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MASTER

Enhancement of the ODYSSEE database : the transformation sector and the use of Combined Heat and Power

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The transformation sector and the use of Combined Heat & Power

Enhancement of the ODYSSEE database

Fraunhofer Institute
Systems and
Innovation Research

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Summary

Title of the research:	Enhancement of the ODYSSEE database; The transformation sector and the use of Combined Heat and Power.
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Problem proposition:

How to (1) develop indicators for CHP, (2) integrate these indicators within the current system of indicators of the ODYSSEE database and (3) interpret the observed trends concerning the penetration of CHP in a qualitative manner against the background of current CHP developments and policies?

Goal proposition

To develop indicators for CHP, which fit into the current system of indicators of the transformation sector of the ODYSSEE database, and which allow for future assessment of CHP's contribution to energy savings and the reduction of CO_2 emissions, if it is considered as a replacement of fossil thermal heat and power plants, and support the exploration of factors that influence the penetration of CHP in a qualitative manner.

Summary:

Combined Heat and Power (CHP) is a complex and heterogeneous concept. It is based on the first and second law of thermodynamics, which inevitably imply that in any process to transform chemical energy or heat into work is accompanied by the rejection of heat. If this heat rejected is used in another process, the transformation process is denoted as CHP. As CHP jointly generates heat and power it has a high potential to save energy, in comparison to separate conversion techniques to generate heat and power. Moreover, if fossil fuels are used to generate heat and power CHP has also a high potential to decrease greenhouse gas emissions.

In December 1997 the European Union (EU) agreed in Kyoto to reduce its greenhouse gas emissions by 8% in 2010 with respect to 1990 The EU considers CHP to be one of the very few technologies that can offer a significant short or medium term contribution to this issue. With respect to the goal set it is regarded to be important to annually monitor the overall development in CHP. The ODYSSEE database (Online Database for a Yearly aSSessment of Energy Efficiency) provides a structure of indicators to annually assess the national achievements in the field of energy efficiency of the EU member states. Though CHP developments cannot be monitored yet within this database.

To do so, it has been proposed to separate CHP heat and electricity from fossil thermal heat and electricity. Besides, in order to conduct an unambiguous assessment of the CHP efficiency indicators, the CHP inputs have to be allocated to the outputs. Therefore it has been proposed to allocate the CHP inputs according to the respective share fossil thermal means would have used to produce heat and electricity. Moreover, it has been possible to explore the diffusion of CHP within the United Kingdom, Germany and the Netherlands, through a qualitatively analysis of the indicator for the share of CHP electricity in the total electricity production of these countries. Thus indicators for CHP have been developed that fit into the current system of indicators, and allow for a qualitative analysis and future assessment of CHP's contribution to energy savings and the reduction of CO_2 emissions. Though their implementation in the ODYSSEE database is difficult due to a lack of separate and standardised data for CHP and fossil thermal heat and electricity

Preface

This paper is a graduation report and aims to clarify my Master of Science research I wrote to complete the study of "Technology and Society" of the University of Technology in Eindhoven. A study I started with, due to earlier experiences with Philips Display Components.

During spring 1998 Philips Display Components initiated a policy for employees to change position on average every five years, this in order to deploy these human resources more effectively. This policy had however a major short-term impact on the department I worked for. People felt very insecure and perceived the cultural change as a threat. Being a student "Physical Engineering" at that time, it was hard to understand the employees as well as the management. Couldn't the employees understand it would benefit their own position? And why was it so hard for the management to explain the apparent advantages for the employees? As a possible employee of Philips Display Components, that would work between the management and the employees of Research and Development I wanted to do better. And to be able to do so, I thought it was necessary to understand the processes and decisions at management level much better. This drive eventually led to the choice to continue studying, though in a different direction, that of "Technology and Society".

The knowledge acquired in the according lectures of L.A.G. Oerlemans and M.T.H. Meeus at that time at the University of Technology in Eindhoven is reflected in this report. It merges the sciences of economics, sociology and politics with that of technology. The report concerns a heterogeneous, and very dynamic, technology (i.e. Combined Heat and Power, CHP) which plays an important role in European Union and Member States policies, to reduce the greenhouse gas emissions and especially of CO_2. However the viability of CHP applications is currently endangered, for the most part due to the liberalisation of the energy markets and consequently lower energy (electricity) prices. This also challenges the targets set. Though the developments in CHP cannot be ex-post monitored or evaluated. This problem has been addressed in this report.

Though the accomplishment of this report was significantly delayed, due to several factors. However most important, I lost faith in a good and advanced solution of the problem sketched. Nevertheless, I defend the result obtained and presented in this report.

Besides I appreciate the opportunity the Fraunhofer Institute for Systems and Innovation Research gave me. I had a most wonderful time at the HEK in Karlsruhe. Moreover my friend Judith Tops as well as my parents for being very patient with me during this year.

Johan Reumers, Valkenswaard 2 December 2002

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1 Introduction

This report discusses a contribution to the enhancement of the ODYSSEE database. It involves an ex-post evaluation of the contribution of Combined Heat and Power (CHP) to energy efficiency in the transformation sector. The request for the enhancement stems from policy makers of the European Union (EU) who partially use the database among others to evaluate ex-post the developments in energy efficiency in different sectors, e.g. households, transport and transformation. The objective of this first chapter is to specify the problems of the database regarding CHP and to introduce a methodological approach to address them.

Therefore in the next section first the background of the research is discussed. Then the ODYSSEE database and its deficiencies are described. Based on those considerations successively an assignment description, the delimitation of the research, a goal and a problem proposition are formulated. Finally, the structure of the report is discussed.

1.1 Background of the research

The goal of this section is to discuss recent policies, which concern CHP and have been initiated by the EU. In 1997 under the Kyoto protocol to the United Nations Framework Convention on Climate Change (UNFCCC) the EU agreed to reduce its greenhouse gas emissions by 8% by 2008-2012, compared to 1990 levels (36, Annex B). The EU considers the efficient use of energy as the most important policy objective to reduce the greenhouse gas emissions. It also considers CHP to be one of the very few technologies that can offer a significant short or medium term contribution to the energy efficiency issue in the EU (13, item 3). Estimates, for example, indicate that the total EU CO_2 emissions (according to J.C.M. Farla the most important greenhouse gas) could be reduced by 4% in 2010, if a doubling of the penetration of CHP (the share of electricity produced by private and public CHP plants in gross electricity production) from 9% to 18% by 2010 were to be achieved, if considered as a replacement for existing thermal electricity and heat plants. Similarly, CHP is considered an essential contributor to the greenhouse gas reduction strategies of individual EU member states, such as Germany.

However, it seems that the liberalisation of the energy markets, which was initiated by the EU, has deprived CHP of any economic basis, due to decreasing electricity prices and consequently user's revenues, see e.g. figures about Germany (2, page 235). This challenges the goals set by the EU and the member states concerning the penetration of CHP. Besides the liberalisation of the energy markets, other factors (e.g. the development of fuel energy prices, energy policies taken to reduce the impact of the liberalisation on CHP) influence the penetration of CHP. According to the European Commission, the overall development in CHP penetration should therefore be monitored annually. Amongst other benefits it would allow the

European Commission (EC) to better quantify the achievement of CO_2 emission reduction (13, item 31). To be able to monitor the goals set, the EU commissioned its Member States to report annual statistics of CHP to EUROSTAT in 1997. EUROSTAT has to ensure that a common statistical basis is used for the survey. It is however not possible to ex-post evaluate the contribution of CHP to energy and CO_2 emission savings with the data provided by EUROSTAT, or with the database set up to do so, i.e. the ODYSSEE database. Besides, the EU does not have the opportunity to explore the factors that influence the penetration of CHP. The deficiencies that cause these problems are discussed in the next section.

1.2 ODYSSEE database

In this section the ODYSSEE database is described by discussing the origination, funding, objective and completion of the database, the database management and, finally, a specification of its deficiencies. The ODYSSEE database (Online Database for a Yearly aSSessment of Energy Efficiency) is an outcome of a European project on energy efficiency indicators initiated in 1992 by the European Network of Energy Efficiency Agencies (E^nR). At that time, the database was financed by the EU SAVE programme and by the national energy efficiency agencies. Since the Cardiff Summit in 1998 the EU uses a selection of ODYSSEE indicators. Therefore the database is currently co-financed by the EU with funds from SAVE 2, the contribution from the members of the network is however still more important.

The main purpose of the database is to set up a permanent structure to be able to annually assess the national achievements in the field of sectoral energy efficiency of the EU member states. The assessment is made by analysing indicators, which reflect the energy efficiency of the economy as a whole, of a sector, of a sub-sector or of an end use (5, page 15). Indicators are used as they allow a structured decomposition of the different factors underlying the energy efficiency trends. Moreover indicators are very suitable for international comparisons and benchmarking, because they translate absolute levels to comparable proportions. The indicators are calculated along a common methodology with harmonised national data. A technical co-ordination group checks the comparability of the data and, if necessary, harmonises the data definition. The Fraunhofer Institute for Systems and Innovation Research (FHG-ISI) is a member of this group.

Due to the current construction of the database (CHP electricity is included in the electricity sector), the ex-post evaluation with ODYSSEE indicators of the dependent variables, the contribution of CHP to energy and CO_2 emission savings and the penetration of CHP, is impossible. To solve this problem the database has to be expanded with indicators for CHP only. Though the concepts of CHP and in particular CHP electricity have not been clearly defined, see K.M. Weber (41, page 141). Moreover not all the data are available to do so, see M. Landwehr (26, page 5). And the translation of some of the concepts involved into measurable terms is notional and not determinate, see M. Hinnells (20, page 9). These problems impede the analysis of the dependent variables mentioned and have to be addressed. These considerations led to an assignment to enhance the ODYSSEE database, regarding the measurement of the dependent variables with indicators, see the next section.

1.3 Assignment description

Enhance the ODYSSEE database with respect to the role of CHP in the transformation sector to be able to monitor the penetration of CHP, its contribution to energy and CO_2 emission savings (if considered as a replacement of existing fossil thermal heat and power plants) and relate the factors that influence the penetration of CHP to the observed trends in CHP

1.4 Delimitation

This assignment has however to be delimited with respect to (1) the analysis performed to relate the factors that influence the penetration of CHP to the observed trends in the according indicator and (2) the countries included in this research. Both subjects are in this section addressed.

To be able to relate the factors that influence the dependent variable, i.e. the penetration of CHP to the observed trends in these indicators, they should in principle be decomposed or correlated with time series describing each factor of influence, the independent variable. Nevertheless, in the framework of the current graduation work, it is not possible to establish a firm causal relationship between the independent variables the development of the indicator for the dependent variable. The development of the indicators can give strong hints on the impact of the independent variables, but the causal relationship cannot be proven directly with the available data. However, this is achieved by describing the development of the policy and economic framework of CHP and linking it in a qualitative manner to the development of the penetration of CHP.

Besides, the discussion is limited to the countries of the Netherlands, Germany and The United Kingdom (UK) for the sake of convenience and the availability of data. These considerations are captured in the goal and problem proposition for this research below.

1.5 Goal proposition

To develop indicators for CHP, which fit into the current system of indicators of the transformation sector of the ODYSSEE database, and which allow for future assessment of CHP's contribution to energy savings and the reduction of CO_2 emissions if it is considered as a replacement of fossil thermal heat and power plants, and support the exploration of factors that influence the penetration of CHP in a qualitative manner.

1.6 Problem proposition

How to (1) develop indicators for CHP, (2) integrate these indicators within the current system of indicators and (3) interpret the observed trends concerning the penetration of CHP in a qualitative manner against the background of current CHP developments and policies?

In the next section, the structure of this report that captures the proceedings to answer this question is discussed.

1.7 Construction of the report

In this section the construction of the report is discussed. To be able to answer the problem description (see the previous section) it is necessary to solve the problems mentioned in section 1.2. Moreover a framework of independent variables has to be explained with which the development of the indicator for the penetration of CHP (the dependent variable) can be examined. This framework is explained in the next chapter and in chapter 8 used to qualitatively explore the penetration of CHP in the United Kingdom, Germany and the Netherlands. At last in chapter 9 and 10 respectively the conclusions and recommendations are discussed.

In the intermediate chapters, viz. 3 to 8, the indicators for the dependent variables concerning CHP are developed. To take into account CHP characteristics when developing these indicators, in chapter 3 the process of CHP is defined and briefly characterised on the basis of general CHP plant features. In order to develop the indicators, which fit into the current system of indicators for the transformation sector of the ODYSSEE database, this system of indicators is described in chapter 4. In this chapter also the problems regarding the analysis of CHP with current indicators are specified. Next in chapter 5 the problems regarding the composition of CHP data are addressed. In chapter 6, a problem regarding the implementation of indicators for CHP is solved. In chapter 7 the data available to calculate the indicators are discussed as well as computation of the indicators.

2 Study of CHP penetration with PET-system approach

In section 1.1 the penetration of CHP has been defined as a relative measure for the amount of CHP electricity produced in gross electricity production. This concept is as a dependent variable used in a qualitative and comparative analysis between the United Kingdom, Germany and the Netherlands to explore the independent variables that influence the diffusion of CHP in these countries. Using the penetration of CHP as an dependent variable in such a diffusion research is in accordance with E. Katz, H. Hamilton & M. L. Levin, they state that: diffusion studies seek (...) to compare the relative rate of acceptance (of an item) in one community with another (23, page 210).

The diffusion of an innovation is the result of accumulated adoption decisions of individuals or other decision-making units, see also E.M. Rogers who refers to the rate of adoption, when discussing the diffusion of an innovation (32, page 206). K.M. Weber additionally underpins that innovation diffusion is a dynamic process, which interconnects social, technological, economic and political driving forces (41, page 73). In co-operation with R.J.F. Hoogma he concludes that the diffusion of an innovation is a complex process influenced by a multitude of heterogeneous factors operating at different levels, see K.M. Weber and R.J.F. Hoogma (40, page 546). Though, it is impossible in this research to analyse the collective interactions of all actors' preferences and priorities regarding the technology. As has been outlined in section 1.7, the objective of this chapter is to discuss a framework, with which the penetration of CHP, i.e. its diffusion, can be qualitatively explored in chapter 8.

Therefore in the next section some approaches to innovation diffusion are reviewed. This review leads to the introduction of the Politics, Economics and Technology (PET) system approach as developed by K.M. Weber, who applied this approach to compare the diffusion of CHP between the United Kingdom and Germany. In this study, this approach is applied in order to understand the complex process of diffusion and to identify the most important independent variables and mechanisms that influence the penetration of CHP. Therefore in separate sections the construction of the PET-system (its main system elements) and the most important variables and according mechanisms to study the diffusion of an innovation are discussed. The chapter ends with a section "chapter summary and conclusion".

2.1 Definitions of innovation diffusion

In the sociological literature, several definitions have been published to describe a diffusion process. E.M. Rogers, for example defined the process of innovation diffusion as (32, page 5):

"... *The process by which an innovation is communicated through certain channels over time among the members of a social system* "

E. Katz, H. Hamilton & M. L. Levin, provide another definition of innovation diffusion (23, page 240):

"*…(1) The acceptance (2) over time, (3) of some specific item, idea or practise (4) by individuals, groups or other adopting units, linked to (5) specific channels of communication, (6) to a social structure, and (7) to a given system of values.*"

These definitions have some similarities. First, they are linear conceptualisations of innovation diffusion. Second, four resembling independent variables are discerned, viz. time, communication channels, the innovation itself and the social system (E.M. Rogers considers the social structure and the system of values as dimensions of the social system). Third, and more important, the rules of behaviour are internalised by the actors, as the actors are bound to a specific social system that determines their customs and norms (i.e. the rules of behaviour).

Consequently, ongoing social relations have peripheral effects on behaviour of the actors. In other words, social relationships and structures are concerned as factually irrelevant, see e.g. L.A.G. Oerlemans (28, page 90). In accordance with Granovetter (1985) and L.A.G. Oerlemans, it is therefore concluded that these definitions are an over-socialised conception of human action. Thus the actors are considered as atoms fixed in lattice points of a crystal structure and their position in the structure determines their actions, see also L.A.G. Oerlemans (28, page 92). He also refers to Granovetter to denote that atomisation also emerges from an under-socialised conception of human action, i.e. a narrow utilitarian pursuit of self-interest. It is therefore required that a framework to be used to explore the diffusion of CHP in this research avoids such an atomisation, i.e. should neither be an under-, or over-socialised conception of human action nor a combination of both. The PET-system approach as introduced by K.M. Weber does avoid this, as it does not neglect the structuring role of ongoing social relationships and recognises that relations between actors have more dimensions besides economic exchange. This partially follows from his definition of innovation diffusion:

"*The diffusion of an innovation is the result of more or less co-ordinated decision processes along economic, political and informational channels based on the aims, interests and expectations of the actors involved*" (41, page 182).

He also concludes that the technology will diffuse, which can achieve the highest degree of consensus among the important actors. In the next sections the construction of this PET-system approach is discussed.

2.2 Construction of the PET-system

K.M. Weber developed the PET-systems approach with the objective to link a detailed technical analysis of an innovation to a detailed analysis of the socio-economic relationships in which the innovation is embedded to study the diffusion of an innovation. In this evolutionary system approach the feedback links between politics and economics are integrated and the black box of technology is opened.

A system of innovation is, according to Lundvall, constituted by elements and relationships, which interact in the production, diffusion and use of new and economically useful knowledge (34, page 82). In the PET-system approach "actors" and "structures" are considered as constituents of the PET-system, in addition to main object of interest, i.e. a specific "technology". Actors are defined as the units that possess or manage resources, perform activities and have relations with other actors. The actors considered include besides the users of the technology also its suppliers, the national institutes of policy making and intermediate organisations. In accordance with Godfroij these groups of organised individual actors can be considered as a single entity or actor, because the organisation has a system that enables it to act as a unit, see L.A.G. Oerlemans (28, page 101 ff). Subsequent structures represent the stable framework in which activities take place. Structures and activities are however interconnected, as according to K.M. Weber structures are the aggregate outcomes of interactions, which are in turn specific activities, by e.g. H. Håkansson denoted as transaction activities.

Besides the influence of the system's internal organisation on the diffusion of a technology, the contextual features also influence these developments. Thus the PET-system has been conceptualised, as an open system. However, according to K.M. Weber, it depends on the specific study, what should be considered as "in-" or "outside" the system.

Before discussing the different exogenous factors and mechanisms that influence the technology diffusion in the PET-system, the system's internal organisation is explained. However according to J. Howells a study of how technical innovation is created and then propagated within the economy must take account of relevant decision-making within the firm (22, page 889). Therefore K.M. Weber's conceptualisation of the system elements "technology", actors "decision-making" and "structures" is briefly discussed in the next sub-sections, as well as the evolutionary elements.

2.2.1 Technology

K.M. Weber considers technology as a dynamic integrated system of elements, which comprises besides hard also soft elements (respectively artefacts and knowledge) that co-evolve in response to interactions. This conceptualisation has a few implications, first being an integrated system of elements a technology has a heterogeneous nature. Second, in order to make a technology work (i.e. to produce and to operate it) actors need knowledge about a technology's usefulness and applications. And third, being dynamic (development in response to interactions) the technology is subjected to permanent changes, transformations and improvements, even new options can emerge to.

Despite this extensive conceptualisation, it is currently not acknowledged that a technology is indispensable for an actor, who uses a technology to transform, i.e. to add value to, other resources. Therefore in this report a technology is considered as a resource, that besides the characteristics discussed, has also a specific function for an actor.

As a consequence of the technology's heterogeneous nature, complex organisational structures of companies, industries and economies, are required to co-ordinate the operation of that technology. Thus according to K.M. Weber, in order to be operational a technology needs to be embedded in a regime (41, page 44). To define a such regime K.M. Weber refers to Kemp, Miles, Smith & al. 1994, who defined a technological regime as: "the whole complex from scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures which make up the totality of a technology". Therefore, according to K.M. Weber, a technology has to be understood in its different implications, constraints, dimensions and meanings before a sensible analysis of actors' decisions with regard to the technology can be made. In the next section the conceptualisation of the actor's decision-making process regarding an innovation are explained.

2.2.2 Actor's decision-making

K.M. Weber's model to conceptualise an actor's decision-making process is applicable to all the different types of actors mentioned in the introduction of section 2.2. It is in this sub-section explained in three parts and takes into account the actor's heterogeneous perceptions, anticipations and behavioural patterns.

First, an actor receives a great variety of information inputs due to different interactions to exchange e.g. (1) money, (2) artefacts or (3) solely information (for example on other actors' strategic positions) and (4) to enforce e.g. legislative measures or interests, see K.M. Weber (41, page 99). Subsequent, K.M. Weber denotes in accordance with Cyert, March (1963) and Simon (1959) that this information is neither completely nor objectively perceived, due to quantitative and qualitative limitations. Thus the actors have a bounded rationality, as a result of decoding, filtering (mostly searching for knowledge close to knowledge possessed by local search procedures) and evaluating the information received. The information subsequent retained is available for the perception of future information.

Second, in the PET-system three main types of innovation related decisions are distinguished, (1) innovation, (2) adoption and (3) political decisions. These decisions are made on the basis of the information retained (also perceptions of the innovation), shared paradigms (i.e. cognitive patterns, e.g. of solutions to solve selected technological problems, amongst other things based on (scientific) knowledge), expectations, environmental concerns, available resources and goals set, see K.M. Weber (41, page 93). Thus it is assumed that each actor actively pursues a specific strategy, which drives the process of decision-making. Therefore, K.M.

Weber assumes that an actor reacts autopoietic, i.e. responds to or deals with external impulses in a way, which is predetermined by its internal mechanisms and logic, not necessarily according to the original intentions of the external impulse.

Finally, these innovation-decisions result in interactions, such as those previously mentioned, either with actors in the system or within the own organisation. Thus it follows from this conceptualisation that an actor's decisions with regard to a technology are made on the basis of his perception of that technology, see also E.M. Rogers (32, page 209), and whether it is consistent with his interests. Moreover it follows that actors have manifold interactions, which activate different types of structures. The latter are discussed in the next sub-section.

2.2.3 Structures

K.M. Weber uses three types of structures to characterise the relationships between the different actors. These are (1) market or economic structures (2) network or informational structures and (3) hierarchical or political structures. Before briefly characterising these three structures, two general features are clarified:

(1) Structures are considered to be continually shaped and reshaped by the actions of actors, see L.A.G. Oerlemans who refers to Nohria (28, page 92). K.M. Weber additionally underpins that structures co-evolve in response to the interactions at the micro-level in the system. Thus during a diffusion process of a specific technology, structures as well as that technology adapt to fit each other, see also section 2.2.1 and D. Leonard Barton (27, page 251).

(2) Structures are considered to express the interdependencies that exist between the system elements, as they represent the context for interaction, see also L.A.G. Oerlemans (28, page 91). Or as K.M. Weber mentions, (complex) organisational structures are required to co-ordinate the operation of different interdependent sub-systems, see also section 2.2.1.

The economic structures characterise the relations of the industries on technology supply and demand side. K.M. Weber characterises these amongst other things on the basis of (1) type of allocation mechanism, (2) size and size distribution of firms, (3) regulatory regime, and (4) distribution of public and private ownership. These concepts resemble with those discussed and defined in the theory of Industrial Organisation, e.g. discussed by K.W. Clarkson & R. Leroy Miller (6) and W.M. Cohen & R.C. Levin (7).

