5	4,5	4,5
Straw biomass, small	5,8	5,2	5,2	5,2	5,2
Hard coal	1,45	1,45	1,45	1,45	1,45
Hard coal, biomass co-firing	1,55	1,55	1,45	1,45	1,45
Hard coal, with CCS	N/A	N/A	3,4	3,2	3
Lignite	1,55	1,55	1,55	1,55	1,55
Lignite, with CCS	N/A	N/A	3,4	3,2	3
OCGT	0,75	0,75	0,75	0,75	0,75
CCGT	0,95	0,95	0,87	0,85	0,82
CCGT, with CCS	N/A	N/A	1,9	1,9	1,9
O&M costs [% of investment/year]					
Waste [€/tonne]	60	60	60	60	60
Woodchips biomass	4	4	4	4	4
Straw biomass	4,5	4,5	4,5	4,5	4,5
Hard coal	2,2	2,2	2,2	2,2	2,2
Hard coal, biomass co-firing	2,2	2,2	2,2	2,2	2,2
Hard coal, with CCS	N/A	N/A	2,2	2,2	2,2
Lignite	2,2	2,2	2,2	2,2	2,2
OCGT	3	3	3	3	3
CCGT	2,5	2,5	2,5	2,5	2,5

Tab. 10.17 Contextualized values for CHP - scenario X16

Technology	Time horizon				
	2015	2020	2030	2040	2050
Investment costs [mln €]					
Waste	8,5	8,5	8,5	8,5	8,5
Woodchips biomass, medium	2,2	2,2	2,2	2,2	2,2
Woodchips biomass, small	3,6	3	3	3	3
Straw biomass, medium	3,5	3,5	3,5	3,5	3,5
Straw biomass, small	4,5	4	4	4	4
Hard coal	1,45	1,45	1,45	1,45	1,45
Hard coal, biomass co-firing	1,55	1,55	1,45	1,45	1,45
Hard coal, with CCS	N/A	N/A	N/A	N/A	N/A
Lignite	1,55	1,55	1,55	1,55	1,55
Lignite, with CCS	N/A	N/A	N/A	N/A	N/A
OCGT	0,75	0,75	0,75	0,75	0,75
CCGT	0,95	0,95	0,87	0,85	0,82
CCGT, with CCS	N/A	N/A	N/A	N/A	N/A
O&M costs [% of investment/year]					
Waste [€/tonne]	53	53	53	53	53
Woodchips biomass	3,5	3,5	3,5	3,5	3,5
Straw biomass	4	4	4	4	4
Hard coal	1,8	1,8	1,8	1,8	1,8
Hard coal, biomass co-firing	1,8	1,8	1,8	1,8	1,8
Hard coal, with CCS	N/A	N/A	N/A	N/A	N/A
Lignite	1,8	1,8	1,8	1,8	1,8
OCGT	2,6	2,6	2,6	2,6	2,6
CCGT	2,2	2,2	2,2	2,2	2,2

11 Conclusions

The main objective of the present document was to provide information on combined heat and power generation technologies according to a homogeneous methodology developed and used for all generation, demand, transmission and storage technology areas. The main feature of the present report on CHP was to focus mainly on the differences between electricity generation in general (as they were covered by other eHigways2050 report, i.e. the VGB Power Tech report) and specific solutions used in CHP technologies.

Different sources of primary energy for CHP technologies, like waste, biomass and coal have been described with their individual advantages and drawbacks. Moreover, where possible, the potential for those sources has been estimated up to 2050. Next, the report covered technologies that are used in processes of co-generation of heat and power. This includes internal combustion engines, diesel engines, gas turbines, traditional coal-fired steam power plants, CCGT with cogeneration, nuclear and micro CHP. Advantages and disadvantages for given technologies have been presented along with possible paths of development.

The main part of the report deals with the issue of defining variables describing various aspects of the analyzed technologies, assigning values to these variables in the foreseen time horizon and finally the contextualization of data with regard to predefined scenarios.

Subsequent stages of the contextualization process, i.e. determining the degree of influence of individual factors (uncertainties as defined for each "future" and options as defined for each "strategy") on variables selected to be contextualized, determining the impact of each selected scenario parameter on potential incentive to develop a given technology and its costs and allocating the values of selected variables to individual scenarios and technologies, have been described in detail in the report. The final outcome of the process is a set of values of investment and O&M costs for the analyzed technologies contextualized for individual scenarios and time horizons.

12 References

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13 Attached document

data_CHP_IEn.xlsx