The network or informational structures concern, according to K.M. Weber the organisation and structuring of the generation and distribution of information regarding the technology under study. E.M. Rogers as well as E. Katz, H. Hamilton & M. L. Levin recognised that information channels influenced the diffusion of an innovation, see their innovation diffusion definitions in section 2.1. Therefore K.M. Weber remarks that technological knowledge is not only supplied through market relationships but also through informal channels, i.e. transferred by the employment of highly skilled employees, by network like relationships with other private or public organisations or by co-operation between firms. Therefore public and private research and development organisations and infrastructures that provide information on and promote the technology under study are important.

The third kinds of structures discerned are political structures. These characterise the settings in which policies are formulated and implemented, such as regulations and regulatory regimes that characterised amongst other features the economic structures. K.M. Weber describes the political structures in terms of (1) distribution of competencies related to the technology under study within the government, (2) the dependence of policy-makers on external sources of information, and (3) overall power of the political authorities to intervene in industrial affairs.

In the preceding sub-sections the main PET-system elements have been characterised. However, this is still rather a static representation and therefore in the next sub-section it is explained how the open PET-system adapts to impulses.

2.2.4 Evolutionary elements

From these impulses (ex- and internal), pressures and incentives originate that drive the process of technological change. To explain the processes that occur, K.M. Weber uses an evolutionary approach, which comprises three main elements viz. variety generation, selection of alternatives and stability/continuity. However this latter stage is in this report denoted as retention. The stages mentioned are discussed in four parts: (1) variation and selection by innovators, (2) selection by users, (3) selection conditions of the regulatory and political framework and (4) retention.

(1) Variation and selection by innovators

According to K.M. Weber, the diversity of actors considered substantially contributes to the generation of a variety of innovations, because innovation conditions and opportunities differ for each innovator. This is a consequence of interactions and perceptions, which differ for each innovator, see section 2.2.2. Driving forces for innovation are, for example, the emergence of new markets, particular technological needs or motivational forces at the level of individuals, such as curiosity, prestige and personal benefits.

Oppositely innovators make decisions to select innovations, as according to K.M. Weber, the decision to develop a specific innovation (e.g. on the basis of economic profitability) inevitably means that an alternative is rejected. Subsequent the innovations selected may be introduced on a market and exposed to selection by users.

(2) Selection by users

In sub-section 2.2.2 it has been discussed that the decision to adopt an innovation depends on several factors, and is not an independent and straightforward selection process. However, according to K.M. Weber, the demand side of a technology is clearly its key selection environment, for example user-producer interactions may already play an important role for defining and refining an innovation in its development phase.

(3) Selection conditions of the regulatory and political framework

Although the importance of the user-producer relationship in the selection process of an innovation, also the regulatory and political framework affects the selection conditions of an innovation. The regulatory and political framework can influence these selection conditions in the following respect, see K.M. Weber (41, page 105):

* Provision of specific advantages in terms of targeted support measures for new technologies, either for the stimulation of innovation or adoption;

* Provision of information on specific technologies;

* Definition of specific regulatory conditions in an economic sector;

* Definition of the general organisational context of an economic sector;

* Moderation of decision processes;

* Definition of the general institutions and rule systems guiding all kinds of socio-economic activities.

In addition to this influence exerted on selection conditions, K.M. Weber denotes that the political realm also defines the possibilities for the other actors considered to participate in the political decision making process. He considers this as an important feature of political self-control, as it enables the adaptation of the PET-system to perturbations.

(4) Retention mechanisms

According to K.M. Weber, without stabilising elements the interplay of variation and selection would hardly lead to path dependency, trajectories (development paths that are believed to be feasible) and institutional settings, which are needed for deliberate innovation and adoption decisions. This is in accordance with Campbell as quoted by P. Anderson and M.L. Tushman, however the stabilising elements are referred to as retention mechanisms (3, page 613). Therefore in this report stabilising elements are denoted as retention mechanisms.

K.M. Weber defines these retention mechanisms at the three levels of the PET-system, i.e. technological, cognitive and structural. At a technological level, systems established have a quality that is analogous to inertia of motion, for example exchanging components or the complete system is difficult due to interdependent components and interdependency with other systems. Or to paraphrase T.P. Hughes, technological systems have a mass of technical and organisational components, they posses direction, or goals, and display a rate of growth suggesting velocity. Besides interdependencies also standardisation of components or infrastructure cause retention at the technological level.

> At the cognitive level retention is the outcome of successful sense-making of the punctuated and connected summary of a previously equivocal display, which then becomes available to change the way in which future enacted events will be perceived, see J. Howells (22, page 886 ff.). In sub-section 2.2.2 some of the outcomes of successful sense-making have been mentioned, viz. the paradigms shared and the (local) search procedures or routines.
>
> At the structural level the mechanisms of retention are the economic, informational and political conditions to the (technological) system and their interdependence.

Therefore K.M. Weber concludes that system evolution and technological change are only possible if the obstacles throughout the entire system are removed with well-tuned changes at several levels. However, this is limited due to the autopoietic character of the objects of control, i.e. they react to external impulses in agreement with their internal organisation.

In this section the construction of a PET-system has been clarified and the elements that influence the diffusion of an innovation discussed. However the perceptions of an innovation (i.e. innovation features) and contextual features have not been specified yet. These are consecutively discussed in the next two sections.

2.3 Innovation features: perceptions of (changing) technology

In sub-section 2.2.2 it had been discussed that an actor's perceptions of a technology are important to decision regarding that technology. Or to quote E.M. Rogers, the receiver's perceptions of the attributes of an innovation, not the attributes as classified by experts or change agents, affect its rate of adoption (32, page 209). Therefore in this section these innovation features and according mechanisms are discussed, which are of general relevance to the diffusion of innovations.

E.M. Rogers discusses five innovation features as perceived by the innovation receiver and according mechanisms, which are determinative to the diffusion of an innovation, viz. (32, page 206 ff.):

(1) *Relative advantage* is the degree to which an innovation is perceived as being better than the idea it supersedes. The degree of relative advantage is often expressed as economic profitability, social prestige or other benefits;

(2) *Compatibility* is the degree to which an innovation is perceived as consistent with the existing values, past experiences and needs of potential adopters. An innovation can be compatible or incompatible (1) with socio-cultural values and beliefs, (2) with previously introduced ideas, or (3) with clients needs for the innovation;

(3) *Complexity* is the degree to which an innovation is perceived as relatively difficult to understand and use. Some innovations are clear in their meaning to potential adopters whereas others are not;

(4) *Trialability* is the degree to which an innovation may be experimented with on a limited basis. Some innovations are more difficult to divide for trial than are others;

(5) *Observability* is the degree to which the results of an innovation are visible to others. The results of some ideas are easily observed and communicated, whereas some innovations are difficult to observe or to describe to others;

In contrast to the focus of E.M. Rogers on one innovation receiver only, there are three more stakeholders involved in the current system considered. They perceive the (changing) technology differently at different moments in time. An aggregation of these different individual perceptions is, according to K.M. Weber, confronted with different problems (41, page 115). He therefore argues to maintain a multiple dimensional technology assessment framework in order to keep a feasible research. He proposes to assess the following innovation features:

(1) *Technological features*· a technology's compatibility with technological structures in which it is embedded, its complexity as well as trialability from both the perspective of the technology users and suppliers;

(2) *Micro-economic features*: a technology's compatibility with an actor's interests (expressed in terms of technological opportunity, market demand and appropriability conditions), as well as its economic feasibility (expressed in terms of price, risk and uncertainty), from the perspective of the individual companies;

(3) *Macro-economic features*, a technology's macro economic impact on society, expressed in terms as sustainability of economic growth and employment, from a governmental perspective;

(4) *Environmental and resource features*, a technology's macro impact on environment and recourses, especially CO_2-emissions and use of primary energy, from the perspective of intermediate and governmental organisations;

(5) *Organisational and power features*, a technology's organisational compatibility, i.e. its impact on the strategic position of the different actors concerned.

These innovation features as proposed by K.M. Weber, can be considered as a specification of those defined by E.M. Rogers and cover the features that are most important to the actors discerned. For example, the micro economic features concern a relative advantage, i.e. economic feasibility, from the perspective of the users and suppliers of the innovation.

Additionally the development of these innovation features has to be assessed in the period under study, in order to take technology changes into account and their influence on the diffusion pattern of the technology under study. In the next section the factors that are considered as exogenous to the development of CHP (i.e. the contextual features) and the according mechanisms are discussed.

2.4 Contextual features

As the PET-system has been conceptualised as an open system, it is exposed to impulses from the environment to which it adapts. Based on the conceptualisation discussed, these impulses lead to adaptation processes, which are determined by a system's internal mechanisms and logic. These external impulses can be considered as changes in the contextual features.

K.M. Weber discussed some typical contextual features that could exert their influence on a general PET-system (41, page 81). Moreover he made a review of studies that examined the influence of several (contextual) features on the penetration of CHP. In this section seven factors are explained that are based on these discussions of K.M. Weber. For each factor it is clarified why it is considered as a contextual feature. Subsequent the according mechanism, which explains the relationship between the contextual feature considered and the degree of diffusion of CHP, is discussed. The contextual features and the according mechanisms are:

(1) Domestic resource situation regarding primary energy;

Whether in a specific country indigenous primary energy sources are available for exploitation, is not determined by that system. It is a given fact whether they are present or not. Therefore this independent variable is considered as exogenous.

If there are hardly any domestic primary energy resources available to produce secondary energy, a country or region's resource situation regarding primary energy is concerned as being bad. To secure the supply of energy in such a case, the actors inside the system might perceive CHP as an option for dealing with these problems (see e.g. section 1.1), which might subsequent positively influence the diffusion of CHP. Therefore it is assumed that a bad domestic resource situation regarding primary energy leads to a higher degree of diffusion of CHP.

(2) Price differential between (international) fuel and electricity;

This difference is considered as a contextual feature, as the markets for (fossil) fuels and electricity are by now liberalised to a large extent, i.e. customers can choose their supplier of natural gas or electricity. Although feedback mechanisms exists between the PET-system considered and these markets, the system actors can only marginally influence these prices and the difference between them.

According to K.M. Weber the price differential between fuels used in a CHP process and electricity is one of the fundamental economic determinants of the viability of CHP. First, the electricity price and the fuel price are respective measures for the variable annual revenues and costs in a Cost-Benefit-Analysis. Thus, if the price difference mentioned is small, the profitability of CHP is lower and subsequent inhibits its degree of diffusion.

Second, if the development of the price difference between fuel and electricity is volatile, the uncertainty on investment returns is increased. If this uncertainty is increased investment decisions may be postponed or even rejected. Thus the larger the uncertainty with regard to the development of the price difference between fuel and electricity is, the more it is inhibiting to the diffusion of CHP.

(3) Climate and geography;

A PET-system is bound to the local climate. The actors inside the system cannot undertake any aimed actions to alter the climate. Thus a certain geographically region on earth is bound to a certain climate, both are therefore considered as contextual features.

Through seasonal variations the local climate affects the outside temperature levels and therefore determines the heat load patterns for space heating, see e.g. Framework Convention on Climate Change (37, item 8 ff). As, according to K.M. Weber the heat load on the user side is a discriminating factor for CHP applications, the heat load patterns for space heating determine whether CHP can be used for district-heating or object heating, i.e. individual buildings or small-local networks. Thus the colder a climate is, the more space heating is required and the higher the degree of CHP diffusion is.

(4) Nature and size of industrial activities;

The PET-system is also bound to a certain nature and size of industrial activities. Although through regulation the political actors can influence this nature and it size, it is assumed that they only marginally influence them. As a consequence it is considered as a contextual feature.

The nature and size of industrial activities determine the patterns of demand for industrial heat and steam. And as previously has been mentioned, the heat load on the user side is a discriminative factor for CHP applications, the size and structure of industrial activities determine the degree of diffusion for industrial CHP applications.

(5) Technological developments outside the system;

Technological developments from outside the system are, as a consequence of its denomination, considered as contextual features. Technological developments from outside the system can induce technological changes that constrain or enable opportunities to CHP. An example in which the diffusion of CHP can be constrained is the development of low energy buildings in which the demand for space heating has been minimised. In these cases the heat demand may be too low to install and use CHP. Thus the technological development from outside the system is detrimental to the diffusion of CHP.

(6) International policy decisions regarding e.g. the environment;

The PET-system considered is delimited to the actors of a specific country. Therefore international policy decisions taken by supranational organisations,

> such as the United Nations or the European Union are regarded as contextual features.
>
> In section 1.1 it has been discussed that under the Kyoto protocol of the UNFCCC the EU agreed to reduce its CO_2-emissions. To reach the goal set the EU and its member states consider CHP as one of the very few technologies that can offer a significant short or medium term contribution. Therefore they consider the promotion of CHP as an important activity. Thus the international policy decisions can positively influence the degree of diffusion of CHP.

With this description of the contextual features, the in- and outside of the PET-system considered have been defined. Despite the intentions of K.M. Weber to develop a framework with which the diffusion of a technology amongst different countries can be examined, he developed an adoption model, i.e. a model to explain the decision of an actor to adopt a technology. In order to apply this model to explore the diffusion of CHP in chapter 8, the PET-systems of the countries under study and their development should qualitatively and comparatively be described for the time-span explored, though not on the basis of a longitudinal survey.

Nevertheless, before the diffusion can qualitatively be explored, the (dependent) indicators have to be developed with which the diffusion of CHP as well as the contribution of CHP to "energy efficiency" can be assessed. In the development of these indicators the heterogeneous technological characteristics of CHP have to be taken into account. These characteristics are briefly discussed in the next chapter.

2.5 Chapter summary and conclusions

The objective of this chapter was to explain a consistent framework with which the diffusion of CHP can be explored, i.e. in this case the spread of CHP can be compared between the United Kingdom, Germany and the Netherlands. Though the diffusion of an innovation is the result of accumulated adoption decisions of individuals or other decision-making units and moreover a dynamic process, which interconnects social, technological, economic and political driving forces. Therefore the diffusion of an innovation is a complex process influenced by a multitude of heterogeneous factors operating at different levels. Though, it is impossible in this research to do a multi-level analysis, i.e. to analyse the collective interactions of all actors' preferences and priorities regarding the technology.

Nevertheless the conception of human action in the framework to discuss is most important. As well as an over- or under-socialised conception of human action has to be avoided, as it would lead to an atomisation of the actors. The PET-system approach as introduced by K.M. Weber does avoid this, as it does not neglect the structuring role of ongoing social relationships and recognises that relations between actors have more dimensions besides economic exchange, such as interdependency and sustainability.

Besides the "actors", "structures" and a specific "technology" are considered as the main elements of the PET-system. Technology is considered as resource consisting of a dynamic integrated system of elements, which comprises besides hard also soft elements that co-evolve in response to interactions. As a consequence of this conceptualisation a technology has a heterogeneous nature and complex organisational structures of companies, industries and economies, are required to co-ordinate the operation of that technology. In the PET-system, actors are defined as the units that possess or manage resources, perform activities (e.g. innovation and adoption decisions on the basis of available resources and perceptions of the technology concerned) and have relations with other actors. Structures represent the stable framework in which activities take place. Structures and activities are however interconnected.

The PET-system is moreover an open system, and impulses from outside the system also influence the diffusion of the technology in the system. For example, the price differential between fuels used in a CHP process and electricity is considered as one of the fundamental economic determinants of the viability of CHP. From the in- and external impulses, pressures and incentives originate that drive the process of technological change. The processes that occur are explained in an evolutionary approach, which comprises three main elements viz. variety generation, selection of alternatives and retention.

Therefore system evolution and technological change are only possible if obstacles throughout the entire system are removed with well-tuned changes at several levels. However, this is limited due to the autopoietic character of the objects of control, i.e. they react to external impulses in agreement with their internal organisation. Thus to paraphrase K.M. Weber, the diffusion of an innovation is the result of more or less co-ordinated decision processes along economic, political and informational channels based on the aims, interests and expectations of the actors involved.

Despite the intentions of K.M. Weber to develop a framework with which the diffusion of a technology amongst different countries can be examined, he developed an adoption model, i.e. a model to explain the decision of an actor to adopt a technology. In order to apply this model to explore the diffusion of CHP in chapter 8, the PET-systems of the countries under study and their development should qualitatively and comparatively be described for the time-span explored, though not on the basis of a longitudinal survey.

3 Technical specification of CHP

In sub-section 2.2.1 a few general characteristics of a technology have been discussed, amongst other features the heterogeneous nature. In order to develop technical based indicators for the ODYSSEE database this heterogeneous nature has to be taken into account. Moreover the concept of CHP has not been defined yet. Therefore the objective of this chapter is to define the concept of CHP and subsequent discuss its heterogeneous nature. In the next section the concept of CHP is discussed and defined. In the second section CHP's heterogeneous nature is characterised on the basis of general CHP plant features. The chapter ends with a section "chapter summary and conclusion".

3.1 Concept of CHP

In the next sub-section it is discussed that in any thermodynamically process generating power all fuel energy inputs are employed to generate power, although these fuel energy inputs cannot completely be converted into power, but they are partially rejected as heat. It is moreover elaborated that this heat can be employed in other processes and that such a cascade system is defined as Combined Heat and Power (CHP). Thus in the following two sub-section the thermodynamics of the concept of CHP are explained and subsequent the concept of CHP is defined.

3.1.1 Thermodynamics of CHP

In a CHP process flow of energy and work is involved. Such a process can only occur, if both the first and second laws of thermodynamics are satisfied, see G.J. van Wylen (42, page 193). The first law of thermodynamics stresses the fact that during any process the amount of energy is conserved. The second law of thermodynamics inevitably implies that some forms of energy, such chemical energy and heat, can only limited be transformed into work, such as electricity, the remainder is rejected as heat, see also K.M. Weber (41, page 143). This second law of thermodynamics moreover implies that in any irreversible process more heat is produced than in an ideal (reversible) process, see also e.g. G.J. van Wylen. For ideal (Carnot) heat engines the theory as previously discussed can easily be quantified, see the next paragraph. For other systems, such as fuel cells it is more difficult and in more detail discussed by e.g. L.J.M.J. Blomen and M.N. Mugerwa.

A heat engine can only perform work, if there are two reservoirs of different temperature levels, and heat is transferred from the high temperature reservoir to the heat engine and from the heat engine to the low temperature reservoir, see G.J. van Wylen (42, page 198). If it is assumed that, such an fictive Carnot engine operates between two temperature levels of e.g. 673K and 373K, its Carnot efficiency, is defined as 1 minus the ratio of the low and high temperature level, see G.J. van Wylen (42, page 209). According to this definition the engine described can only convert 45% of the energy inputs into work, the other 55% are sequentially rejected as heat. Although this example is not generally applicable, it follows that heat is available for other processes, as it is rejected at a temperature above the surrounding temperature.

Though in actual processes generating work the available heat rejected is mostly considered as waste. If the available heat from a process generating work is usefully employed for, e.g. heating purposes, the process is considered as Combined Heat and Power (CHP), which therefore has a (high) potential to save energy.

3.1.2 Definition of CHP

The goal of this sub-section is to define the concept of CHP on the basis of the previous analysis and within the context of this report. As this report only concerns the CHP units generating electricity and heat, the CHP process is defined as:

A process characterised by the employment for other purposes of available heat, which is sequentially released in a thermodynamically process to generate power (such as thermal power stations and fuel cells), used to produce electricity.

AGFW (1, page 31) and the Department of Trade and Industry of the UK (9, item 6.2) give similar definitions. They however do not restrict their definition to CHP plants only producing electricity, but also include plants that generate mechanical power.

Despite the simple definition, K.M. Weber remarks, it is in practise very difficult to decide whether a specific plant should be regarded as a CHP plant, as in some plants the co-generation capacity is only exploited to a very limited extent (41, page 141). Or, according to the Digest of UK energy statistics 2001, some CHP schemes may not be sized to use all of the available heat (9, item 6.10). In chapter 5 this discussion is continued, in the next section the characteristics of various CHP plants are discussed.

3.2 Technical characteristics of CHP plants

A CHP plant typically consists of (1) a prime mover, (2) a distribution system for heat and electricity and (3) a control system. Depending on the prime mover used also boilers, heat storage or an exhaust gas cleaning system may be added to the plant. The type of prime mover used in a CHP plant strongly determines the technical characteristics of the entire system. Currently four types of prime movers are commercially available, steam turbine units (back-pressure and extraction condensing), gas turbine units, combined gas steam cycles (back-pressure and extraction condensing) and internal combustion engines (Otto- and Diesel cycles).

These CHP options have been described for example, by, K.-H. Suttor & W. Suttor (35), K.M. Weber (41, page 147 ff), J.H. Horlock (21) and in the Digest of United Kingdom Energy Statistics of 2001 (9, item 6.30).

A fifth prime mover, fuel cells, is expected to become commercially available on short term. Vaillant (a manufacturer) expects a market volume for small-scale CHP fuel cells of 250.000 pieces per year in Europe in 2010. Independent sources expect that fuel cells will be a competitive prime mover for the near future energy supply, see e.g. Energie Spektrum 1-2 1999 or M. Gailfuß (18, page 85). For the stationary power market four main types of fuel cells are concerned as major contenders, viz. proton exchange membrane (PEMFC), phosphoric acid (PAFC), molten carbonate (MCFC) and solid oxide fuel cells (SOFC). See for a description of their characteristics ONSITE SYCOM (29, page 20 ff) or R. Heß (19, page 50 ff).

Thus a CHP plant can be constructed with different prime movers. These prime movers have again different characteristics, e.g. regarding power range, overall CHP efficiency (ratio of total energy outputs and input), electricity yield, output heat temperature and fuel input. To give an impression of the heterogeneity of these CHP characteristics table 3.1 has been composed on the basis of a summary of characteristics by C. Vierthaler (39), R. Heß (19, page 52) and ONSITE SYCOM (29).

Table 3.1: Overview of typical CHP plant characteristics

Technology		**Power Range [MW]**	**Overall Efficiency [%]**	**Electricity yield [%]**	**Heat Temperature [°C]**	**Fuel**
Internal Combustion Engine	Otto cycle	<0,05	80-90	23-30	60-110	Natural Gas, Biogas, Propane
		0,05-0,5		30-34		
		0,5-2		32-37		
	Diesel cycle	0,05-0,5	80-90	± 42	60-110	Diesel and residual Oil
		2-20		35-40		
Gas-turbine units		1-3	80-85	20-23	120-600	Natural gas, Biogas, Propane, distillate oil
		3-10		25-30		
		10-100		± 33		
Steam turbine units	Back-pressure	3-20	80-90	10-20	120-250	All
		20-100		20-30		
		100-300		30-35		
	Extraction Condensing	100-300		30-35	120-350	
Combined gas\steam cycle units	Back-pressure	10-100	80-90	± 42	120-250	Natural gas, Biogas, Propane, distillate oil
		100-300		45-48		
	Extraction Condensing	100-300		45-48	120-350	
Fuel Cell	PEMFC	0,0001-0,5	± 80	Up to 50	50-100	Hydrogen
	PAFC	0,005-0,2 (plants up to 5)	± 82	40-45	160-210	Hydrogen
	MCFC	0,8-2 (plants up to 100)	± 85	50-57	670	Hydrogen and Carbon-mono-oxide
	SOFC	0,0025-100	± 90	45-50	810-980	Hydrogen and Carbon-mono-oxide

This heterogeneous nature of the technical characteristics has to be taken into account whenever analysing the contribution of CHP plants to e.g. a country's electricity production. In the next chapter the framework is discussed, which will be used to analyse the contribution of CHP to energy efficiency, i.e. the system of indicators of the ODYSSEE database is described.

3.3 Chapter summary and conclusion

In this chapter it has been discussed, that in any thermodynamically process generating power all fuel energy inputs are employed to generate power. Moreover that the fuel energy inputs cannot completely be converted into power, but are also rejected as heat, which may partially be employed in other processes. On the basis of that discussion the concept of CHP has been subsequently defined as:

A process characterised by the employment for other purposes of available heat, which is sequentially released in a thermodynamically process to generate power (such as thermal power stations and fuel cells), used to produce electricity.

Despite the definitions of CHP, K.M. Weber noticed that it is in practise very difficult to decide whether a specific plant should be regarded as a CHP plant. Because, the co-generation capacity is in some plants only exploited to a very limited extent.

Besides it has been shown that a CHP has very heterogeneous technical features, e.g. regarding prime mover and fuel use, as well as the power range and electricity yield. Thus a plant can be realised in a number of ways with different characteristics. This heterogeneous nature has to be taken into account when developing a framework to analyse CHP within the ODYSSEE database.

4 System of indicators of the transformation sector

In chapter one it has been indicated, that in this chapter the current construction of the system of indicators of the transformation sector of the ODYSSEE database is described. This description has the objective to specify the problems, that impede the analysis of CHP, i.e. the measurement of the concepts "penetration of CHP" and "energy and CO_2 emission savings", and the consequences for the future analysis of CHP. In general the structure of the system of indicators is determined by its application. The latter determines (1) the disaggregation of the data and indicators and (2) their definition and quantification. Besides, to assure the validity of the system of indicators, the data used have to be reliable and valid (do they measure what they are supposed to measure?). Therefore in the next sub-sections the fields of application, the disaggregation, the definition and quantification of the indicators and the reliability and the validity of the data are described. In a subsequent section, the consequences for the analysis of CHP are described. The chapter ends with a section "chapter summary and conclusion".

4.1 Application of transformation sector indicators

The goal of this section is to determine the fields of application of the indicators of the transformation sector. This sector, in which energy products are converted, was initially analysed in order to understand the trends and differences between countries in the figures of the ratio of the final and primary energy intensities. This indicator is a quotient of the final energy available for consumption and the gross inland energy consumption of one year (see for connotation figure 4.2; consumption is in this case not restricted to end-use as it is in economics). This indicator is a measure for the amount of energy used to produce one unit of final energy in a specific year in a specific country. Figure 4.1, for example, depicts the figures for this ratio of the Netherlands, the United Kingdom and Germany, German figures concern the reunified republic and Dutch figures are only available since 1980.

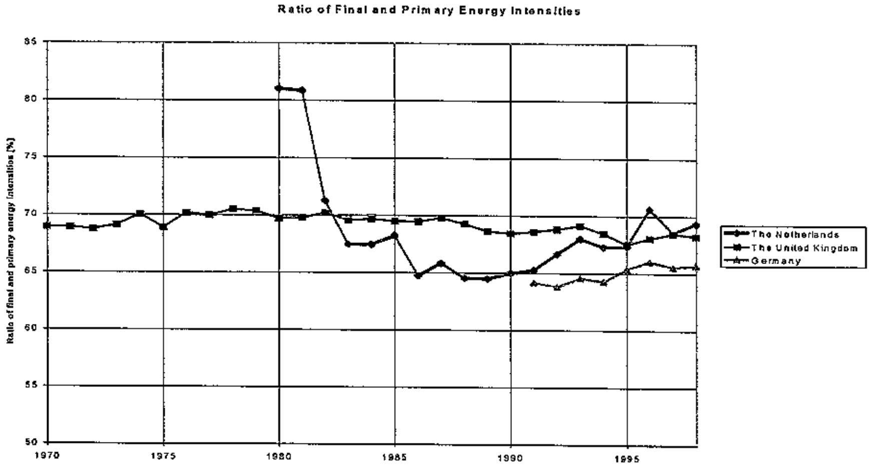

Figure 4.1· The ratio of final and primary energy intensities (Source ODYSSEE 2000)

Striking in the figure is the sharp decrease of the ratio (more energy used to gain one unit of final energy) for the Netherlands in 1982 and its increase since 1990, relatively to the small changes for the UK since 1970 and the small increase for Germany during the nineties.

To be able to understand these trends and differences, it is necessary to investigate the difference between the gross inland energy consumption and the final energy available for consumption of these countries. Therefore in figure 4.2 an arbitrary example of energy flows of a country is shown, from the gross inland consumption to the final energy available for consumption.

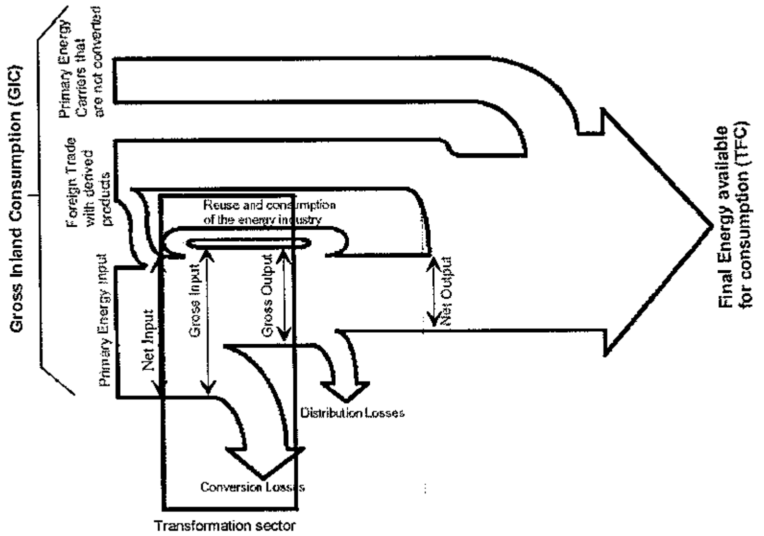

Figure 4 2 *Example of energy flows before it is available for final consumption (Source M Landwehr (26, page 2))*

Since the indicator discussed is a quotient of the final energy available for consumption and the gross inland energy consumption, the magnitude of the ratio depends on the characteristics and shares of the different routes via which the final consumers procure their energy. Thereby the route concerning the inland production of derived energy is of importance, as it contains significant energy losses in the production as well as in distribution of that energy (see figure 4.2). The transformation sector covers all processes aimed at the production of the derived energy products.

This sector again consists of several sub-sectors and branches (these are described in the next section) having different conversion efficiencies (e.g. nuclear electricity and hydro electricity which conventionally given have an efficiency of respectively 33% and 100%), and that might have a different share in the sector in different countries. On the basis of these and previous considerations M. Landwehr and others formulated the following research questions (5, page 135):

(1) "How can efficiency in the transformation sector be compared among countries, in order to distinguish policy impact in the transformation sector while taking into account the differences in natural resources (especially of hydropower) between countries?";

(2) “How can the impact, which efficiency changes in the transformation sector had in the past be determined and compared with the role of energy carrier substitution (mainly increasing electricity penetration)? This comparison is necessary in order to distinguish trends in the penetration of energy efficient transformation technologies and successful policies to promote CHP and renewables from structural changes, which may counterbalance these.”

Since the EU agreed to reduce its greenhouse gasses (see section 1.1), the contribution of the transformation sector to the emissions of the transformation sector is also of concern. These three issues in transformations led to the current structure of the systems of indicators for the transformation sector, which is described in the following sections.

4.2 Disaggregation of the transformation sector

In this section the disaggregation of the transformation sector is described. With disaggregation is meant the division of a sector into sub-sectors and branches, each defined by an output respectively conversion technique. By definition the following sub-sectors are distinguished in the transformation sector: electricity generation, heat generation, incl. CHP heat, production of petroleum products, and production of coal products (e.g. coke, briquettes, etc.).

Especially in electricity generation there are differences in natural resources and the penetration of renewables. To take into account these differences, the electricity sub-sector has been disaggregated into: hydro electricity, electricity from non-combined thermal electricity plants and CHP plants, nuclear electricity and other sources of electricity generation (e.g. wind and geothermal power). The complete disaggregation of the transformation sector is summarised in figure 4.3 below.

It has consequences for the data stored and the definition of the indicators. The data stored in the database only concern the levels of disaggregation discerned. More specific, the data of e.g. CHP electricity are currently not separately stored from fossil thermal electricity. Moreover the indicators are only defined at the levels of disaggregation discerned. The indicators defined are described for the discerned levels of disaggregation of the transformation sector in the next section.

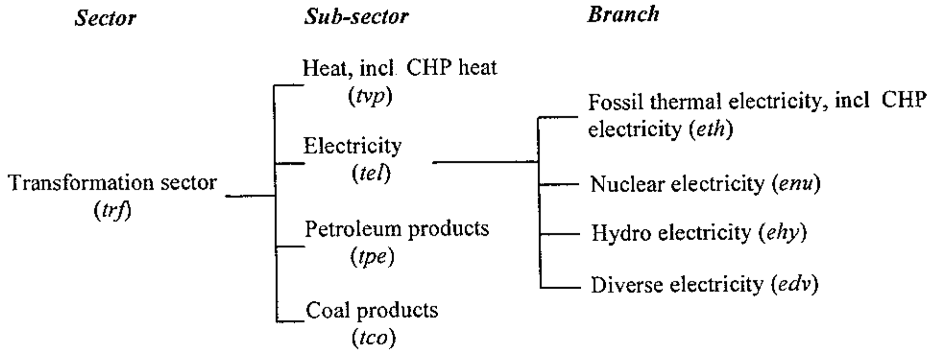

Figure 4.3 Disaggregation of the transformation sector (database abbreviation in parentheses)

4.3 Description of energy efficiency indicators

The goal of this section is to describe the definition and quantification of the indicators of the transformation sector. Energy efficiency trends are in the ODYSSEE database assessed from four complementary perspectives with according indicators, which are denoted as “*energy intensities*”, “*techno-economic ratios*”, “*techno-economic effects*” and “*CO_2 emission factors*”. The first category is used from an economic perspective to relate energy consumption to an indicator of activity measured in monetary units. The second category is used from an engineering perspective to relate energy consumption to an indicator of activity measured in physical terms. The third category is used from the energy saving perspective to characterise energy savings within a sector and across sectors. The last category is used from the emission saving perspective to describe the CO_2 emissions on an overall or sectoral level. In accordance with the issues discussed in section 4.1, the last three categories of indicators are applied in the transformation sector. Their definition and quantification is discussed in methodological papers, sections of these are added in the Appendix A1 and A2 (26 page 8 ff and 4 annex 5). Therefore in next sub-sections the description of the definition and quantification of the indicators for the transformation sector is limited to a brief description of their definition.

4.3.1 Techno-economic ratios

In this section the techno-economic ratios are defined for the transformation sector and their mutual coherence is described. In section 4.1 it has been indicated that the “efficiency” and the “share” of the conversion processes discerned are of concern. These are the techno-economic indicators in the ODYSSEE database.

The “efficiency” is defined as the ratio of the gross energy produced (i.e. secondary energy) and the gross energy used for its production. This indicator is a measure for the amount of the gross secondary energy produced from one unit of gross energy input. Its definition is based on the gross figures, as they allow an assessment of the efficiencies of the cumulated conversion processes of the different transformation products (see figure 4.2).

The reverse of the efficiency is however of more importance in the database, this is shown later in this sub-section. It is denoted as the “unit consumption”, which is a measure for the amount of energy used to produce one unit of secondary energy. The “share” is defined as the contribution of a sub-sector or branch to respectively the sector or sub-sector output. All three indicators are defined for each level of disaggregation.

The unit consumption is disaggregated along the sub-sectors or branches discerned. In fact, it is constructed of each sub-sector “unit consumption” and “share” (in the total sector output), see equation 4.1 on the next page.

$$cu = \frac{in}{pd} = \sum_{k=1}^{n} \frac{in_k}{pd_k} * \frac{pd_k}{pd} = \sum_{k=1}^{n} cu_k * sh_k \qquad \text{(eq. 4.1)}$$

with:
cu: Gross unit consumption;
in: Gross energy input;
pd: Gross energy output;
sh: Share of gross sub-sector output in total gross sector output;
k: Codification for sub-sectors.

Thus the unit consumption, the efficiency and the share are the techno-economic ratios, and they are defined for each level of disaggregation (see also Appendix A1). In the next section the energy savings indicators are discussed.

4.3.2 Energy savings indicators

The energy savings indicators are, in case of the transformation sector, defined for the transformation sector as a whole and for its electricity sub-sector. The energy savings indicators measure the changes in the energy input of the transformation sector respectively the electricity sub-sector. For this objective the (sub- or sector) input is calculated as:

$$in = \sum_{k=1}^{n} cu_k * sh_k * pd \qquad \text{(eq. 4.2)}$$

with:
cu: Gross unit consumption;
in: Gross energy input;
pd: Gross energy output;
sh: Share of gross sub-sector output in total gross sector output;
k: Codification for sub-sectors.

This equation forms the basis for the calculation of the changes in the input due to changes in (1) efficiency (i.e. unit consumption), (2) shares of converted energy carriers or (3) output. These three effects are respectively calculated with three indicators denoted as "*unit consumption effect*", "*structural effect*" and "*activity or quantity effect*". The unit consumption effect measures the changes in total (sector or sub-sector) input under the assumption of frozen shares and output. The structural effect measures the changes in total (sector or sub-sector) output under the assumption of frozen efficiency and output. Finally the activity effect measures the changes in (sector or sub-sector) output under the assumption of frozen efficiency and share. See also appendix A1 for the quantification of these indicators.

Summarising, three additional indicators are defined for respectively the transformation sector and the electricity sub-sector. As they are defined on the overall levels, they do not make a comparison between specific technologies to assess the energy input savings, obtained by the introduction of a specific technology, which is supposed to substitute another. In the next sub-section the CO_2 emission indicators for the transformation sector are described.

4.3.3 CO_2 emission factors

For the ODYSSEE database CO_2 or carbon indicators have been developed to monitor the international targets for the reduction of CO_2 emissions (Kyoto targets). These indicators are based on the “IPCC guidelines for greenhouse gas inventories”, IPCC is an abbreviation for International Panel on Climate Change. In Berlin 1995 it was agreed, that these IPCC guidelines should be used by the industrialised countries in preparing the national communication pursuant to the convention of the UNFCCC (United Nations Convention on Climate Change).

The carbon dioxide (CO_2) emissions are produced when carbon-based fuels are burned. Within the transformation sector carbon-based fuels are only burned in the heat and electricity sector. The electricity sector can be specified with the branch of fossil thermal electricity, as in the other electricity branches no carbon-based fuels are burned. Therefore only CO_2 indicators for the heat and electricity sectors have been implemented into the ODYSSEE database.

According to the guidelines of the IPCC, estimates of the CO_2 emissions can be made based on the amounts of fuels burned and their (defined) carbon content. However instead of calculating the total emissions per sector and branch, the calculations currently yield the CO_2 emission per unit of secondary energy (heat or electricity) generated, see appendix A2. These two indicators are respectively called the electricity and heat carbon emission factor. They do not assess the contribution of specific fossil thermal transformation technologies to the total CO_2 emissions.

Before discussing the consequences of the disaggregation, definition and quantification of the indicators for the analysis of CHP, the data used to calculate the indicators, their sources, gathering and storage are briefly described.

4.4 ODYSSEE Data: sources, gathering and storage

The data are decentrally gathered, by national teams (e.g. national statistic institutes) which execute surveys and provide the aggregated data available in the respective country. Most data are taken from the common national energy statistics (e.g. energy balances and national accounts). Due to this statistical nature of the data, there is a delay of 1 to 2 years in data gathering. Moreover only the net supplied figures are available (see e.g. energy balances of EUROSTAT and CBS), although to obtain a valid result for the efficiency indicators the gross figures are preferred for the ODYSSEE database, see sub-section 4.3.1.

In the ODYSSEE database these data are stored in a primary data library, according to the disaggregation of the different sectors. Then these data are harmonised to a common format and stored in the secondary data library of the ODYSSEE database. Finally a third data library is created which contains the energy efficiency indicators. To be able to calculate the three kinds of indicators described in the previous section for the transformation sector the respective sector, sub-sector and branch inputs and outputs are stored in the database. Besides, for the calculation of the CO_2 emission factors the IPCC carbon emission factors per fuel are stored.

The CHP data situation is unclear, as a consequence of the CHP data gathering, processing and storage. The CHP data gathered are limited to those of plants with an electrical capacity larger or equal to 1 [MWe]. Although due to expected future decentralisation of power generation (thus lower average power output per plant) enabled by existing and new technologies (e.g. internal combustion engines and fuel cells, see section 3.2) and different policies targeted towards large and small-scale CHP plants, it might be necessary to take small-scale CHP plants into account. Moreover for some countries even the CHP heat production is included in the electricity sector, see M. Landwehr (26, page 5).

4.5 ODYSSEE indicators and CHP

In the previous sections the construction of the current system of indicators of the transformation sector of the ODYSSEE database and its data gathering and storage were described. The goal of this section is to discuss the consequences of the previous description for the current and future analysis of CHP with the ODYSSEE indicators. Therefore firstly in the next sub-section the characteristics of the data and the construction of the current system of indicators of the transformation sector, that concern the analysis of CHP, are summarised. Subsequently the consequences for the current and future analysis of CHP are discussed in separate sub-sections.

4.5.1 Data and construction of database concerning CHP

Regarding CHP, the data and the construction of the current system of indicators of the transformation sector have the following characteristics:

(1) CHP heat is separated from CHP electricity (see figure 4.3);

(2) CHP heat and electricity are not separated from respectively fossil thermal heat and electricity (see figure 4.3);

(3) The CHP data gathered do not concern small-scale CHP plants, that have an electrical output power less than 1 [MWe] (see section 4.4), although their contribution to the production of (CHP) electricity might be significantly;

(4) For some countries the CHP heat production is stored in the electricity sector (see section 4.4), although separation is required (see the first characteristic);

(5) The energy savings and CO_2 emission factor indicators have not been designed to make a comparison between specific transformation technologies.

4.5.2 Current analysis of CHP

In this sub-section the consequences, that follow from the characteristics previously mentioned, for the current analysis of CHP are discussed. First, the items 2 to 4 imply that the data with regard to CHP are contaminated with other data (item 2), incomplete (item 3) and not correctly stored (item 4). These negatively affect the validity of the data stored in the database with regard to CHP, and therefore they do not allow for an assessment of CHP with (current) ODYSSEE indicators. Consequently, it is currently not possible with the ODYSSEE indicators to:

(i) Monitor the penetration of CHP electricity (defined as the share of CHP electricity in the electricity sector);

(ii) Assess the contribution to energy and CO_2 emission savings by CHP plants replacing existing fossil thermal heat and power plants.

Second, the ODYSSEE database is structured as a hierarchy in which CHP heat and electricity are separately analysed (see the first characteristic on the previous page). Moreover, for almost every indicator on the different levels of disaggregation discerned, the gross energy input has to be known (see e.g. the definition of the unit consumption). As CHP has been characterised as a process with one energy input and two outputs (heat and electricity, see section 3.1), it follows that the CHP energy input has to be allocated to these outputs of heat and electricity. This in order to avoid double counts of the CHP inputs on the overall transformation level.

The current method weighs heat and electricity equally, splitting the common input according to the share of the energetic content of each output in the total output (see also section 6.1.1). As a consequence, the efficiency of CHP heat and electricity are equal and equivalent to the overall CHP efficiency (see also section 6.4.1), which may range between 80% and 90% (see table 3.1). This is not desirable, as it currently costs more energy to produce a unit of electricity than a unit of heat. M. Hinnells, e.g. denotes that it is around twice as hard to generate a unit of electricity than a unit of heat in the UK (20, page 9). Besides, if these CHP efficiencies are implemented in the ODYSSEE database, the efficiency of fossil thermal electricity and the efficiency of the overall electricity sector is increased and the efficiency of the heat sector might decrease, see M. Landwehr (26 page 14). Although it has not been assessed whether CHP is more or less efficient than fossil thermal heat and electricity plants, i.e. produces less or more energy from one energy input (see sub-section 6.4.1). Summarising, the current allocation method impedes a correct assessment of the efficiency indicators, as it equally weighs heat and electricity.

Thus to be able to analyse CHP with ODYSSEE indicators the problems of the data validity (contamination, completeness and storage) and the allocation of the inputs have to be addressed. By separating CHP heat and electricity from respectively fossil thermal heat and electricity, i.e. adapting the design of the database, the problems with the contamination are addressed and specific indicators to compare CHP with fossil thermal heat and electricity can be defined. In the next sub-section the proposed design of the database to future ex-post evaluate CHP with ODYSSEE indicators is discussed, including its consequences for the future research.

4.5.3 Future analysis of CHP

Regarding CHP, the design of the database is currently characterised by the fact that the CHP data are not separately stored from fossil thermal heat and electricity. To be able to make a comparison between CHP and fossil thermal heat and electricity it is of importance to make this separation. For the future construction of the database this means that branches for CHP heat and electricity and branches for fossil thermal heat and electricity have to be introduced. This conclusion leads to the following proposed disaggregation of the transformation sector (see figure 4.4).

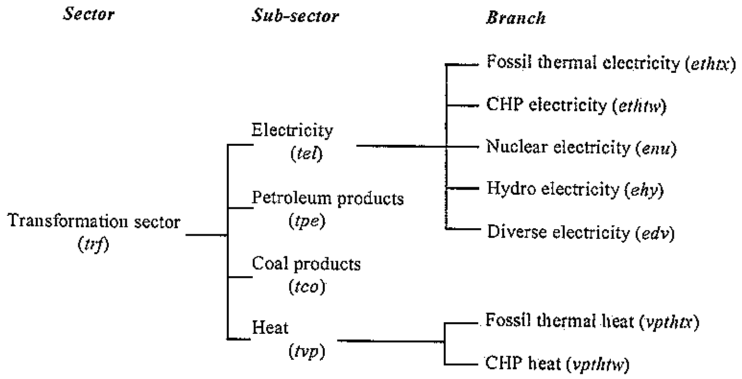

Figure 4 4 *Proposed disaggregation of the transformation sector (database abbreviation in parentheses)*

Whether this proposed disaggregation can be implemented depends on the availability of the data needed, such as the separate input and output figures for CHP and fossil thermal heat and electricity. Moreover the proposed adaptations in the current disaggregation of the transformation sector of the ODYSSEE database have consequences for the future data processing and definition of indicators:

(1) For each of the branches discerned, the unit consumption, efficiency and share have to be defined, analogue to those discussed in the sub-section 4.3.1;

(2) For those CHP plants that are flexible in the available heat production in relation to the electricity production, only the part of the electricity produced corresponding to the available heat used should be counted as CHP electricity the other part of the electricity produced (i.e. condensed electricity) should be allocated to the branch of fossil thermal electricity including according inputs;

Besides it has already been established in section 4.5.1 and 4.5.2 that:

(3) The significance of the contribution of small-scale CHP plants with an output power lower than 1 MWe to a country's electricity production has to be assessed;

(4) The CHP inputs have to be allocated to the outputs of CHP heat and electricity with a more appropriate method than the one currently used;

According to the first item the definition of the indicator for the penetration of CHP is fixed, as it in section 1.1 was defined as the share of CHP electricity in the electricity sector. Besides a complementary set of indicators has been defined, which is easily expandable to make the comparison between CHP and fossil thermal heat and electricity. However, in order to obtain a reliable result for the indicators, the items 2, 3 and 4 have to be addressed. In the next chapter (chapter 5) the conventions used to determine the condensed electricity produced by CHP plants and the according inputs are discussed, and moreover whether small-scale CHP plants significantly contribute to the production of CHP electricity. In chapter 6 the allocation problem of the aggregated CHP inputs to the CHP branches of heat and electricity is addressed. In chapter 7 the quest for available data is described, in order to determine whether the ODYSSEE database can be expanded as previously has been proposed.

4.6 Chapter summary and conclusion

In this chapter the problems that impede the analysis of developments in CHP with the ODYSSEE indicators of the transformation sector have been identified. To identify these problems the framework to analyse the transformation sector was described.

Initially the transformation sector was analysed in order to understand the trends and differences between countries in the figures of the ratio of the final and primary energy intensities. This indicator is a measure for the amount of energy used to produce one unit of final energy in a specific year in a specific country. It was shown that the outcome of this indicator is influenced by the significant energy losses in the transformation sector, which covers all processes aimed at the production of the derived energy products.

To be able to analyse the differences in the ratio of the final and primary intensities between different countries, the transformation sector is divided into sub-sectors and branches. The sub-sectors discerned are (1) heat (incl. CHP heat), (2) electricity, (3) petroleum and (4) coal transformations. The electricity sector is further divided into the branches: (1) nuclear, (2) hydro, (3) fossil thermal incl. CHP and (4) wind and other electricity.

For each level the efficiency (ratio of the (sub-)sectoral or branch outputs and inputs) and the share (contribution of a sub-sector or branch output to the respective sector or sub-sector output) are defined. Energy savings indicators measure the changes in transformation or electricity input, due to changes in output, efficiency or shares of respectively the sub-sectors or branches for the transformation sector and the electricity sub-sector. And CO_2 emission factors are defined for both the heat and electricity sub-sectors, which measure the amount of CO_2, emitted per unit of energy produced in the respective sub-sector.

The indicators are calculated with data aggregated to a branch, sector or national level. The data, gathered by national institutions, are stored in the primary data library of ODYSSEE, and in a common format stored in the secondary library. With these data the indicators are calculated. Ideally the data would concern the gross transformation branches and sector in- and outputs, however only the net supplied figures are available and stored in the database.

Regarding CHP, the data are contaminated with data of fossil thermal heat and electricity (stored in the same branches), incomplete (small-scale CHP plants are not taken into account) and not correctly stored (CHP heat included in the electricity sector). Moreover a disputable method is used to allocate the CHP inputs to the outputs, which is necessary due to the indicators defined and the separate analysis of the CHP outputs. Thus with ODYSSEE indicators it is currently not possible to make an assessment of CHP.

By defining separate branches for CHP heat and electricity, the problems with the contamination are addressed and indicators can be defined to compare CHP with fossil thermal heat and electricity. It however raises also a new problem, the allocation of condensed electricity produced by CHP plants to the branch fossil thermal electricity. Moreover the contribution of small-scale CHP to the electricity production has to be assessed and a new method to allocate the CHP inputs to the outputs, in order to obtain unambiguous outcomes for the notional efficiency indicators for CHP heat and electricity.

5 Composition of CHP data

In this chapter the problems regarding the composition of the CHP data are discussed. First, the conventions used to determine the condensed electricity produced by a CHP plant and the according inputs are discussed. Second, it is assessed whether small-scale CHP plants contribute significantly to a country's electricity production. These subjects are separately discussed in the next two sections. The chapter ends with a section "chapter summary and conclusion".

5.1 CHP and condensed electricity

In general the electricity produced by a CHP plant is totally considered as CHP electricity, whenever the available heat produced is completely used. The electricity produced by a CHP plant consists of a share of condensed electricity, when the available heat is on purpose (partially) cooled away into the environment.

According to AGFW, for a CHP plant of the latter category the share of CHP electricity (W_{CHP}) can be calculated by multiplying the available heat used ($Q_{CHP,U}$) with the plant specific power to heat capacity ratio (C), see equation 5.1 (1, page 32).

$$W_{CHP} = Q_{CHP,U} * C \qquad \text{(eq. 5.1)}$$

Next, the difference between the total electricity produced and the CHP electricity is defined as condensed electricity ($W_{non\text{-}CHP}$). The according inputs ($I_{non\text{-}CHP}$) can proportionally be calculated (see equation 5.2), as all the energy inputs (I_{tot}) of a CHP plant are employed to generate electricity, see section 3.1:

$$I_{non\text{-}CHP} = \frac{W_{non\text{-}CHP}}{W_{non\text{-}CHP} + W_{CHP}} * I_{tot} \qquad \text{(eq. 5.2)}$$

This methodological approach leads to a scheme to discuss the different conventions that are applied to separate the CHP electricity and condensed electricity produced in a CHP plant. For each convention the threshold criteria to distinguish CHP plants producing condensed electricity from those that do not, the power to heat capacity ratios used and the allocation of the inputs are discussed.

These three subjects are discussed in the next sub-sections for three differing conventions. Two conventions are used by EUROSTAT for different CHP surveys, first the survey of CHP in the EU from 1994-1998, and second the survey of CHP in the EU of 2000. Information about these methods stems from Pekka Lösönen, EUROSTAT. The third is defined by DETR (Department of the Environment, Transport and Regions of the UK) and used for the surveys of CHP in the UK, see for information: http://www.chpqa.com, the CHPQA standard and CHPQA (10 and 11). In the last sub-section these conventions are compared.

5.1.1 Method 1: EUROSTAT survey of CHP in 1994-1998

For this survey EUROSTAT made a correction for the condensed electricity produced by CHP plants, in the following three cases:

(1) Marginal CHP units with an actual power to heat capacity ratio more than 4;

(2) Steam-units with condensing turbine operated with low heat production compared to electricity generation;

(3) Gas turbines or internal combustion engines, which could be operated without heat recovery, whenever there is low heat production compared to electricity generation.

Similar to the approach previously discussed, EUROSTAT calculates the CHP electricity as the actual available heat used multiplied with a default value for the heat to power capacity ratio. The values for this ratio are depicted in table 5.1.

Table 5.1: Default heat to power values (Source. EUROSTAT survey 1994-1998)

Type of Cycle	Default power to heat capacity ratio (C)
Combined cycle	1
Steam turbines	0,25
Gas turbines	0,5
Internal Combustion Engines	0,5

The fuel input is defined as the total fuel consumed during a year by a CHP plant for the production of heat and electricity. According to J. Kloots of the CBS (the official Dutch statistics office that reports the Dutch CHP statistics to EUROSTAT) this means that the fuel input is proportional calculated (see equation 5.2).

This convention however consists of questionable elements, such as the subjective threshold criteria to assess a plant as a pure CHP plant or the default power to heat capacity ratio's used. It is moreover remarkable in terms of continuance of methodology, that the method for the subsequent survey has been changed. This changed methodology is discussed in the next sub-section.

5.1.2 Method 2: EUROSTAT survey of CHP in 2000

For the survey of 2000, EUROSTAT set a quantitative threshold criterion of at least 75% overall CHP plant efficiency, to distinguish between CHP plants producing pure CHP electricity and those producing a non-CHP component. EUROSTAT set this threshold criterion to minimise the amount of calculations for transparency and to increase the objectivity. According to EUROSTAT, this threshold criterion is so high, that even the best available separate heat and power generation technologies would have a lower combined efficiency (which is a ratio of the combined products and inputs).

For CHP plants with an overall efficiency lower than 75%, the CHP electricity generated is calculated analogue to the methods previously discussed. However the power to heat capacity ratio is the actual one, whenever the plant characteristics are known, otherwise default values are used, see table 5.2. These default values have however been adapted compared to those used for the previous EUROSTAT survey.

Table 5.2: Default power to heat values (Source: EUROSTAT survey 2000)

Type of CHP Cycle	**Default power to heat capacity ratio**	
	District-heating	**Industrial heating**
Combined cycle	0,95	0,75
Steam, condensing turbines	0,45	0,30
Steam, back-pressure turbines	0,45	0,30
Gas turbines	0,55	0,40
Internal Combustion Engines	0,75	0,60

There is no additional information available concerning the calculation of the inputs. Although this method is much more transparent and objective compared to the previous method, it is for this method also unclear how the default power to heat capacity ratio's are determined. In the next section the British CHP quality assurance method is discussed.

5.1.3 Quality assurance for CHP: CHPQA

In the CHP quality assurance method, two different criteria are used to assess, whether a CHP plant's fuel energy inputs and the electricity produced should be counted as CHP inputs and electricity. The assessment is made on the basis of the power yield (ratio of the total annual power output and the total annual fuel input) and the quality index. The latter assesses the fuel energy input use of CHP plant relative to alternative fossil thermal means producing the same amount of heat and electricity. To determine the CHP fuel energy input and electricity generation of existing plants, the threshold criteria are as follows defined:

- **For fuel inputs under annual operation:**

  A scheme qualifies as good quality CHP for its entire annual energy inputs (I_{tot}) when the power yield (PY) equals or exceeds 20%. If the PY is lower than 20% the qualifying CHP fuel inputs (I_{CHP}) are calculated as:

  $$I_{CHP} = \frac{PY}{PY_{threshold}} * I_{tot} \qquad \text{(eq. 5.3)}$$

  Under transitional arrangements for existing steam turbines the threshold power yield is reduced to 15% until 1 April 2005.

- **For power outputs and capacity under annual operation:**

  A scheme qualifies as good quality CHP for its entire annual power outputs if the quality index (QI) equals or exceeds 100, i.e. when annually less or an equal amount of fuel energy input is used by the CHP plant compared to alternative means. The QI is calculated as:

$$QI = X * PY + Y * HY \qquad \text{(eq. 5.3)}$$

Therein HY is the heat yield (ratio of the available heat produced and the total annual fuel input), X and Y are coefficients that respectively relate to the efficiencies of alternative (fossil thermal) power and heat supply options (values are depicted in table 5.3). DETR discussed the determination of the X and Y factors (11, page 16 ff). The QI is normally based on annual operation, but it can be based on, e.g. the heating season for residential community heating.

Table 5.3: Values for X and Y for various sizes and types of CHP schemes (Source: The CHPQA standard, November 2000)

Size of Scheme		**X**	**Y**
1	≤ 1 MW$_e$	230	125
2	> 1 to ≤ 10 MW$_e$	220	125
3	> 10 to ≤ 25 MW$_e$	205	125
4	> 25 to ≤ 50 MW$_e$	190	125
5	> 50 to ≤ 100 MW$_e$	185	125
6	$> 100 \leq 200$ MW$_e$	180	125
7	$> 200 \leq 500$ MW$_e$	170	125
8	> 500 MW$_e$	160	125
Special Cases			
9	Fuell Cell Schemes	180	125
10	Internal Combustion Engines (including those in Combined cycle applications) ≤ 25 MW$_e$	200	125
11	Transitional arrangements for existing Steam Turbine and Reciprocating Steam Engine Schemes to April 2005	240	125
Alternative Fuel Schemes (As defined in the CHPQA guidance notes)			
12	Alternative Fuel Gases (e.g. hydrogen, ethane, propane)	240	125
13	Biogas, Waste gas or Waste heat	300	140
14	Biomass or solid or liquid Waste	400	140

If for a CHP scheme the QI calculated is lower than 100, the electricity produced by that plant partially consists of condensed electricity. In such a case the CHP electricity produced is similar calculated to the method discussed in the introduction of this section, but with a power to heat capacity ratio at QI=100, see equation 5.4 below:

$$\begin{aligned} W_{CHP} &= Q_{CHP,U} * C \\ &= Q_{CHP,U} * \frac{PY}{HY_{(QI=100)}} \qquad \text{(eq. 5.4)} \\ &= Q_{CHP,U} * \frac{PY}{[100 - (X * PY)]/Y} \end{aligned}$$

By calculating the electricity this way, it represents the share of electricity that could be produced by a Good quality CHP plant with a QI of 100. The good quality CHP power capacity is analogous calculated, however the available heat used is substituted by the maximum heat capacity.

Although the approaches discussed in the previous sub-sections are analogously designed, there are major differences in the definition of the threshold criteria used to distinct CHP inputs and electricity from condensed electricity and according inputs. Especially these differences are discussed in the next sub-section.

5.1.4 Comparison of methods

It is the objective of this sub-section to visualise and elaborate the differences between the methods previously discussed to determine the share of condensed electricity produced by a CHP plant. The comparison between the different methods is made on the basis of overall CHP plant efficiency. Therefore the minimum overall efficiency of a CHP plant has been calculated under CHPQA, which would obtain a quality index equal to 100. The calculations were made in MS Excel 97 for a power yield ranging from 15 to 50%. The results are depicted in figure 5.1 below.

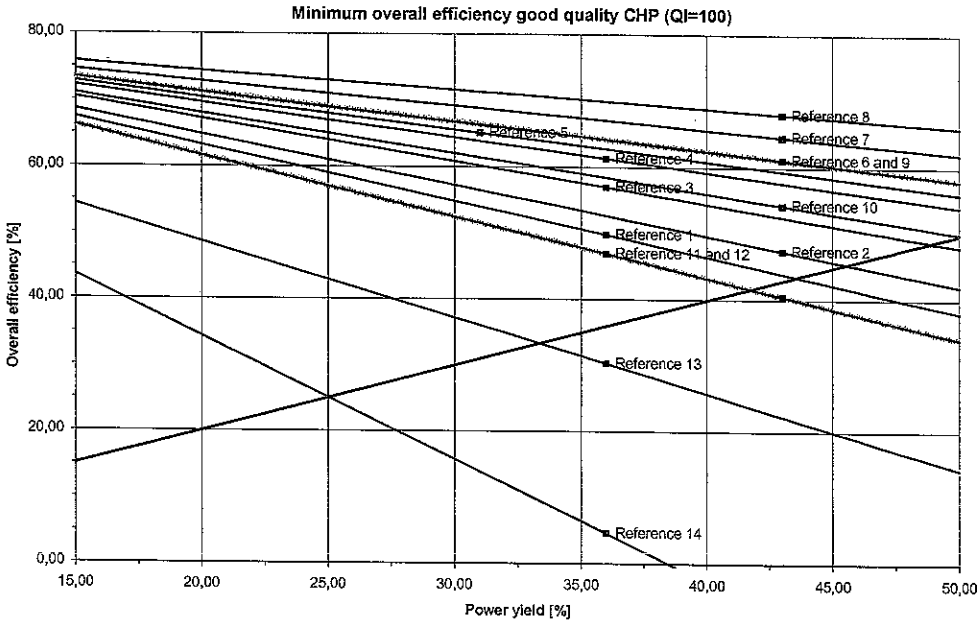

Figure 5 1 The minimum overall efficiency for a plant to obtain a QI of 100

The red line in this figure represents schemes only producing electricity, in these cases the electricity yield is equal to the overall efficiency. The references refer to the schemes distinguished in table 5.3. From this figure it follows that from CHP schemes applying to reference 1,2,3, 10, 11, 12, 13 and 14 a (very) small share of the available heat can be used and the electricity it produces is considered as CHP electricity. This is a result of the chosen methodology and the fact that the production of electricity is appreciated much more than that of heat, see table 5.3.

In the document CHPQA it is argued in favour of the methodology chosen, that a simple overall CHP efficiency threshold criterion is not used because the efficiency target does not provide a clear indication of the environmental benefits of a CHP scheme (11, item 2.2). It is however recognised that "good quality" CHP often achieves efficiencies in excess of 70%. Considering this figure, the statement from EUROSTAT regarding the threshold criterion of an minimum overall CHP efficiency of 75% seems to be correct, see sub-section 5.1.2.

In the CHPQA standard it is moreover remarked, that the QI definitions are subjected to review and may change over time, but transitional arrangements are applied to provide continuity, see CHPQA standard (10, item 6.1). However, any change in the methodology of the determination of data of time series influences the assessment of these time series. The methodology should be consistent over a longer period to be able to assess the developments over time in the data series.

On the basis of the previous information and considerations it is concluded, that a methodology based on a comparison of energy inputs between CHP and fossil thermal heat and electricity does not adequately distinguishes between CHP electricity and condensed electricity. And is moreover less consistent over a longer period and more complex. The latter concerns the amount of calculations that have to be implemented and the reference efficiencies that have to be determined.

It is also concluded, that to distinguish between CHP and condensed electricity on the basis of the overall CHP efficiency is more adequate, consistent over a longer period and less complex. Besides, the CHP inputs should be allocated according to the share of condensed electricity produced by the CHP plant, whenever according to the threshold criteria, the CHP plant produces condensed electricity. This in order to prevent misinterpretations whenever comparing the ODYSSEE efficiency indicators of CHP with those of fossil thermal heat and electricity.

The previous conclusions have to be taken into account when discussing the data to be used in this project in chapter 7. Moreover the considerations concerning the consistency have to be taken into account when choosing a method to allocate the CHP inputs to CHP heat and electricity in the next chapter. In the next section however firstly the contribution of small-scale CHP plants to the CHP electricity production is discussed.

5.2 Significance of small-scale CHP plants

In this section the significance of the contribution of small-scale CHP plants (electrical capacity less than 1 [MWe]) to the production of CHP electricity is assessed, taking into account its perspective for future developments. The assessment is made, according to the delimitation of the research on the basis of data available for the United Kingdom, the Netherlands and Germany.

Before the assessment can be made, a threshold criterion has to be set to determine when the contribution of small-scale CHP to the total electricity production is considered significantly. Such a threshold criterion is always subjectively, but striving after a certain accuracy of the database, it is assumed that the contribution of small-scale CHP plants to the electricity production is significant, whenever they have a share of 5% in the total electricity production of the respective countries.

Moreover, some remarks have to be made regarding the delimitation of small-scale CHP, the prime movers they are based on and the construction of the assessment. First, the delimitation of small-scale CHP plants seems to be unambiguous, though the definition in the different countries differs. In the UK the definition of small-scale CHP plants refers to plants smaller than 1 MWe, while in the Netherlands the upper limit is 2 MWe, see K.M. Weber (41,page 157).

Second, at present small-scale CHP plants are mostly based on internal combustion engines, see K.M. Weber (41, page 157). According to ECN, the engine running on natural gas is the only relevant option for small-scale CHP in the Netherlands also in the next few years, see F. Bijkers and others (31, page 15). Therefore the analysis of the contribution of small-scale CHP plants to the current and future electricity production is restricted to the ICE-CHP plants. Small-scale CHP plants based on fuel cells are not considered, although it is in general expected that CHP fuel cells are a promising option for future small-scale CHP applications, see e.g. M. Gailfuß and M. Seidel (18, page 88).

Third, for small-scale CHP plants only the data of the installed electrical capacities are available. Whether the installed capacity of small-scale CHP is a valid indicator for the electricity produced, depends on the typical annual operating time of an average electricity plant and small-scale CHP plant. This because the product of the electrical capacity and the typical annual operating time equals the electricity annually produced. The determination of the typical annual operating time of small-scale CHP and electricity plants is for each country separately discussed.

In the next three sub-sections the contribution of small-scale ICE-CHP plants to the total electricity production is discussed for the three countries mentioned. In every sub-section first the electrical capacities of the small-scale CHP plants and their share in the total electrical capacity is discussed. Second, the average typical annual operating time of small-scale CHP and of electricity plants is discussed. Subsequent the contribution of small-scale CHP to the total electricity production is assessed. To take future developments into account, at last the perspective of small-scale CHP in the each country is discussed.

5.2.1 United Kingdom

The data used in this sub-section to assess the contribution of small-scale CHP to the electricity production in the United Kingdom stem from the chapters 5 and 6 of the "Digest of the United Kingdom energy statistics 2001". These data comply with the methodology discussed in sub-section 5.1.3 to determine "good quality" CHP, i.e. are corrected for non-CHP components.

The electrical capacities of the CHP plants are reported according to four size ranges, among others: less than 100 kWe and 100 kWe to 999 kWe (9, table 6.1). Both categories have been summarised to obtain the total installed electrical capacity of small-scale CHP in the United Kingdom, which is depicted in the bars in the figure below. The total installed electrical capacity of all generating companies (9, table 5.7) has been used to calculate the share of small-scale CHP in the total installed electrical capacity of the UK, represented by the blue line in the figure below.

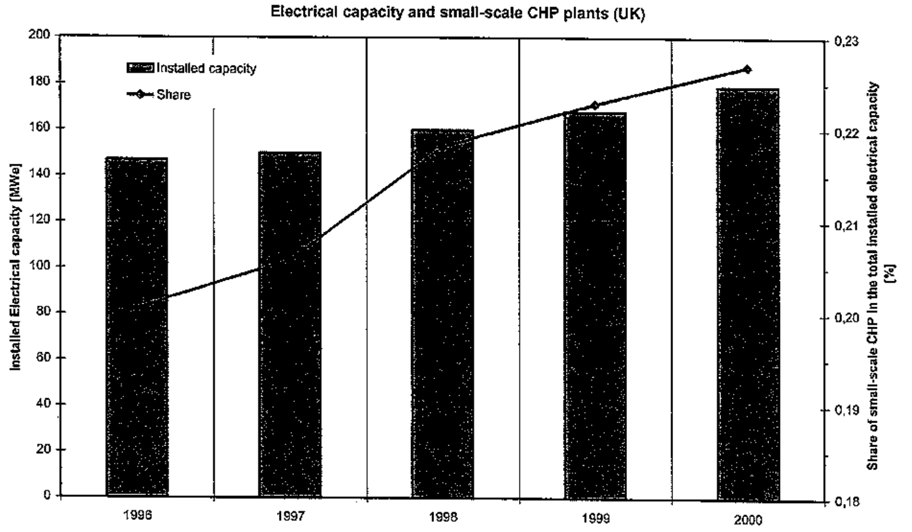

Figure 5 2· Share of small-scale CHP in the total electrical capacity of the United Kingdom

It follows from this figure, that the share of small-scale CHP in the total installed electrical capacity of the United Kingdom is very small. However before assessing the contribution of small-scale CHP to the total electricity production, the typical annual operating time of small scale CHP is estimated, as the annual electricity production of the small-scale CHP plants is not reported.

As has been stated before, currently the internal combustion engines with small electrical capacities are the only small-scale CHP option. As all the CHP-ICE plants are equally applied, i.e. in applications where hot water is required, it is assumed that an average small-scale CHP plants is equally applied as an average CHP-ICE plant. And therefore, that both have approximately equivalent typical annual operating times.

The typical annual operating time of an ICE-CHP plant as well as of an electricity plant can be calculated, by division of their annual electricity production and respective installed electrical capacity (9, table 6.4, 6.5, 5.6 and 5.7). The results are depicted in figure 5.3 on the next page. The relative difference between both the typical annual operating times has also been calculated and depicted.

Due to a lack of data, it is impossible to conclude on possible trends in this figure. In the period depicted, the differences between the typical annual operating time of an average ICE-CHP plant and of an electricity plant range from about –7% (1996) to +5% (2000). If it is assumed that the typical annual operating time of small-scale CHP equals that of average ICE-CHP plants, this indicates that the share in the total electricity production of small-scale CHP differs about –7% to +5% from the share of small-scale CHP in the total electrical capacity.

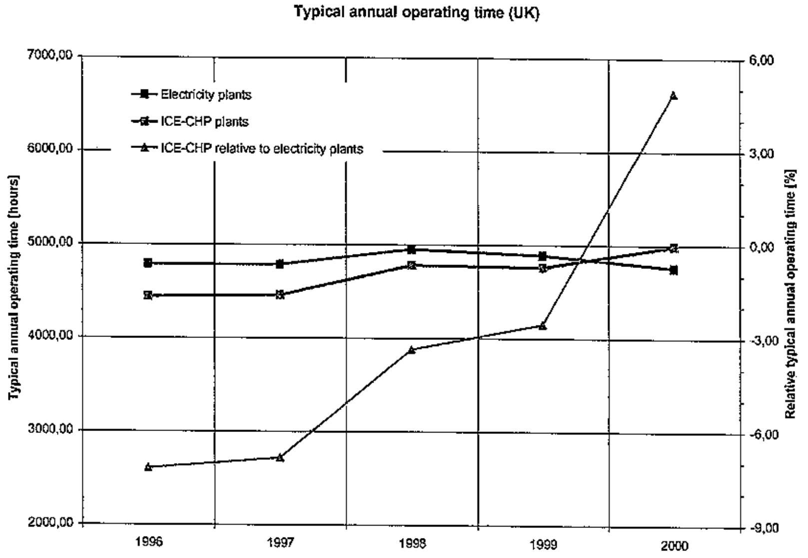

Figure 5 3 Typical annual operating time of CHP-ICE plants and for all electricity plants of the United Kingdom.

However the difference between the typical annual operating time of an average electricity plant and a natural gas fuelled ICE-CHP plant is about 11%. This difference is set as upper and lower limit, to indicate a range of possible outcomes for the share of small-scale CHP in the electricity production. This is depicted in figure 5.4 below.

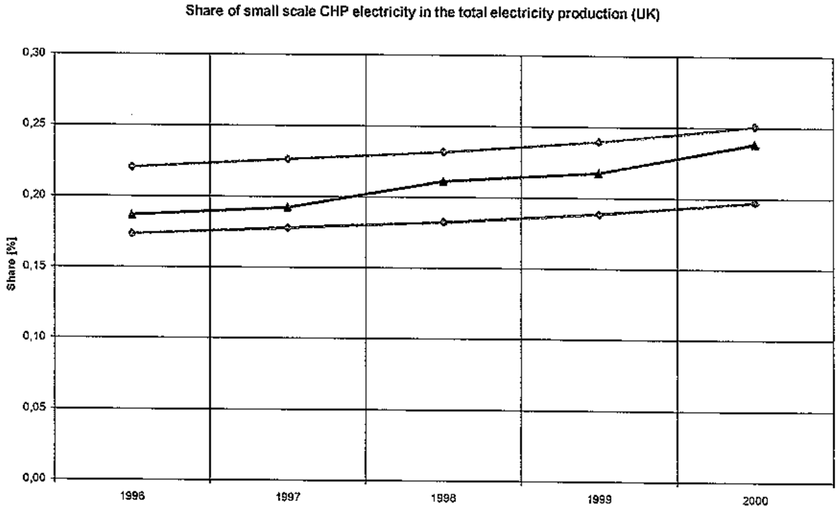

Figure 5 4. Estimated share of small-scale CHP in electricity production of the United Kingdom.

The blue line in this figure represents the share of small-scale CHP electricity in the total electricity production when the operating time of small-scale CHP would be equal to that of the average ICE-CHP plant. It however follows from this figure that, in each scenario sketched the share of small-scale CHP in the total electricity capacity is very small. Therefore it is concluded, that the contribution of small-scale CHP to the total electricity production is currently insignificant.

For the future, the British Government set a target of at least 10.000 MWe of installed CHP electrical capacity by 2010 (9, item 6.8). This target has however not been specified regarding the electrical capacity of small-scale CHP, which share in the total CHP electrical capacity currently seems to decrease (9, table 6.1). Although, to contribute significantly to the total electricity production, the share of small-scale CHP in the total electrical capacity has to substantially increase, from about 0,227% up to 5%, and the typical annual operating time should approximately be equivalent to that of an average electricity plant. Thus, if the decreasing trend of small-scale CHP in the CHP electrical capacity persists and although the target of doubling the CHP electrical capacity by 2010 is met, the contribution of small-scale CHP to the total electricity production of the United Kingdom by 2010 will still be marginal.

5.2.2 Germany

For Germany no specific data are available concerning small-scale CHP plants. However, the Fördergemeinschaft Blockheizkraftwerken (FGBHKW) publishes data about the so-called "Blockheizkraftwerken", which are CHP plants aimed at a local energy supply and include CHP plants based on the ICE as well as the gas turbine. The data published are specified for these two prime movers. The data about the ICE-CHP plants are used in this section. However, the maximum electrical capacity included in the figures is unknown as well as whether the figures have been corrected for non-CHP components. Moreover, in an E&M article it is remarked that the figures from FGBHKW differ from those of VDEW, i.e. Verband Deutscher der Elektrizitätswerke e.V. (E&M, 15 Mai 1998). Nevertheless, it is assumed that the figures used in this sub-section are representative for the installed small-scale CHP electrical capacity in Germany, as the average electrical capacity of the ICE-CHP plants included in the figures is about 0,5 MWe.

In figure 5.5 on the next page, the electrical capacity of ICE-CHP plants and their share in the total electrical capacity in Germany from 1982 to 1997 are depicted. From the article "Motorische Blockheizkraftwerke und stationäre Brennstoffzellen" in BWK it follows, that the electrical capacity of ICE-CHP plants was about 2100 MWe in 1998 and has only marginally changed since then. It is therefore concluded that currently the share of ICE-CHP plants in the total installed electrical capacity in Germany is still below 5,0%.

To be able to assess whether the share of small-CHP electricity in the total annual electricity production is significant, the typical annual operating time of all electricity plants and ICE-CHP plants has to be estimated. The typical annual operating time of all electricity plants has been estimated on the basis of data from the ODYSSEE database (the electricity produced) and from FGBHKW (the total installed electrical capacity). For 1994 to 1998 this results in an almost constant typical annual operating time of 4500 hours. For the ICE-CHP plants in Germany no data are available from which the typical annual operating time can be derived.

However in the period of 1995 to 1998 a typical annual operating time of all CHP plants around 1800 hours is calculated from the CHP data for Germany provided by EUROSTAT. This typical annual operating time is only 40% of that of an average electricity plant.

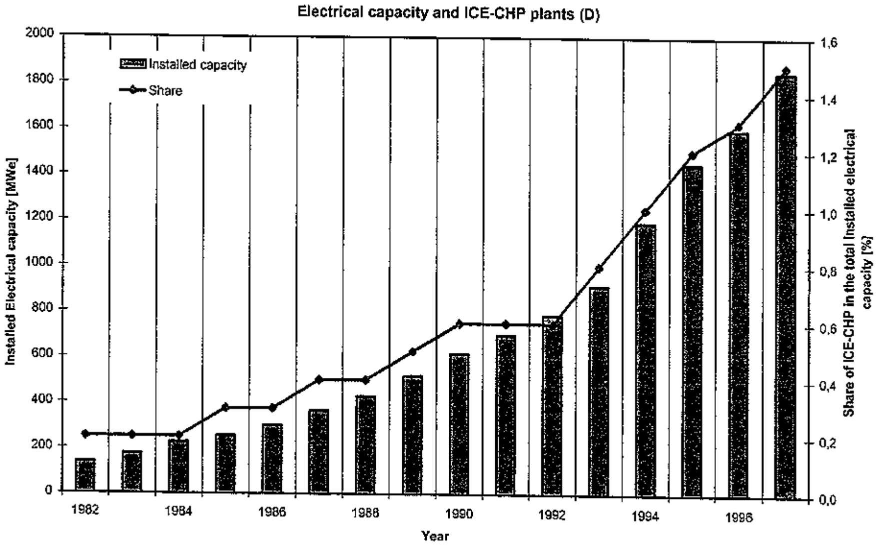

Figure 5 5 Share of small-scale CHP in the total electrical capacity of Germany

Thus assuming that the ICE-CHP plants have annually an equivalent operating time as an average CHP plant, it implies that the share of ICE-CHP plants in the electricity production of Germany in the period of 1994 to 1998 is only 40% of their share in the installed electrical capacity. Which means that for the assumption made, the share of electricity produced by ICE-CHP plants in the total German electricity production would be insignificant in these years. Even if the typical annual operating time of ICE-CHP plants would equal that of an average electricity plant, the contribution of ICE-CHP plants to the electricity production of Germany would still be insignificant. It is therefore concluded that currently the contribution of ICE-CHP plants to the electricity production of Germany is insignificant.

For the future the German government has set no explicit target for CHP development in Germany, apart from the general commitment of government to extend its capacity in response to environmental and resource-related concerns, see K.M. Weber (41, page 311). Regarding BHKW, which includes small-scale CHP, it is stated by M. Gailfuß and M. Seidel that the short-term developments depend fully to what extend and over which time span the investors obtain certainty and clarity for their investments (18, page 90). Moreover in 1993 Fenzl & Pummer estimated the future potential of small-scale CHP at 5700 MWe, taking technical and economic constraints into consideration, which is less than 5% of the electrical capacity of the power plant park in Germany. Besides, the label small-scale does in this context not restrict the plant size to 1 MWe. Thus it is concluded, that small-scale CHP will not contribute significantly to the electricity production in Germany by 2010, assumed that the typical annual operating time of small-scale CHP is equal or less than that of an average power plant.

5.2.3 The Netherlands

The data used in this sub-section to assess the contribution of small-scale CHP to the Dutch electricity production stem from STATLINE, an online statistics database of the Dutch Central Office for Statistics (w15). The CHP data have been corrected for non-CHP components, however which method has been used is not reported on STATLINE. Moreover, as previously has been stated the upper limit of small-scale CHP in the Netherlands is set at 2 MWe. Therefore the assessment in this sub-section regards CHP plants with an electrical capacity up to 2 MWe.

The data available on STATLINE do not distinguish electrical capacity size ranges. However for local installed plants the electricity capacities are reported according to the main prime movers discerned. As already has been stated in the introduction of this section, currently the internal combustion engine CHP plant that runs on natural gas is the only relevant small-scale CHP option in the Netherlands. The total installed electrical capacity of these plants and their share in the total installed electrical capacity in the Netherlands is depicted in figure 5.6 below.

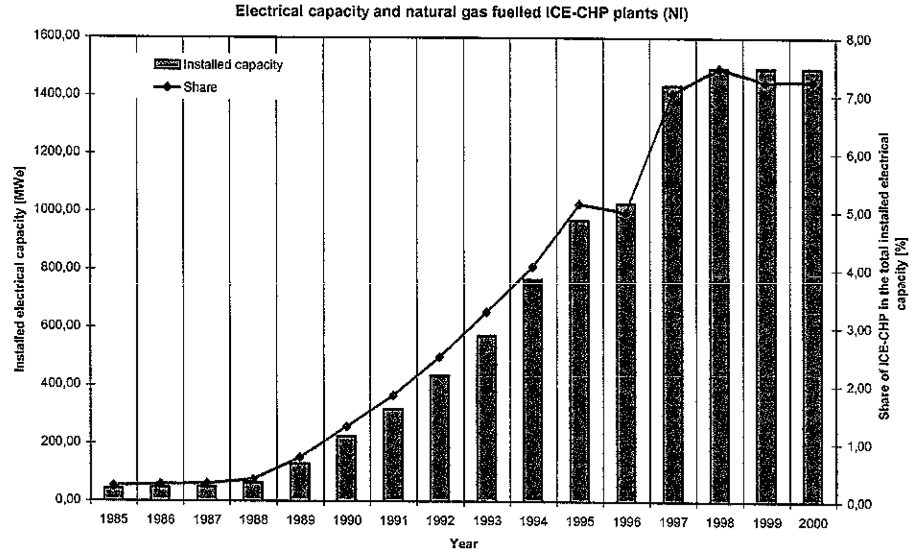

Figure 5.6 Share of natural gas fuelled ICE-CHP in the total electrical capacity of the Netherlands

From this figure it follows that the share of natural gas fuelled ICE-CHP plants in the Dutch installed electrical capacity is significantly from about 1995. However, to be able to make an assessment of the contribution of these plants to the total Dutch electricity production, the typical annual operating time of these plants has to be estimated. Contradictory to the publication of the electrical capacity according to the prime movers discerned, only the total electricity produced by all local CHP plants is published. Implying that only the average typical annual operating time of all installed local CHP plants can be derived from these data.

According to ECN the natural gas fuelled ICE-CHP plants are in the Netherlands mostly used in the greenhouse-farming sector, see F. Bijkers and others (31, page 15). ECN moreover assumes that these CHP plants have a typical annual operating time of 4000 hours. It is however noted that, whenever a natural gas fuelled ICE-CHP plant is equipped with an exhaust-gas cleaning installation, the typical annual operating time could rise up to 6000 hours (31, page 40). These typical annual operating times are respectively set as lower and upper limit when estimating the electricity produced by the natural gas fuelled ICE-CHP plants. Figure 5.7 below, depicts besides the typical annual operating time of an average power and local CHP plant also the annual relative difference between both.

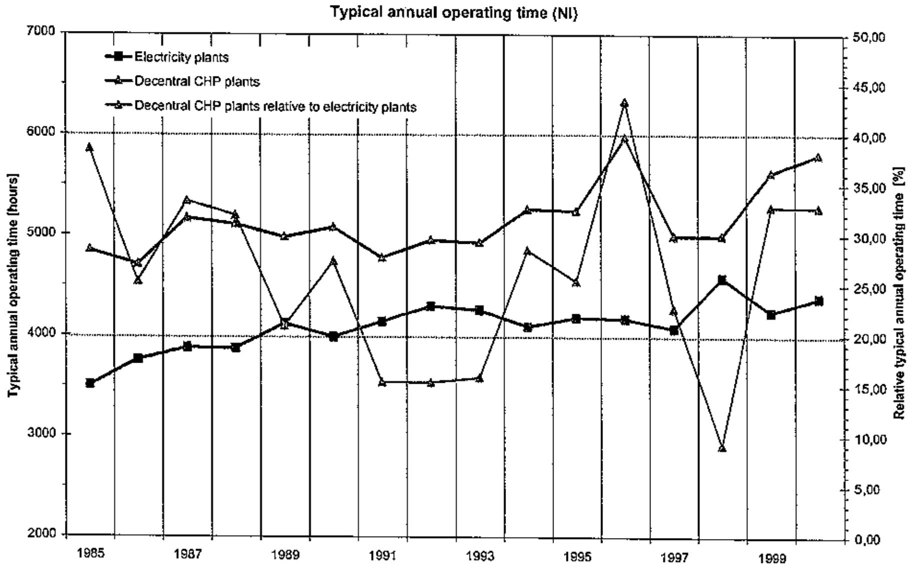

Figure 5.7 Typical annual operating time of Dutch local CHP plants and power plants

From this figure it follows that whenever the typical annual operating time of natural gas fuelled ICE-CHP plants would be 4000 hours, their share in the total electricity production would not significantly differ from their share in the installed electrical capacity. When however the typical annual operating time would approximate that of the local installed CHP plants the share of natural gas fuelled ICE-CHP plants in the total electricity production would increase on average with 26%.

See also figure 5.8 on the next page, in which the estimated share of natural gas fuelled ICE-CHP electricity in the total Dutch electricity production is depicted. It follows from this picture that natural gas fuelled ICE-CHP plants with an electrical capacity up to 2 MWe contribute significantly to the total electricity production in the Netherlands from 1995.

Future Dutch scopes and policies regarding the development of CHP up to 2010 are based on the results of the "global competition scenario" as developed and calculated by ECN (12, page 40). The results of this scenario for small-scale ICE-CHP with an electrical capacity up to 2 MWe are depicted in table 5.4 on the next page. This table also includes the installed electrical capacity of small-scale ICE-CHP in 1999, besides the findings of ECN from two market scenarios calculated in 1999 and 2000 to estimate the installed ICE-CHP electrical capacity for a variety of options and conditions by 2010. Whereby the latter was update of the study in 1999, regarding new published tariffs on electricity transport and energy taxes (30, page 2).

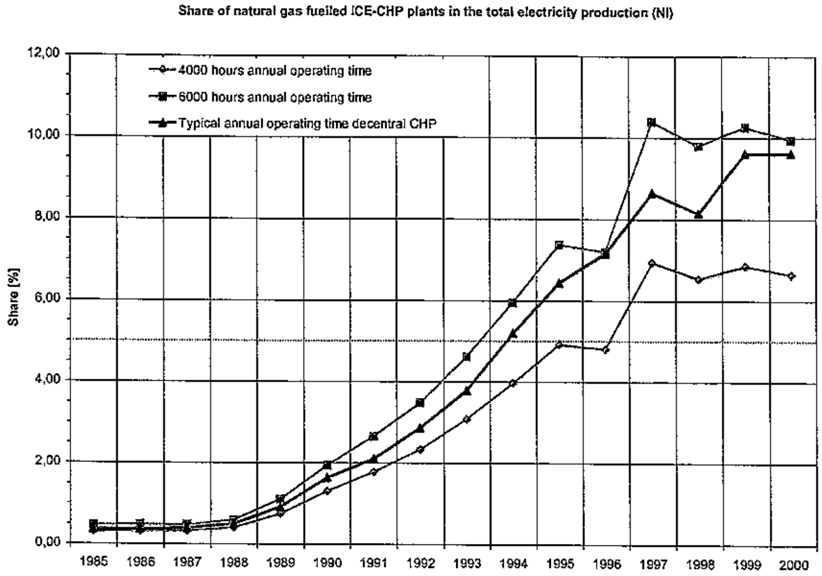

Figure 5.8: Estimated share of natural gas fuelled ICE-CHP plants in the total electricity production of the Netherlands for different typical annual operating times

As is concluded by ECN, the combined effects of the policy measures mentioned have a positive impact on the profitability of CHP (30, page 2). However due to the current political climate (September 2002) and according policy measures it is not possible to conclude on the realisation of targets set by the previous coalition government. Therefore no estimation is made of the installed electrical capacity of small-scale CHP in the Netherlands by 2010.

Table 5.4: Small-scale CHP electrical capacity (Source: ECN)

Electrical capacity [MWe]	***1999***	*Scenarios 2010*				
		Global Competition	*Low*		*High*	
			minimum	*maximum*	*minimum*	*maximum*
Oktober 1999	1500	2600	400	700	1400	2100
February 2000			1100	1600	2100	3300

5.3 Chapter summary and conclusion

In this chapter the problems regarding the composition of the CHP data have been discussed. First, the conventions used to determine the condensed electricity produced by a CHP plant and the according inputs were discussed. And second it has been assessed whether small-scale CHP plants (CHP plants with an electrical capacity smaller than 1 MWe) contribute significantly to the electricity production of the United Kingdom, Germany and the Netherlands.

In general the electricity produced by a CHP plant is totally considered as CHP electricity, whenever the available heat produced is completely used. The electricity produced by a CHP plant consists of a share of condensed electricity, when the available heat is on purpose (partially) cooled away into the environment. In these cases the CHP electricity is calculated by multiplying the specific power to heat capacity ratio of a CHP plant with the total heat produced. The according inputs can proportionally be calculated, as a CHP plant uses all inputs to produce electricity.

To distinct between CHP plants that waste the available heat and that do not, in international statistics two objective conventions are used. The first is used by EUROSTAT and considers electricity produced by a CHP plant as CHP electricity, whenever the overall CHP plant efficiency is 75%. The second convention considers the electricity produced by a CHP plant as CHP electricity whenever the CHP plant has used less energy inputs to produce a certain amount of heat and electricity than alternative means would. This method is however not adequately, more complex and less consistent over a longer period. This method is used to compose CHP statistics of the United Kingdom.

These statistics were also used to assess the contribution of small-scale CHP to the British electricity production. The methods used to compose the German and Dutch small-scale CHP statistics are unknown. To assess whether small-scale CHP currently contribute significantly, i.e. for at least 5%, to the total electricity production in the three countries mentioned, their installed capacity and typical annual operating time have been deviated and estimated.

It followed that in the United Kingdom as well as in Germany their contribution is insignificant. Regarding the future contribution of small-scale CHP plants to the British and German electricity production in 2010 it has been concluded, that it will also be insignificant, due to a lack of capacity and presumably a small typical annual operating time with respect to an average power plant (Germany). In the Netherlands CHP plants with an electrical capacity up to 2 MWe contribute significantly to the electricity production from around 1995. Whether their contribution to the Dutch electricity production will also be significant in 2010 is uncertain. Anyway, if it is necessary to follow the developments in small-scale CHP, also for the other countries, it can be considered to introduce a sub-branch for small-scale CHP in the ODYSSEE database.

6 Allocating CHP in- to outputs

As has been outlined in sub-section 4.5.3, in this chapter the problem concerning the allocation of the aggregated CHP inputs to the outputs is addressed. This chapter has the objective to find a more appropriate method to allocate the CHP inputs to the outputs. It must however be noted, that the allocation of the CHP inputs between the electricity generated and available heat used is notional and not determinate, see M. Hinnells (20, page 9). Moreover A. Lambert denotes that any solution will always partially be subjective (25, page 145).

Before deciding to implement another method into the ODYSSEE database, the variety of possibilities to allocate the CHP input to the outputs have to be listed and evaluated. This leads to the following questions:

(1) What are the options to allocate the CHP inputs to the outputs of CHP?

(2) What are their advantages and disadvantages from a technical and policy point of view?

These questions are answered in the next sections. First an inventory is made of methods to allocate the CHP inputs to the outputs. Second the requirements are formulated which have to be fulfilled by the method to be chosen. Third, the allocation methods are assessed on the basis of the requirements defined. Fourth, on the basis of the assessment, a method is chosen to allocate the CHP input to the outputs. Finally the consequences of the method chosen for the database are discussed. The chapter ends with a section "chapter summary and conclusion".

6.1 Inventory of methods

In the next sub-sections, 5 methods (including the method currently used) to allocate the CHP inputs to the branches of CHP heat and electricity are listed. For each method it is briefly discussed how it weighs heat and electricity, as it influences the characteristics of the efficiency indicators (see section 4.5.2). Moreover, the formulas to determine the inputs for the branches of CHP heat and electricity are added for each method.

6.1.1 Method 1: Current method

As has been stated in sub-section 4.5.2, this method equally weighs heat and electricity, as the common CHP input (F_{CHP}) is split according to the share of the energetic content of each output in the common output. The common output is defined as the sum of the available heat used (pdvpthtw) and electricity (pdethtw) produced. The inputs attributed to the production of heat (invpthtw) and electricity (inethtw), are calculated as follows, see also M. Landwehr (26, page 14):

$$invpthtw = F_{CHP} * \frac{pdvpthtw}{pdvpthtw + pdethtw} \qquad \text{(eq. 6.1)}$$

$$inethtw = F_{CHP} * \frac{pdethtw}{pdvpthtw + pdethtw} \qquad \text{(eq. 6.2)}$$

6.1.2 Method 2: Artificial thermal input

For this method it is assumed, that the CHP input to supply the available heat used is equivalent to producing the same amount of heat in the best available comparator, see also M. Hinnells $^{(20,\text{ page } 9)}$ or J.H. Horlock $^{(21,\text{ page } 26)}$. The remaining portion of the CHP input is subsequent allocated to electricity generation. To apply this method in the ODYSSEE database, it could be assumed that the heat is produced by the mix of existing fossil thermal heat plants, captured in the branch of fossil thermal heat. The artificial heat input, is calculated as the quotient of the CHP heat (pdvpthtw) and the efficiency of the branch of fossil thermal heat (rdvpthtx). Accordingly the remaining portion of the CHP input is allocated to the branch of CHP electricity. Thus the inputs for CHP heat (invpthtw) and electricity (inethtw) are calculated as:

$$invpthtw = \frac{pdvpthtw}{rdvpthtx} \qquad \text{(eq. 6.3)}$$

$$inethtw = F_{CHP} - \frac{pdvpthtw}{rdvpthtx} \qquad \text{(eq. 6.4)}$$

6.1.3 Method 3: Artificial power input

In contrast with the previous method it is also possible to assume that the CHP input to supply electricity is equivalent to producing the same amount of electricity in the best available comparator, see also M. Hinnells $^{(20,\text{ page } 9)}$. The remaining portion of the CHP input is than allocated to the heat supply. To apply this method in the ODYSSEE database, it could be assumed that the electricity is produced by the mix of fossil thermal electricity plants captured in the branch of fossil thermal electricity. The artificial electricity input is calculated as the quotient of the CHP electricity (pdethtw) and the efficiency of the branch of fossil thermal electricity (rdethtx). Accordingly the remaining portion of the CHP input is allocated to the branch of CHP heat. Thus the CHP inputs (invpthtw and inethtw) are calculated as:

$$invpthtw = F_{CHP} - \frac{pdethtw}{rdethtx} \qquad \text{(eq. 6.5)}$$

$$inethtw = \frac{pdethtw}{rdethtx} \qquad \text{(eq. 6.6)}$$

6.1.4 Method 4: Relative efficiencies of separate heat and electricity

This method is a midway between method 2 and 3, see also M. Hinnells (20, page 9). It allocates the common CHP input (F_{CHP}) according to the respective share of the common input, that would have been used to produce the CHP heat (pdvpthtw) and power (pdethtw) by alternative means, i.e. fossil thermal heat and electricity plants. For application in the ODYSSEE database it is assumed, that the heat and electricity are produced in the existing mix of fossil thermal heat and electricity plants. The inputs attributed to the production of heat (invpthtw) and electricity (inethtw), are calculated as:

$$invpthtw = F_{CHP} * \frac{\frac{pdvpthtw}{rdvpthtx}}{\frac{pdvpthtw}{rdvpthtx} + \frac{pdethtw}{rdethtx}} \qquad \text{(eq. 6.7)}$$

$$inethtw = F_{CHP} * \frac{\frac{pdethtw}{rdethtx}}{\frac{pdvpthtw}{rdvpthtx} + \frac{pdethtw}{rdethtx}} \qquad \text{(eq. 6.8)}$$

6.1.5 Method 5: Allocation for Carnot heat engine

This method proportionally allocates the CHP inputs between the power produced and the power that could have been produced with the heat available for other processes. To determine the power that could have been produced with the available heat, the Carnot efficiency is used (see sub-section 3.1.1). Therefore it is assumed that the heat rejected from the CHP plant is delivered to an intermediate heat reservoir of temperature (T_H). The surroundings are assumed to be the heat reservoir of low temperature, which has a fixed temperature (T_0). These assumptions result in the following equations for the allocated fuel energy inputs:

$$invpthtw = F_{CHP} * \frac{pdvpthtw * \left(1 - \frac{T_0}{T_H}\right)}{pdethtw + pdvpthtw * \left(1 - \frac{T_0}{T_H}\right)} \qquad \text{(eq. 6.9)}$$

$$inethtw = F_{CHP} * \frac{pdethtw}{pdethtw + pdvpthtw * \left(1 - \frac{T_0}{T_H}\right)} \qquad \text{(eq. 6.10)}$$

From the methods to allocate the CHP inputs to the outputs discussed in the previous sub-sections one will be chosen and implemented into the ODYSSEE database. They are assessed on the basis of requirements, which are formulated in the next section.

6.2 Assessment requirements

The requirements to be discussed in this section are derived from conclusions in previous chapters regarding the data availability, the intended use of the indicators and the heterogeneous technical characteristics of CHP. The requirements are in the subsequent section used to assess the allocation methods previously discussed.

(1) Data availability:

In chapter 4 it has been concluded, that the current data situation regarding CHP is problematic. Moreover, according to EUROSTAT, the data requested from the plant operators should be kept as low and as simple as possible to avoid misinterpretations and to ensure a high response rate. It is therefore required that the data to be used are available and easily accessible. For the methods to be assessed this implies, that they may use the indicators and the branch input and output data to be stored in the proposed disaggregation of the ODYSSEE database, see section 4.5.3.

(2) Unambiguous assessment of efficiency indicators:

In section 4.5.2 it has been noted, that the current allocation method impedes the comparison of the efficiency indicators of CHP and fossil thermal heat and electricity plants regarding the supposed energy efficiency of CHP. Moreover that heat is by alternative means more efficiently generated than electricity. Thus the efficiency indicators have to reflect whether CHP produces more, equivalent or less output from one fuel energy input than fossil thermal plants and that it currently costs more energy to produce a unit of electricity than a unit of heat.

Besides this, the efficiency indicators have to comply with the first law of thermodynamics. This law explains that it is impossible to create a device, which would create work, other forms of energy or mass from nothing (see also section 3.1). These three requirements regarding the efficiency indicators are summarised as (for abbreviations see figure 4.4):

a) $\left.\begin{array}{lll} \text{rdethtw} & > & \text{rdethtx} \\ \text{rdvpthtw} & > & \text{rdvpthtx} \end{array}\right\}$ If CHP plants produce more energy output from one energy input compared to fossil thermal heat and electricity plants

$\left.\begin{array}{lll} \text{rdethtw} & = & \text{rdethtx} \\ \text{rdvpthtw} & = & \text{rdvpthtx} \end{array}\right\}$ If CHP plants produce an equal amount of energy output from one energy input compared to fossil thermal heat and electricity plants

$\left.\begin{array}{lll} \text{rdethtw} & < & \text{rdethtx} \\ \text{rdvpthtw} & < & \text{rdvpthtx} \end{array}\right\}$ If CHP plants produce less energy output from one energy input compared to fossil thermal heat and electricity plants

b) $\text{rdvpthtw} > \text{rdethtw}$ if $\text{rdvpthtx} > \text{rdethtx}$

c) $\text{rdvpthtw} \leq 1$ & $\text{rdethtw} \leq 1$

(3) Avoid double counting of inputs:

In sub-section 4.5.2, it has been explained that the CHP inputs had to be allocated in order to avoid double counts on the overall transformation level. Thus the sum of the allocated inputs, calculated for respectively CHP heat and power, must be equal to the total CHP input.

(4) No complex theory for the allocation of the inputs:

In section 1.2 and 4.1 it has been explained, that the indicators are used for the analysis of the energy efficiency, which is a relatively simple concept. It is therefore required, that a complex technical analysis is avoided, as it would impede a quick and understandable analysis of the efficiency indicators.

6.3 Assessment of methods

In the next five sub-sections, the methods to allocate the CHP inputs to the outputs (see section 6.1) are assessed on the basis of the requirements defined in the previous section.

6.3.1 Method 1: Current method

(1) Data availability

This method uses fundamental data (CHP input and output), which have to be implemented in the ODYSSEE database to be able to calculate the different indicators. Thus it is assumed, that all the necessary data are available.

(2) Unambiguous assessment of efficiency indicators

The efficiency indicators for CHP heat and electricity are defined analogue to those defined in sub-section 4.3.1 (see also section 4.5.3). However for CHP the inputs have to be substituted by the allocated CHP inputs, for this method they follow respectively from equation 6.1 and 6.2. The results are:

$$rdvpthtw = \frac{pdvpthtw}{F_{CHP} * \dfrac{pdvpthtw}{pdvpthtw + pdethtw}} = \frac{pdvpthtw + pdethtw}{F_{CHP}} \qquad \text{(eq. 6.11)}$$

$$rdethtw = \frac{pdethtw}{F_{CHP} * \dfrac{pdethtw}{pdvpthtw + pdethtw}} = \frac{pdvpthtw + pdethtw}{F_{CHP}} \qquad \text{(eq. 6.12)}$$

Thus, as already has been stated in sub-section 4.5.2, both the CHP heat and electricity efficiency are equal and equivalent to the overall CHP efficiency. On the basis of an example it is subsequently explained, that the implementation of the current allocation method leads to contradictory conclusions, whenever comparing the CHP and fossil thermal efficiency indicators. The figures used are depicted in table 6.1 on the next page.

According to the method discussed CHP heat and electricity would both have a notional efficiency of 79% (equal to the overall CHP efficiency). Compared to the efficiencies of fossil thermal heat and electricity generation, CHP heat seems to be generated less efficient than heat in a boiler and CHP electricity seems to be generated much more efficient than electricity in a high performance combined gas and steam cycle. Despite the fact that, the overall CHP efficiency is higher than the combined efficiency of fossil thermal heat and electricity, see table 6.1. Thus the comparison of the CHP and fossil thermal efficiency indicators is not unambiguously.

Table 6.1: Comparison of efficiencies (Source: AGFW (1, page 58 and 60))

	Input (GWh)	Output (GWh)		Overall Efficiency	Combined Efficiency
		Heat	Electricity		
CHP	133918	72522	33250	0,79	0,79
Boilers	85320*	72522*		0,85	0,73
Combined gas and steam cycle	57826*		33250*	0,575	

(* Calculated for the case that the boilers and Combined gas and steam cycle plants would produce an equal amount of heat and electricity as the CHP plants)

Summarising, this method does not comply with the requirements 2a and b. It, however, does comply with requirement 2c, as according to the first law of thermodynamics the ideal overall efficiency of CHP can maximally be 1.

(3) Avoidance of double counting of inputs

As the inputs are allocated according to the share of each output in the total output, the sum of the allocated inputs is equal to the total energy input. Thus there is no double counting of inputs on the overall transformation level.

(4) Understandable methodology

This method avoids a complex technical analysis of the mix of CHP plants, as it only uses the aggregated CHP input and output data. It does therefore not impede a quick and understandable analysis of the efficiency indicators.

6.3.2 Method 2: Artificial thermal input

(5) Data availability

This method uses fundamental data (CHP input and output), which have to be implemented in the ODYSSEE database to be able to calculate the different indicators. Moreover the efficiency of fossil thermal heat generation follows directly from the ODYSSEE database according to the proposed disaggregation. Thus it is assumed, that all the necessary data are available.

(6) Unambiguous assessment of efficiency indicators

From the introduction to this methodology it follows that, due to the assumption that the CHP heat could have been produced by the mix of existing fossil thermal heat plants, the indicator for the efficiency of the CHP heat generation equals the one of fossil thermal heat. In ODYSSEE terms this means that: rdvpthtw = rdvpthtx and consistently, that their reverses (the unit consumptions) are equally, ucvpthtw = ucvpthtx. Subsequent, the CHP electricity efficiency is calculated as:

$$rdethtw = \frac{pdethtw}{F_{CHP} - \dfrac{pdvpthtw}{rdvpthtx}} \qquad \text{(eq. 6.13)}$$

Since the heat efficiency is equal for CHP and fossil thermal heat and therefore equivalent to 85%, it follows that potential energy savings are completely allocated to the CHP electricity production and only depicted in the efficiency indicator for CHP electricity. This is clarified by substituting the data from table 6.1 in equation 6.13. It follows that the efficiency indicator for CHP electricity would be 0,684, which is 19% higher than efficiency indicator for fossil thermal electricity.

Moreover it follows from equation 6.13, that the efficiency indicator for CHP electricity is indefinite whenever the CHP heat yield (for a definition see sub-section 5.1.3) is equal to the efficiency of fossil thermal heat plants. This is also illustrated in figure 6.1, which has been made in MS Excel 97 with the array function for all possible combinations of CHP heat and power yields. The reference efficiency for fossil thermal heat has been set at 0,85.

The purple area in figure 6.1 indicates CHP electricity efficiencies higher than 1. The red line indicates whenever CHP is as efficient as fossil thermal heat and electricity and the efficiency indicator of CHP electricity is equivalent to the one of fossil thermal electricity, in this case 57,5%. Above this red line CHP is more efficient than fossil thermal heat and electricity.

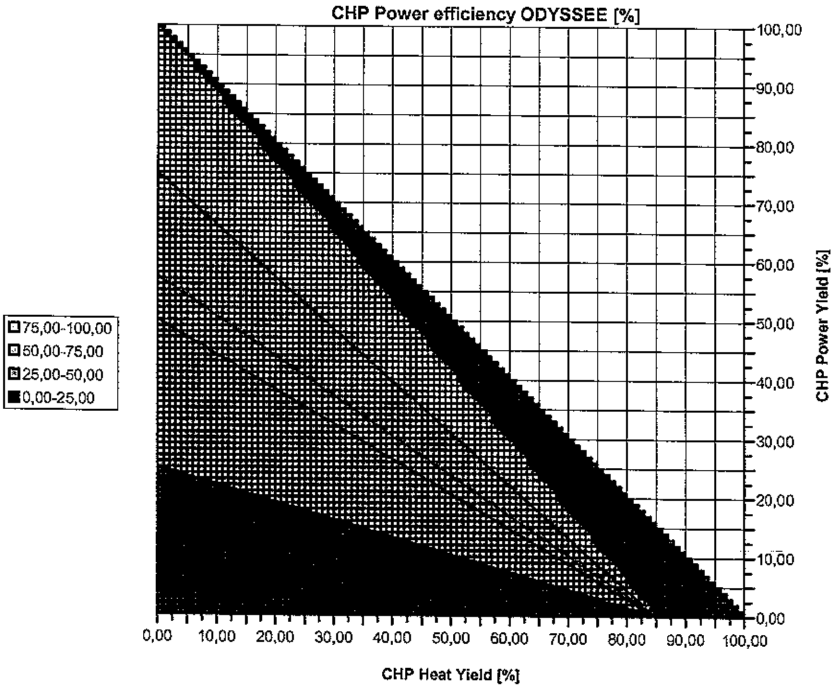

Figure 6.1 ODYSSEE CHP electricity efficiency, method 2

From figure 6.1 it moreover also, that whenever overall CHP efficiency (sum of both the CHP heat and power yield) is constant and the power yield increases, the efficiency of CHP electricity decreases until the heat yield is 0,85. This is not desirable, as it currently costs more to produce a unit of electricity by alternative means and whenever it is possible to produce more electricity with an equal amount of input it should be appreciated.

On the basis of the previous considerations it is concluded, that this method does not comply with the efficiency requirements, because potential energy savings are not attributed to CHP heat as well as electricity. Which moreover causes that, depending on the reference efficiencies of fossil thermal heat and electricity and the potential energy savings obtained by applying CHP, the efficiency of CHP heat may be lower than that of CHP electricity and the efficiency of CHP electricity can be larger than 1.

(7) Avoidance of double counting of inputs

The sum of the allocated fuel inputs is equal to the total energy input, as first the portion allocated to the heat production is calculated and second the remaining portion is allocated to the electricity production.

(8) Understandable methodology

This method avoids a complex technical analysis of the mix of CHP plants, as it only uses the aggregated CHP input and output data and the efficiency for the mix of current heat generation. It does therefore not impede a quick and understandable analysis of the efficiency indicators.

6.3.3 Method 3: Artificial power input

Compared to the previous method only the point of view for the reference taken differs, in stead of assuming that the heat is produced by alternative means it is assumed that the electricity is produced by alternative means. Although the calculations are reversed (compare section 6.1.2 and 6.1.3) and the reference efficiency is different, the assessment of this method is analogously. For example, the reference efficiency for fossil thermal electricity follows from the proposed disaggregation of the transformation sector and whenever the power yield is equal to or larger than the efficiency of fossil thermal electricity plants the heat efficiency is indefinite. Therefore the assessment is as follows summarised:

(1) Data availability: It is assumed that all the necessary data are available.

(2) Unambiguous assessment of efficiency indicators: This method does not comply with the efficiency requirements.

(3) Avoidance of double counting of inputs: There is no double counting of inputs on the overall transformation level.

(4) Understandable methodology: This method does not impede a quick and understandable analysis.

6.3.4 Method 4: Relative efficiencies of separate heat and power

(1) Data availability

This method uses fundamental data (CHP input and output), which have to be implemented in the ODYSSEE database to be able to calculate the different indicators. Moreover, the efficiencies of fossil thermal heat and electricity follow directly from the ODYSSEE database according to the proposed disaggregation of the transformation sector. It is therefore assumed, that all the necessary data are available for the calculations.

(2) Unambiguous assessment of efficiency indicators

As has been stated in sub-section 6.3.1, the efficiency indicators for CHP heat and electricity are defined analogue to those defined in sub-section 4.3. However for CHP the inputs have to be substituted by the allocated CHP inputs, for this method they follow respectively from equation 6.7 and 6.8.

To examine the consequences of the results obtained, the CHP efficiencies for heat and electricity are calculated with the array function in MS Excel 97. The calculations have been made for all possible combinations of CHP heat and power yields. Moreover the calculations have been made with the reference efficiencies of 0,85 and 0,575 for respectively fossil thermal heat and electricity generation, see also table 6.1. The results are respectively depicted in figure 6.2 below and 6.3 on the next page. The red lines indicate whenever CHP is as efficient as fossil thermal heat and electricity and the efficiencies of CHP heat and electricity are equivalent to those of fossil thermal heat and electricity, respectively of efficiency 0,85 and 0,575. The purple area in the figure below indicates CHP heat efficiencies higher than 1.

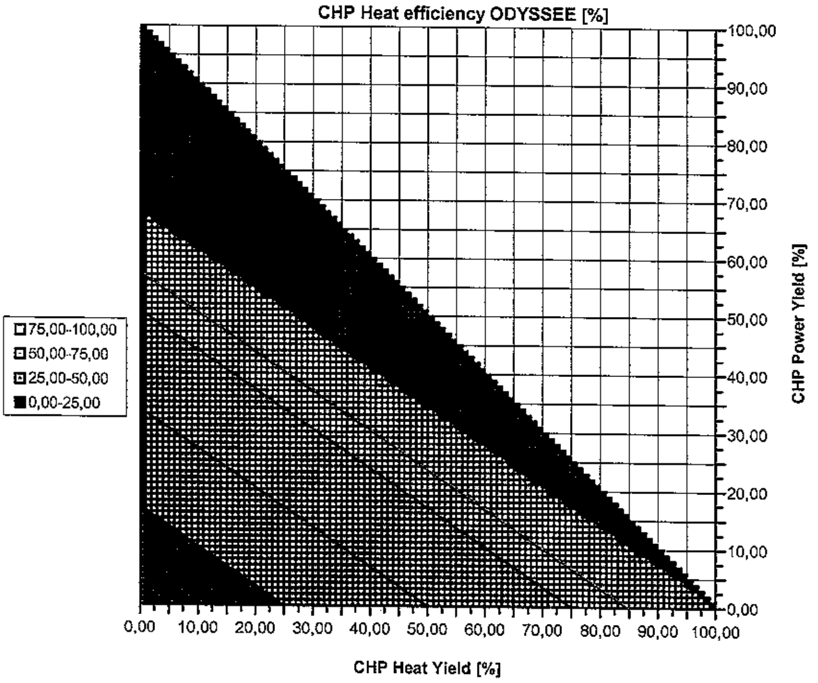

Figure 6 2 ODYSSEE CHP heat efficiency, method 4

It follows from a comparison of these figures that in any case the CHP heat efficiency is higher than the efficiency of CHP electricity. It also follows, that whenever overall efficiency of CHP (sum of both the CHP heat and power yield) is constant and the power yield increases, the efficiency of CHP electricity increases. This is desirable, as this method appreciates whenever more electricity is produced by CHP with an equal amount of input, this in contradiction to method 2 (Artificial thermal input).

However from figure 6.2 it also follows, that with the current reference efficiencies chosen the efficiencies of CHP heat could be larger than 1 for a range of combinations of CHP heat and power yields. This is acceptable, as it is the heat, which is recovered in a CHP plant, see section 3.1.1.

It is therefore concluded that this method complies with the efficiency criteria set, as it from both CHP heat and efficiency indicators follows whether CHP has been more efficient than fossil thermal heat and electricity. Moreover the efficiency of CHP heat is larger than CHP electricity as long as costs more to produce a unit of electricity than a unit of heat by fossil thermal means.

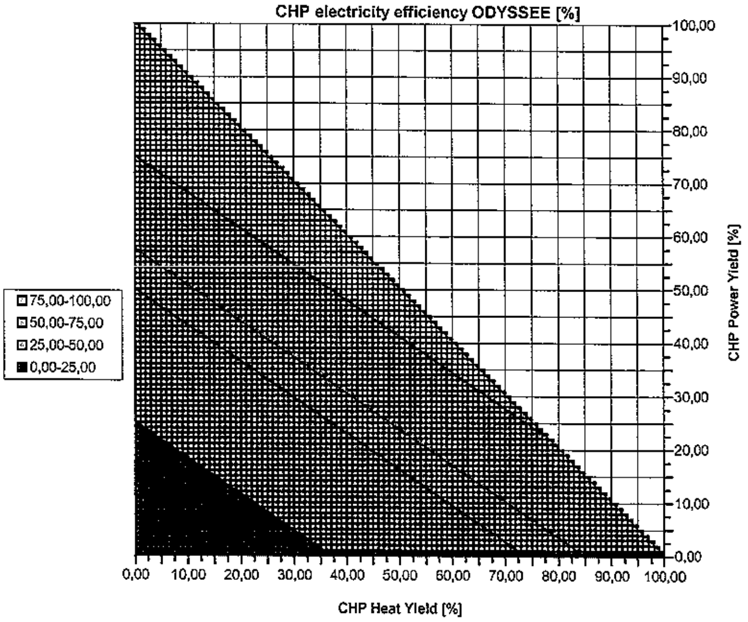

Figure 6 3 ODYSSEE CHP power efficiency, method 4

(3) Avoidance of double counting of inputs

As the inputs are allocated according to the share of each output in the total output, the sum of the allocated fuel inputs is equal to the total energy input. Thus there is no double counting of inputs on the overall transformation level.

(4) Understandable methodology

In section 1.2 and 4.1 it has been explained, that the indicators are used for the analysis of the energy efficiency, which is a relatively simple concept. It is therefore required, that a complex technical analysis is avoided, as it would impede a quick and understandable analysis of the efficiency indicators.

6.3.5 Method 5: Allocation for Carnot heat engine

(1) Data availability

This method uses fundamental data (CHP input and output), which have to be implemented in the ODYSSEE database to be able to calculate the different indicators. However also temperature data should be available.

These are currently not gathered by the national statistics institutes or EUROSTAT, as the data requested from the plant operators should be kept as low and as simple as possible to avoid misinterpretations and to ensure a high response rate. Therefore they cannot be stored in the ODYSSEE database.

Conclusion, the necessary data and especially the temperature data are not available for the calculations. As the data are not available, no test of efficiency indicator has been undertaken.

(2) Unambiguous assessment of efficiency indicators

Not tested.

(3) Avoidance of double counting of inputs

As the inputs are allocated according to the share of each output in the total output, the sum of the allocated fuel inputs is equal to the total energy input. Thus there is no double counting of inputs on the overall transformation level.

(4) Understandable methodology

The method is understandable as it tries to weigh heat and power on an equal scale, the ability to perform work. But the heat rejected from a CHP unit is used as process heat and won't be transformed into work, which makes this methodology somehow irrelevant.

6.4 Selection of a method

In the preceding section five methods to allocate the aggregated CHP inputs to the outputs have been discussed on the basis of the requirements defined in section 6.2. In this section an allocation method is chosen, which can be implemented in the ODYSSEE database and allows a comparison between CHP and fossil thermal heat and electricity. Therefore the foregoing section is summarised in the table 6.2, which is depicted on the next page. This table shows the scores of each method on each requirement defined in sub-section 6.2. The scores in this table form the basis for the selection of a method to allocate the inputs to the outputs in the ODYSSEE database.

Table 6.2: Selecting a method to allocate the CHP inputs to the outputs

		Method 1 (Current method)	**Method 2** (Artificial thermal efficiency)	**Method 3** (Artificial power efficiency)	**Method 4** (relative efficiencies of separate heat and power)	**Method 5** (Allocation for Carnot engine)
Data Availability		Data in proposed database	Data in proposed database	Data in proposed database	Data in proposed database	Data not in database
Unambiguous assessment of efficiency indicators	*Comparison of CHP and fossil thermal efficiency indicators*	Contradictory conclusions	Contradictory conclusions	Contradictory conclusions	No-contradictory conclusions	Not tested
	rdvpthtw > rdethtw	Equal	Depends on references and CHP heat and power yields	Depends on references and CHP heat and power yields	if rdvpthtx > rdethtx	Not tested
	rdvpthtw ≤ 1	Yes	Yes	Depends on references and CHP heat and power yields	Depends on references and CHP heat and power yields	Not tested
	rdethtw ≤ 1	Yes	Depends on references and CHP heat and power yields	Yes	Yes, if rdethtx < rdvpthtx	Not tested
Avoid double counting of inputs		All methods do not double count the inputs F_{CHP} = invpthtw + inethtw				
Understandable methodology		Yes	Yes	Yes	Yes	Yes, but irreleveant

From this table it follows that only for one method the data are not available, viz. method 5, which has therefore not been assessed on the efficiency criteria. Besides it follows that none of the other methods fulfils all the criteria set for an unambiguous assessment of CHP. Method 4 however, fulfils as only method the sub-criteria of an unambiguous assessment of the efficiency indicators. Thus it is the only method that allocates potential energy savings to as well CHP heat and electricity, which is visible whenever comparing the efficiency indicators of CHP heat and electricity with those of fossil thermal heat and electricity.

Regarding the maximum of 1 set for as well as the CHP heat and electricity efficiency indicators, only the current method fulfils both criteria independent of the fossil thermal reference efficiencies set and the CHP heat and power yields. For the other the methods 2,3 and 4 the results depend on (1) the reference efficiencies of fossil thermal heat and electricity and (2) the CHP heat and power yields. Regarding the last two requirements, no double counting of inputs and understandable methodology, there are no differences between methods 1 to 4. Only the last method is considered as irrelevant.

On the basis of the previous assessment it is concluded, that method 4 is the best alternative to be implemented into the ODYSSEE database. It is the only method that does not lead to contradictory conclusions regarding the comparison of the CHP and fossil thermal efficiency indicators. However the use of reference efficiencies which may be held constant or that annually vary, has consequences for the analysis of the course of the efficiency indicators over time. These consequences are discussed in the next section.

6.5 Consequences for the database

In the previous section method 4 has been selected to allocate the CHP inputs to the outputs. This method uses reference efficiencies for both fossil thermal heat and electricity to determine the notional CHP heat and electricity inputs. With these allocated inputs the CHP efficiency indicators are calculated according to the proposed disaggregation of the transformation sector, as discussed in sub-section 4.5.3. However as the ODYSSEE database concerns a yearly energy assessment, the indicators stored may annually vary.

Whenever the CHP efficiency indicators are computed with these annually varying fossil thermal indicators, the developments in the CHP efficiency indicators of a country cannot be assessed over time, nor can these CHP indicators be compared with those of other countries. It makes only sense, to compare the obtained CHP efficiency indicators with the fossil thermal heat and electricity efficiency indicators with which they have been computed. The differences between these indicators reflect the relative annual savings obtained by using CHP to produce a certain amount of heat and electricity instead of using the mix of fossil thermal alternatives.

To obtain CHP efficiency indicators, which are comparable over time, the reference efficiencies of fossil thermal heat and electricity should be kept constant over time with respect to those of a reference year of a country. A comparison of these CHP indicators would reflect the CHP efficiency improvements over time within the specific country (see also sub-section 6.3.4). Moreover these indicators reflect the savings obtained, by producing a certain amount of heat and electricity with CHP, in stead of the mix of fossil thermal alternatives with respect to the reference year in that specific country.

However to make a comparison of the developments in CHP efficiency between countries, it is necessary to equalise the reference efficiencies of fossil thermal heat as well as those of fossil thermal electricity throughout the EU. For example by using the efficiency indicators of fossil thermal heat and electricity on the European level to calculate the CHP efficiency indicators for all member states.

These three kinds of CHP efficiency indicators reflect valuable information. Therefore it is proposed to implement them into the ODYSSEE database. In the next chapter the actual data availability is discussed, to determine whether the proposed disaggregation of the ODYSSEE database can be implemented and the different indicators, especially the shares and efficiencies, can be calculated. If the actual data situation allows the computation of the indicators of CHP and fossil thermal heat and electricity, then they are calculated on the basis of the allocation method chosen.

6.6 Chapter summary and conclusions

In this chapter a method has been chosen to allocate the aggregated CHP inputs to the branches of CHP heat and electricity. Therefore five alternatives have been discussed and assessed on the basis of four requirements, viz. data availability, unambiguous assessment of efficiency indicators, double counting of inputs and understandable methodology.

From the assessment it followed, that there were no differences between the five methods regarding the double counting of inputs and understandable methodology. Although one method is unusable as it weighs heat and electricity on the basis of the ability to perform work, after all the heat produced by a CHP plant is not transformed into work, i.e. electricity. Moreover, the data, to calculate the efficiency indicators with this allocation method, are not available.

For the methods 1 to 4 it is assumed that all the data are available, as the data should be stored in the database according to the proposed disaggregation discussed in sub-section 4.5.3. Therefore the selection made between these methods is to a large extend based on the performance of the methods 1 to 4 on the requirements defined for an unambiguous assessment of the efficiency indicators.

The method chosen allocates the CHP inputs according to the share that would have been used by the mix of fossil thermal alternatives to produce the same amount of heat and electricity, as produced by CHP. Therefore it allows for an unambiguous comparison of the actual fossil thermal and CHP heat and electricity efficiency indicators. Moreover, it causes that the efficiency indicator for CHP heat will always be larger than that for CHP electricity, as long as it costs more energy to produce electricity than heat by alternative fossil thermal means.

However the CHP heat efficiency indicator can be larger than 1. Although it is inconsistent with the first law of thermodynamics, it is accepted as the heat is recovered in a CHP process. It should moreover, be noted that the CHP efficiency indicators to be implemented into the ODYSSEE database do not assess the overall CHP process.

Besides, the implementation of allocation method 4 requires the use of three kinds of CHP efficiency indicators. To calculate the first kind, the actual fossil thermal efficiencies are used. These CHP indicators reflect the actual savings obtained by using CHP in stead of the mix of fossil thermal alternatives. To calculate the second kind, the efficiencies of fossil thermal heat and electricity are kept constant over time. These CHP indicators reflect the CHP efficiency improvements over time. Moreover they reflect the savings obtained by the application of CHP in stead of the mix of fossil thermal alternatives with respect to a reference year. The third kind allows a comparison of the developments in CHP efficiency between countries, as constant reference efficiencies of fossil thermal heat as well as those of fossil thermal electricity are used for all countries.

7 Data and computation of indicators

In sub-section 4.5.3 it was proposed to expand the system of indicators of the ODYSSEE database for the transformation with branches for CHP heat and electricity by splitting them off the branches for fossil thermal heat and electricity. Therefore it was subsequently concluded that to be able to implement this proposed disaggregation, the in- and output data for CHP as well as those of fossil thermal heat and electricity have to be separately available. This in order to be able to calculate the different indicators. Though according to the current disaggregation of the transformation sector these data are not separately stored. Therefore in the next section the data availability for the United Kingdom, the Netherlands and Germany is discussed, as the research has been delimited to these countries. In the subsequent sections the techno-economic ratios are calculated, for the countries for which the data are available. The chapter ends with a "chapter summary and conclusion".

7.1 Data and sources

To analyse the developments in a transformation sector of a country and compare these between countries, the aggregated data to be used in the database should ideally fulfil the following two conditions:

(1) Aggregated data should concern a well-defined population, if possible according to the branches discerned in the database;

(2) Aggregated data should be composed on the basis of a common methodology according to an unambiguous definition of subjects measured.

To fulfil the second condition it is preferred to use data of the transformation sector as published by an international or supranational office, such as the IEA (International Energy Agency) or EUROSTAT, the European Union Statistics Office. These offices publish energy data according to a common methodology for all member states.

In section 1.1 it has been noted that EUROSTAT is commissioned to gather the CHP statistics of the EU member states. Therefore in the next sub-section the composition of the data of the energy-supplied balance sheets and CHP of EUROSTAT are discussed. It will however turn out that the data from fossil thermal heat and electricity cannot be separated from those of CHP. Therefore more specific data have been sought, to be able to calculate the indicators for fossil thermal heat and electricity. The national statistic institutes publish more specific data, e.g. for the United Kingdom in the "Digest of United Kingdom Energy Statistics" (9) and for the Netherlands on STATLINE (w15). For Germany no additional data are available, therefore only those of the United Kingdom and the Netherlands are discussed in the sub-sections subsequently following that of the EUROSTAT data.

7.1.1 EUROSTAT data

EUROSTAT acquires its data from the national statistic institutes according to a common methodology defined by EUROSTAT. In this sub-section the composition of the in-and output data of CHP and fossil thermal heat and electricity from the energy-supplied balance sheets and the CHP survey of 1994 to 1998 are discussed.

In the document "Principles and methods of the energy balance sheets" the composition of the energy-supplied balance sheets as published by EUROSTAT is explained (15, page 11 ff.). In the energy-supplied balance sheets the lines for the aggregated in- and outputs of conventional thermal power stations include the figures for electricity production as well as for commercialised steam. Thus the figures for CHP and fossil thermal heat and electricity are not reported separately.

Moreover the transformation output always includes own consumption of transformation plants. Thus only the energy outputs supplied, e.g. to the electricity grid are reported, although the gross energy outputs produced should ideally be used in the ODYSSEE database, see figure 4.2. On the basis of the previous considerations it is concluded, that the supplied balance sheets, as published by EUROSTAT, cannot be used to acquire the in- and output data of the fossil thermal and CHP branches discerned in the ODYSSEE database and subsequent to calculate the indicators defined. Or, according to EUROSTAT, the statistical system did not allow an adequate assessment of the CHP production at the European level before the survey made from 1994 to 1998.

The CHP data of this survey concern among others, aggregated data of the total CHP input and the electricity and heat produced. The population of CHP plants included in this survey, was restricted to plants with an electrical capacity of at least (16, page 5):

- 1 [MW] for plants based on steam turbines;
- 0,5 [MW] for plants based on gas turbines;
- 0,1 [MW] for plants based on internal combustion engines.

Moreover a correction has been made for the condensed electricity produced by CHP plants. The correction made has briefly been discussed in sub-section 5.1.1. It was concluded that the correction applied consists of questionable elements, e.g. the threshold criteria to distinguish condensed electricity produced by a CHP plant from pure CHP electricity.

Unless the corrected in- and output fossil thermal data (i.e. those including the condensed electricity produced by a CHP plant and the according inputs used) are available, these CHP data cannot be used in the ODYSSEE database. They can however be used in this project to qualitatively assess the developments in the share of CHP electricity in the total electricity production in the next chapter. As these data are based on the same definition they allow a comparison of the figures of the different countries. In the next sub-sections the data of the United Kingdom and the Netherlands are discussed, to be able to calculate their efficiency indicators.

7.1.2 DTI: Data of the United Kingdom

In chapter 5 of the Digest of United Kingdom Energy Statistics 2001 the statistics on electricity from generation to sales are published as at the end of each year. Subsequent in chapter 6, the CHP inputs and the contribution of CHP to the heat and power production of the United Kingdom are reported as at the end of each year. Statistics about the heat production by fossil thermal means, e.g. boilers, are not reported in the digest. Therefore only the derivation of the gross aggregated in- and output data of fossil thermal electricity is discussed in this sub-section.

Chapter 6 of the Digest of United Kingdom Energy Statistics (DUKES) 2001 includes only the CHP figures that qualify as good quality CHP, see sub-section 5.1.3 for an explanation. Table 6.3 of the DUKES 2001 gives the overall good quality CHP input, whereas tables 6.6 and 6.4 respectively give the gross CHP heat produced and the gross good quality CHP electricity produced. The electricity used on works is not reported and therefore the gross CHP input cannot be derived from the available statistics. All electricity produced by CHP plants is included in chapter 5 of the DUKES 2001.

In order to provide a comprehensive picture of the electricity generation in the United Kingdom, the CHP input is in the statistics allocated between the CHP heat and electricity produced, on the basis of a convention, whereby a CHP plant displaces a heat-only-boiler plant with an overall efficiency of 75%. This method is similar to method 2 “Artificial thermal input” as discussed in sub-section 6.1.2.

To obtain the aggregated input data of fossil thermal electricity, the allocated CHP electricity inputs (inethtw_ETSU) have to be subtracted from the total thermal input (inethtx_ETSU). In table 5.6 the nuclear inputs (inenu) are also included in the total thermal input, they should therefore also be subtracted. Moreover the electricity used on works is reported in table 5.6. Thus the gross fossil thermal input can be approximated on the basis of this table. Approximated, because the electricity used by CHP plants is included in this table and cannot be subtracted, as it is not separately reported in chapter 6 of the digest. The computed gross fossil thermal electricity inputs (inethtx) from 1996 to 2000 are in table 7.1 below.

Table 7.1: Computation of inputs of fossil thermal electricity, in GWh (UK)

	1996	**1997**	**1998**	**1999**	**2000**	**Digest**
inethtx_ETSU	917084	905367	929808	912495	925110	table 5.6
inethtw_ETSU	-27693	-30146	-31477	-33822	-37148	table 6.2
inenu	-257953	-267428	-272642	-258372	-228355	table 5.6
used on works total	17610	16409	17284	16561	16141	table 5.6
used on works nuclear	-8851	-8805	-8896	-7641	-6729	table 5.6
inethtx	*640197*	*615397*	*634077*	*629401*	*669013*	

The gross fossil thermal electricity (pdethtx) can be derived from table 5.6 by subtracting the nuclear electricity (pdenu) and good quality CHP electricity

(pdethtw) from the total electricity of thermal sources (pdethtx_ETSU). The gross fossil thermal electricity is computed from 1996-2000 in table 7.2 on the next page.
Table 7.2: Computation of fossil thermal electricity, in GWh (UK)

	1996	**1997**	**1998**	**1999**	**2000**	**Digest**
pdethtx_ETSU	345110	342129	355102	395250	366149	table 5.6
pdenu	-94671	-98146	-99486	-95133	-85063	table 5.6
pdethtw	-16079	-16949	-18835	-20477	-23295	table 6.4
pdethtx	234360	227034	236781	279640	257791	

Thus data of fossil thermal and CHP electricity as well as of CHP heat are available. There are however still some lacunae, which impede the computation of all the according indicators. First, there are no in- and output data available of fossil thermal heat and the according indicators cannot be calculated, among other indicators the efficiency of fossil thermal heat. As has been mentioned in section 6.5, this indicator is necessary to allocate the CHP inputs and therefore to calculate the CHP efficiency indicators. Assuming that the efficiency of generating fossil thermal heat is 75%, as has been done in the digest, might be a solution for this problem.

Second, the CHP electricity data are based on a complex method which may change over time and the CHP inputs are disputable composed (see sub-section 5.1.4). Therefore also the validity of the fossil thermal electricity data and subsequent the according indicators is influenced. And third, the gross input data of CHP are not available for the UK, which influences the outcomes of the CHP efficiency indicators. The computation of the efficiency indicators of CHP and fossil thermal heat and electricity is discussed in the next section, however firstly in the next sub-section the data available from the Dutch energy statistics are discussed.

7.1.3 CBS: Data of the Netherlands

The Dutch energy statistics are gathered by the CBS and are published according to a certain methodology to assure the continuity in the time series. According to J. Kloots of the CBS, the Dutch energy statistics gathered do not concern fossil thermal heat, only the heat produced by CHP plants.

Moreover it follows from the Dutch energy balance sheets that no distinction is made between CHP and fossil thermal electricity, see e.g. those published on STATLINE (w15). This distinction is only made for the electricity plants, whose electricity production was not co-ordinated by the so-called Samenwerkende Elektriciteitsbedrijven (SEP) before the liberation of the Dutch power market.

It is therefore concluded that it is not possible to separate the data of the fossil thermal electricity and those of CHP. As a consequence no data are available to calculate the indicators for the Netherlands according to the proposed disaggregation of the transformation sector, see sub-section 4.5.3. The indicators that can be computed with the data available are discussed in the next sections.

7.2 Efficiency indicators: the United Kingdom

In the previous section the data available from EUROSTAT, DTI and the CBS have been discussed. It follows that only for the United Kingdom the efficiency of fossil thermal electricity generation can be computed with the data available. However, the notional input and efficiency of CHP heat and electricity in the United Kingdom can only be calculated, if an assumption is made regarding the efficiency of fossil thermal heat generation. Therefore the computation of the efficiency indicators of fossil thermal heat and electricity is firstly discussed.

Then, according to section 6.5 three kinds of CHP efficiency indicators have to be calculated. First, the CHP inputs have to be calculated on the basis of the actual efficiencies of fossil thermal heat and electricity. In the second and third case, the CHP inputs have to be calculated on the basis of constant efficiencies of fossil thermal heat and electricity respectively for a country and throughout the EU. The indicators of the third kind are not computed, as currently an international comparison between CHP efficiency indicators is not possible due to the fact that only the data are available for the United Kingdom. Thus in the sub-sections two and three the "actual" and "constant" efficiency indicators for CHP are computed, according to those proposed in section 6.5.

7.2.1 Efficiency indicators of fossil thermal heat and electricity

In this sub-section first the efficiency indicators of fossil thermal electricity in the United Kingdom are calculated on the basis of the fossil thermal electricity in- and outputs derived in sub-section 7.1.2. Next an assumption is discussed regarding the efficiency of fossil thermal heat, with which subsequent the CHP efficiency indicators are calculated. The calculations are made on the basis of the data reported in the Digest of United Kingdom Energy Statistics 2001.

The efficiency indicators of fossil thermal electricity, i.e. the unit consumption (cuethtx) and the efficiency (rdethtx) see sub-section 4.3.1, can easily be calculated on the basis of the data in table 7.1 and 7.2. Because the efficiency is the ratio of the output (pdethtx) and the input (inethtx) and the unit consumption is its reverse, see sub-section 4.3.1. The indicators are computed in table 7.3 on the next page. The efficiency indicator computed for fossil thermal electricity can now be used to calculate the allocated inputs of CHP heat and electricity and the according efficiency indicators. However the efficiency for fossil thermal heat has to be estimated first.

Table 7.3: Computation of efficiency indicators of fossil thermal electricity UK

	1996	**1997**	**1998**	**1999**	**2000**
pdethtx (GWh)	234360	227034	236781	243640	257791
inethtx (GWh)	640197	615397	634077	629401	669013
cuethtx	*2,73*	*2,71*	*2,68*	*2,58*	*2,60*
rdethtx	*0,36*	*0,37*	*0,37*	*0,39*	*0,39*

According, to M. Hinnells recent survey work by ETSU for the department of the Environment, Transport and the Regions shows a fossil basket of 8% coal, 31% oil and 61% natural gas in the stock of boilers at present in the UK. Moreover they respectively have on average an efficiency of 70%, 74% and 76% (20, page 4 ff). From these data a weighed average boiler efficiency is calculated of 75%, which may increase marginally over time. An increase as, according to M. Hinnells, new natural gas boilers can achieve around 80% efficiency, based on the gross calorific value (GCV) of the fuel used. The efficiencies based on the GCV may be 6 to 10 percentage points lower than efficiencies based on the net calorific value.

According to M. Hinnells there are two reasons why the increase in boiler efficiency is marginally, see M. Hinnells (20, page 5). First a boiler replacement does not happen quickly, because boilers may remain in stock for 40 years or more. Second, the potential of switching fuels to natural gas is limited by the prohibitive cost where a site is not very close to a gas main (£0,4 million per kilometre at 1999 prices). Therefore the allocated inputs and the efficiencies of CHP heat and electricity are in the next two sub-section calculated with a constant efficiency of 75% for fossil thermal heat generation.

7.2.2 Actual CHP efficiency indicators

The notional inputs of CHP heat and electricity are in all cases computed, by substituting the reference efficiencies of fossil thermal heat and electricity, the total CHP input (F_{CHP}) and the CHP heat and electricity produced (pdvpthtw and pdethtw), into respectively equations 6.7 and 6.8 (see also section 6.4). The according efficiency indicators can be calculated on the basis of the definitions discussed in sub-section 4.3.1. The results, i.e. the notional CHP heat and electricity inputs and efficiency indicators on the basis of the actual fossil thermal electricity indicator (see table 7.3) are in table 7.4 below.

Table 7.4: Computed "actual" CHP inputs and efficiency indicators (UK)

	1996	**1997**	**1998**	**1999**	**2000**	**Digest**
pdvpthtw (GWh)	63634	61775	62801	61203	61513	table 6.6
invpthtw (GWh)	69416,42	67399,62	66873,65	64920,43	63232,72	
cuvpthtw	*1,17*	*1,17*	*1,14*	*1,14*	*1,12*	
rdvpthtw	*0,86*	*0,86*	*0,87*	*0,87*	*0,90*	
pdethtw (GWh)	16079	16949	18835	20477	23295	table 6.4
inethtw (GWh)	43122,58	45112,38	48338,35	50500,57	55930,28	
cuethtw	*2,39*	*2,38*	*2,30*	*2,22*	*2,17*	
rdethtw	*0,42*	*0,42*	*0,43*	*0,45*	*0,46*	

7.2.3 CHP efficiency indicators with respect to 1996

The notional inputs and efficiency indicators of CHP heat and electricity, which are calculated with the constant indicator of fossil thermal electricity are similar computed as the inputs and indicators discussed in the previous sub-section. However in this sub-section the inputs and indicators are computed with respect to 1996, thus the efficiency indicator of fossil thermal electricity of 1996 has been set as reference. The inputs and the indicators calculated are in the table below.

Table 7.5: Computed CHP inputs and efficiency indicators based on constant efficiency indicator for fossil thermal electricity of 1996 (UK)

	1996	**1997**	**1998**	**1999**	**2000**	**Digest**
pdvpthtw (GWh)	63634	61775	62801	61203	61513	table 6.6
invpthtw (GWh)	74152,00	72025,57	71362,76	68480,23	67101,31	
cuvpthtw	*1,17*	*1,17*	*1,14*	*1,12*	*1,09*	
rdvpthtw	*0,86*	*0,86*	*0,88*	*0,89*	*0,92*	
pdethtw (GWh)	16079	16949	18835	20477	23295	table 6.4
inethtw (GWh)	38387,00	40486,43	43849,24	46940,77	52061,69	
cuethtw	*2,39*	*2,39*	*2,33*	*2,29*	*2,23*	
rdethtw	*0,42*	*0,42*	*0,43*	*0,44*	*0,45*	

Though the efficiency indicators can be calculated for the United Kingdom, it is not possible to calculate them for the other countries under study, and therefore a comparison is not allowed. The focus in the following section and chapter is respectively on the computation and interpretation of the shares of CHP electricity in the electricity production of the United Kingdom, Germany and the Netherlands.

7.3 CHP shares: United Kingdom, Germany and Netherlands

In contrast to the calculation of the efficiency indicators for the United Kingdom on the basis of the data published in the "Digest of United Kingdom Energy Statistics 2001", in this section the indicators of the share of CHP electricity are given on the basis of the EUROSTAT data. The reason to do so, is that these statistics allow a comparison of these indicators between the different countries. The shares of CHP electricity in the electricity sector of the countries mentioned (see table 8.2) are reported in the report "Combined Heat and Power production (CHP) in the EU; Summary of statistics 1994 to 1998" (16).

These statistics are composed on the basis of a questionable convention, which was discussed in sub-section 5.1.1. Therefore these data may (significantly) differ from others e.g. based on the second convention of EUROSTAT, see sub-section 5.1.2. However, in the next chapter these data are used to explore the share of CHP electricity in the electricity sectors of the United Kingdom, Germany and the Netherlands.

7.4 Chapter summary and conclusion

In this chapter the availability of the in- and output data of CHP and fossil thermal heat and electricity has been discussed, in order to calculate the indicators for the branches of CHP and fossil thermal heat and electricity for the United Kingdom, Germany and the Netherlands. Moreover those indicators have been computed for which the data are available.

First the data from the energy-supplied balance sheets of EUROSTAT were discussed. It followed that these sheets cannot be used to acquire the in- and output data of CHP and fossil thermal heat and electricity, as they are not separately reported. Regarding CHP, EUROSTAT made a survey of 1994 to 1998, in a summary of statistics the share of CHP electricity in the total electricity sector of the EU member states is reported. These statistics are based on a disputable convention. Nevertheless these are used to qualitatively assess the developments in the penetration of CHP in the next chapter.

Second, in order to be able to calculate the efficiency indicators for CHP and fossil thermal heat and electricity additional data were sought. For the United Kingdom and the Netherlands more specific data are published about CHP heat and electricity and the inland electricity production, respectively by DETR and the CBS. For both countries no data are published about fossil thermal heat. In contrast with the data published for the UK, for the Netherlands the in- and output data required for the calculation of the indicators of CHP heat and electricity as well as fossil thermal electricity cannot be derived from the statistics published on the Internet. Therefore only for the UK the efficiency indicators have been computed, although the CHP and fossil thermal electricity data are based on the convention of "Good Quality CHP", which is based on a relatively complex method and regarding the determination of the CHP and fossil thermal electricity inputs also disputable.

The indicators computed only concern those of CHP heat and electricity and fossil thermal electricity, as for fossil thermal heat no in- and output are available. To be able to calculate the CHP indicators, the efficiency for fossil thermal heat was based on a survey about the efficiency of heat-only-boilers estimated at 75%. The outcomes obtained are analysed in the next chapter.

However, to implement the proposed disaggregation as discussed in sub-section 4.5.3 for all participating countries in the ODYSSEE database, data have to be acquired from these countries with which the energetic in- and output of the branches of CHP and fossil thermal heat and electricity can be determined. As long as these cannot be acquired the developments in CHP cannot be analysed with ODYSSEE indicators as the data of fossil thermal heat and electricity and CHP are included in the same branches. Moreover, to be able to compare the developments between countries, data have to be available that are based on a common methodology.

8 Interpretation of CHP indicators developed

In response to a request of the policy makers of the EU to enhance the ODYSSEE database regarding the possibility to ex-post evaluate the use of CHP in the transformation sector, in the previous chapters the indicators for CHP have been developed, data collected and indicators calculated according to the data available. However the following question arises: What kind of information do these indicators provide to the policy side to judge the development of CHP and the impact of the policies set up to promote CHP? In accordance with section 1.6, the objective of this chapter is to answer this question by a qualitative analysis of the indicators developed, especially regarding the indicator for the penetration of CHP electricity, i.e. the share of CHP electricity in total electricity.

To qualitatively analyse the developments in this indicator of the United Kingdom, Germany and the Netherlands, the PET-systems of these countries and their development should be described and especially the differences between them (see also the concluding remarks of chapter 2). Although the time-span covered by the data available concerning the penetration of CHP is very limited (1994 to 1999, see table 8.2), the description that has to be made is very laborious, as a PET-system consists of many elements and is rather complex (see chapter 2). In this respect, inferences of K.M. Weber and R.J.F. Hoogma are very useful, they described with respect to CHP the main differences between the three countries under study around 1995. Therefore their inferences provide a starting point for the analysis to be made.

In the next section especially the differences in the PET-systems of the countries mentioned are described as they were around 1995 on the basis of inferences of K.M. Weber and R.J.F. Hoogma. Then, as this description is rather static and due to the political interest in the indicators of the ODYSSEE database, an event analysis is made of European Union and governmental interventions in the respective countries between 1995 and 1998, which affect the diffusion of CHP. Subsequent the development of the price differential between natural gas and electricity is discussed for the time-span under study, as it is one of the fundamental economic determinants of the viability of CHP. At last, the diffusion of CHP is explored in a bi-variate analysis in the countries mentioned between 1994 and 1998. Thus, for each country the development of the independent variables affected is compared to the development of the dependent variable.

8.1 Description of PET-systems around 1995

In the concluding remarks of chapter 2, it has been discussed that a PET-system is consists of three elements. These elements are: (1) technology, (2) relevant actors and (3) structures. It also been argued, that an actor's perceptions of the technology are most important, denoted as the innovation features. Moreover the PET-system has been conceptualised as an open-system, which is influenced by its context.

Therefore in the following five sub-sections the technology, the relevant actors, structures, contextual features and the innovation features are discussed.

8.1.1 Technology

In section 2.2.1 a technology has been conceptualised as a system consisting of sub-elements (hardware and knowledge) with a heterogeneous nature, which is subjected to changes and is embedded in a regime. Additionally in sub-section 2.2.4 it has been discussed that technological innovation in a system is limited, due to inertia in current systems (such as reflected in existing technologies and structures). In the following paragraphs these considerations are successively discussed for CHP, though in addition to the characterisation of the heterogeneous nature of CHP in chapter 3. Therefore first the major advancements in CHP technology from the mid-eighties to 1995 are described and its applications at that time. Subsequent the fundamental alternative to CHP, i.e. the existing technological supply structure for heat and electricity is briefly discussed.

Advancements in CHP technology

According to K.M. Weber and R.J.F. Hoogma, commercial CHP systems (thus excluding the CHP fuel cells that are under development, see the description of CHP in chapter 3) are similar in all countries. They for example denote that CHP gas turbines and internal combustion engines became available at about the same time, and followed similar diffusion patterns. Moreover, K.M. Weber considers CHP as a mature technology due innovations, such as computer based control systems. Though K.M. Weber and R.J.F. Hoogma observe differences with respect to the date of introduction of these novelties, in the United Kingdom and the Netherlands the computer-based control systems were introduced already in the mid-1980s, while in Germany they became widely used in the early 1990s only. Later on these systems were remotely monitored and significantly improved the reliability of small-scale CHP systems. Regarding this connotation it has to be denoted, that in this context "small-scale" CHP does refer to CHP systems that supply the heat produced to individual buildings or small industrial sites and not to a certain electrical capacity as before.

CHP applications

Besides these small-scale applications CHP is also used for district heating (i.e. heating of groups of buildings interconnected by a grid to distribute heat) and industrial process heating applications. In Germany CHP district heating has been exploited after the Second World War, see K.M. Weber (41, page 364). According to him and R.J.F. Hoogma, the United Kingdom and the Netherlands have expanded CHP only since the beginning of the 1980s. Though in the United Kingdom district heating is hardly applied. The CHP applications mentioned have in common that the heat produced is used locally (heat transport is limited by distance due to significant losses in transport) and the electricity simultaneously produced is either consumed onsite or exported to the electricity grid.

Alternative to CHP and existing heat and electricity supply chains

According to K.M. Weber, CHP competes with several sets of "sub-"alternatives (e.g. electricity from the grid and individual gas-, oil-, or coal fired heating systems) once the different perspectives of the adopting actor are taken into account. Although in principle separate production of heat and electricity can be seen in opposition to CHP, see also K.M. Weber (41, page 177). He subsequently discusses that the supply-chains to separately supply heat and electricity emerged in a historical process. Whereby heating has remained a decentralised activity for industrial and space heating applications, because heat supply systems could not balance the additional costs for the network. Besides significant losses are involved in the transport of heat. On the contrary electricity is supplied through a pervasive system, enabled by high voltage transmission of electricity that reduced the losses involved in electricity transport. The electricity supply system is amongst other features, see K.M. Weber (41, page 131 ff), characterised by: (1) large production units that are (2) centralised controlled and (3) interconnected through an high voltage electricity grid, which also connects them to the end-users of electricity. Both the heat and electricity supply chains are complemented by the supply of gas or other fossil fuels, although electricity is also generated in nuclear plants.

Consequences for application of CHP

As a CHP system simultaneously supplies heat and electricity and is linked to the local or on-site heat supply as well as in many cases connected to the electricity grid, it is according to K.M. Weber embedded in these supply structures and moreover it merges them. Besides being a network technology, CHP implies horizontal integration of heat and power services as it simultaneously produces them. It also implies decentralisation of energy supply, as heat cannot be transported over large distances.

K.M. Weber additionally underpins that within this context the co-ordination of the combined production of heat and electricity is complex. It is even more complex as the heat and electricity load patterns mutually differ, which is difficult to account for because the storage and transport characteristics of heat and electricity differ.

As a consequence of being a network technology, K.M. Weber remarks that CHP ties therefore large number of actors with different interest together. And being a complex technology, it also needs to be integrated carefully within each individual site. For example, a CHP plant should be sized according to a base load, e.g. of heat, of a site, in order to operate it economic and resource efficient compared to the separate production of heat and power. He also denotes that this holds for all CHP applications, though the high level technical complex co-ordination of combined production of heat and electricity (that rises with the size of a plant) often goes beyond the competencies of a non-specialised company (41, page 196).

The following sub-section further embroiders on this theme of actors tied together by CHP. It has the objective to review the main groups of actors that were active with respect to CHP in the PET-systems under study around 1995.

8.1.2 Relevant actors

In section 2.2 four main groups of actors were distinguished, viz. besides the national institutes of policy-making (the government), technology suppliers and users, also intermediate organisations (e.g. environmental interest groups). Within this framework the interests and actions of the respective national governments can be described. The Dutch government set for example a challenging CHP electrical capacity target of 8000 MWe that should be reached by the year 2000, the English of only 5000 MWe and the German government none. It however follows from the inferences of K.M. Weber and R.J.F. Hoogma, that this list of groups of actors is not detailed enough to describe the role of the technology suppliers (e.g. technology manufacturers, universities and research institutes) and technology (e.g. electricity utilities) users in the diffusion of CHP. In the next two paragraphs the role of the actors in these groups is successively reviewed.

Technology suppliers

According to K.M. Weber and R.J.F. Hoogma, the Netherlands is the only country, where the research capacities of universities were exploited to a significant extend to support the advancement of CHP. The Dutch government promoted the collaboration between the universities and manufacturers. Moreover the Dutch government founded the “Projectbureau Warmte-kracht” (PWK) in1987, which co-ordinated and stimulated most activities related to CHP in the Netherlands.

On the contrary in Germany industrial organisations, such as VIK (Verband der Industriellen Energie und Kraftwirtschaft) and VDEW (Vereinigung Deutscher Elektrizitätswerke), fulfilled several functions regarding CHP, which in the United Kingdom and the Netherlands fall into the realm of government institutions. Moreover German engineering associations, e.g. AGFW (Arbeitsgemeinschaft Fernwärme) and ASUE (Arbeitsgemeinschaft für Sparsamen und Umweltfreundlichen Energieverbrauch) have been very active in the dissemination of experiences and the establishment of common design standards regarding CHP. Besides in Germany newcomers willing to provide full service support to their clients, pioneered especially in the small-scale CHP development. Later on the established manufacturers were able to take over the German CHP market, through increasing sophistication of CHP technology. In the United Kingdom the pioneers dominated also the small-scale CHP market, until they were taken over by incumbents in the 1990s.

The government of the United Kingdom adopted an information policy only, which was essentially implemented through the EEO (Energy Efficiency Office) and ETSU (Energy Technology Support Unit), sometimes in co-operation with CHPA

(Combined Heat and Power Association). The latter is the most important organisation for all CHP related issues in the United Kingdom. It is therefore concluded that the group of technology suppliers has to be divided into sub-groups, viz. technology manufacturers (pioneers and incumbents), universities, industrial organisations, engineering organisations and public research institutes, as they act differently regarding CHP in the respective countries.

Technology users

Such a division is also desirable regarding the group of technology users. K.M. Weber and R.J.F. Hoogma see between the three counties under study one similarity, the initial hostility of the large electricity utilities towards CHP, because it was incompatible with their large-scale, power only supply philosophy.

In the Netherlands the utility companies maintained a major role as CHP plant operators, though in co-operation with energy end users in industry and business. In Germany the local utilities supported the extension of a significant district-heating capacity. They are also the main users of small-scale CHP. Though the influence of large supra regional and regional power utilities represent a barrier to a wider expansion of CHP in Germany.

In the United Kingdom district-heating hardly exists. However due to a stepwise liberalisation of the energy markets, private service companies that emerged used the opportunities to set-up CHP plants. Also Regional Electricity Companies (REC's) redefined their strategies and started to expand their activities including the use of CHP plants. Their activities regarding CHP are however compared to Germany local utilities rather small. Thus it is also important to distinct between large (supra regional) electricity utilities, REC's, regional and local utilities, private service companies and end users.

8.1.3 Structures

Besides the different actors that are active in the PET-systems of the United Kingdom, Germany and the Netherlands, K.M. Weber and R.J.F. Hoogma also discuss differences in the relationships between these actors (i.e. structures, see sub-section 2.2.3) in these countries. Differences that manifest themselves especially in the economic structures of the Energy Supply Industry (ESI), and to some extend in the political structures of these countries. In the following two paragraphs the differences regarding the structures mentioned are successively elaborated.

Economic structures of the ESI

Before discussing the differences in the structures of the ESI of the United Kingdom, Germany and the Netherlands the regulatory frameworks within these countries are consecutively described. According to K.M. Weber, within the United Kingdom a revolutionary transformation of the ESI has taken place, breaking up the monopolistic structure of the old Central Electricity Boards (CEGB), of the regional boards and of British Gas in order to introduce more competition into the British ESI (41, page 251 ff). British Gas has been privatised in 1986, later in 1989 the new Electricity Act was accepted, which regulates the British ESI since March 1990. From a discussion by K.M. Weber of the main elements of the British Electricity Act, the following five elements are deduced (41, page 251 ff):

(1) The CEGB in England and Wales was broken up and its main generating assets were transferred to the new private companies National Power and Power Gen. In Scotland, the situation remained roughly as it had been before, i.e. the two major electricity companies Scottish Power and Scottish Hydro continued to operate as vertically integrated utility companies;

(2) Privatisation of the major companies in the ESI (e.g. the regional boards become the Regional Electricity Companies), with exception of the grid operation that remained under the control of the public National Grid Company as well as the nuclear industry (British Energy);

(3) An Electricity Pool was set up as an artificial market for bulk generation. Based on half-hourly bids for the next day, the pool prices for these intervals are determined and thereby also the operation times of the different plants. For power generation outside the pool prices are negotiated individually between generator and supply company, though the RECs are not obliged to purchase independently produced power. The RECs power prices for small users (electricity peak loads smaller than 100 kWe) continue to be subjected to price control by OFFER (Office of Electricity Generation);

(4) OFFER was founded as central regulatory body under the responsibility of the Department of Trade and Industry. The regulator is formally independent of the government and its main functions are to guarantee competition in the British ESI and to protect the consumers. The regulator has also the duty to monitor the spread of CHP in the United Kingdom;

(5) Liberalisation in generation and supply is being introduced in three steps. From March 1990 onwards customers beyond an electricity peak load demand of 1 MWe can choose their electricity supplier. From April 1994 also customers with an electricity peak load demand between 1 MWe and 100 kWe can choose their supplier. Below the latter limit customers are bound to their REC until September 1998. In generation there is competition through the pool system and through direct contracts between power generators and large users.

To complement this new regulatory framework, the British government introduced a number of specific regulations and programmes; one of them was defining a target of installed electrical capacity for CHP plants by 2000 of 4000 MWe. In contrast to the previously discussed reform of the British ESI, the Germany the ESI is around 1995 still regulated by the Energy Supply Act of 1935, though K.M. Weber remarks a debate on the need for a reform has been started. According to K.M. Weber the main features (4) of the regulations in force around 1995 are (41, page 311 ff):

(1) It is based on the assumption that the entire supply chain has the characteristics of a natural monopoly, therefore gas and electricity companies

(these operate at three levels, viz. supra regional, regional and local) have closed supply areas. They have the right to negotiate exclusive demarcation contracts among each other and exclusive concession contracts with local authorities. These are concluded over periods up to 20 years, after which they can be re-negotiated. This authorisation is linked to the obligation to guarantee connection and supply, and consequently to an obligation to invest in power supply. Similar demarcation agreements are also concluded among supra regional electricity supply companies to determine their supply areas. In addition all electricity supply companies need supply permission from the regional state authorities.

(2) To avoid an abuse of the monopolistic supply position, there is regulatory control that consists of three elements. First, electricity prices and tariffs are regulated, though for low voltage customers only, i.e. usually households and small commerce. Second, the cartel or monopoly commission controls the prices for the large customers, though they can negotiate their tariffs individually. Third, there is a control on investment. About major investments the supply companies have to inform the regulatory body, which assess these projects on principles of economic and secure supply.

(3) Technical grid connection conditions are not subjected to any regulation, but the norms are defined by technical associations and by the association of electricity utilities (VDEW, see sub-section 8.1.2);

(4) Gas supply is subjected to competition among different supply companies at regional and supra-regional level, but not at local level. Though in contrast to electricity supply, at a local level the utilities are not obliged to connect customers to the grid. Correspondingly customers can choose the form of heat supply they prefer.

In 1991 the Electricity feed-in Act (Stromeinspeisungsgesetz) came into force, according to P.E. Gronheit (19, page 65) the German model for support of renewable energy for electricity generation, see also K.M. Weber (41, page 326). According to this Act the interregional electricity companies were requested to buy electricity from a range of renewable sources at minimum prices depending of the technology. According to P.E. Gronheit this Act has led to a very considerable increase in electricity generation from renewable energies during the 1990s (19, page 65). As in the United Kingdom the Dutch ESI has been reformed. Within the Netherlands a new Electricity Act came into force in 1989. The objective of this act was to introduce more competition into the ESI. The Electricity Act 1989 has, among other thighs, the following features:

(1) The power producers were unbundled from the distribution companies, which became public limited companies;

(2) The distribution companies and large industrial energy users were allowed to buy electricity from any of the power producers. In addition large industrial energy users were allowed to import electricity from abroad.

(3) The distribution as well as the large industrial energy users were allowed to generate their own electricity, though the distribution companies were not allowed to built plants with an electrical capacity larger than 25 MWe.

(4) The distribution companies were obliged to buy the surplus of electricity produced and to pay the providers a remuneration fee.

In 1994 these regulations have been adapted, in order to avoid a surplus in electrical capacity in the future. According to an anonymous source, the Dutch government decreased the remuneration fees for electricity supply to the grid. It moreover remarks that the distribution companies became indirectly responsible for the central power production, because it would have to pay a fine, if it would buy less electricity from the grid due to an increase in decentralised power capacity within its service area. It also mentions that the large industrial energy consumers were financially compensated in order get their approval for the decisions made.

Taking into account these regulations regarding the ESI within the United Kingdom, Germany and the Netherlands, it follows that the structures of the ESI of the respective countries differ significantly regarding liberalisation, (de-) regulation and public/private ownership around 1995. It moreover follows that the energy supply structure of the Netherlands is more conductive to CHP as those of the United Kingdom and Germany.

Political structures

Regarding the political structures K.M. Weber and R.J.F. Hoogma remark that in the United Kingdom they were real obstacles to CHP until 1990 when the ESI was reformed and a market based governance approach was introduced, see the previous sub-section. Both in the Netherlands and Germany the political systems are more open, i.e. consensus oriented and aim to involve several stakeholders. Many niches for experimentation with CHP opened up in Germany due to the decentralisation of competencies and the co-operative-corporatist policy-making process, while in the Netherlands this was the result of a very pragmatic approach.

8.1.4 Contextual features

In section 2.4 six different contextual features have been discussed that can influence the diffusion of CHP. Though this sub-section is limited to a description of the external impulses that have been regarded to be most important to this process to 1995. According to the International Energy Agency in 1983 the role of the energy supply context in terms of availability and fuel energy prices has been recognised as an important factor for the use of highly efficient technologies like CHP. However, regarding the fuel energy prices it has been elaborated in sub-section 2.4, that the price differential between the fuel energy and electricity is most important to the diffusion of CHP. In addition to the external impulses of security of supply and price differential, also those from the Framework Convention on climate change of the United Nations Conference in Rio de Janeiro in 1992 are discussed in this sub-section for the three countries under study.

Security of energy supply

Although the security of energy supply is not endangered around 1995, K.M. Weber and R.J.F. Hoogma, remark that this issue is more important in Germany than in the United Kingdom and the Netherlands. They do so because in contrast to Germany, the United Kingdom and the Netherlands can exploit major indigenous fuel reserves, and especially gas. Though in the Netherlands it has been an issue, as in the first oil crisis in 1973 the export of fossil fuels to the Netherlands was boycotted by the OPEC-countries, see also the Energy Report 2000 (12, page 63 ff). To cope with this issue of security of energy supply Germany adopted an efficiency-oriented energy policy during the 1980s and 1990s, which, according to K.M. Weber, includes the support for CHP (e.g. investment grants typically of 7.5%). He and R.J.F. Hoogma also denote that the Netherlands as well as Germany adopted an efficiency-oriented energy policy. Once the advantages of CHP were acknowledged in the Netherlands an extensive support plan for CHP was set in motion, consisting of e.g. restructuring the ESI (see the previous sub-section) and of massive financial support (e.g. investment grants and guaranteed remuneration fees for delivering electricity to the grid). Thus differences in policies pursued regarding security of energy supply exist amongst the three countries, and it has had an impact on the support of the diffusion of CHP.

Price differential between electricity and fuel energy

Regarding the price differential between the fuel energy and the electricity, K.M. Weber remarks that in the United Kingdom this differential has decreased since 1989 and had a negative impact on the economic viability of several CHP projects. This price differential decreased, according to K.M. Weber, because the price for "interruptible" gas (the most common type gas used for CHP) did not drop in contrast to the electricity prices, in addition it became interruptible due to the "dash for gas" (an fast increasing gas demand). Though from the prices for gas used in electricity generation and the industrial electricity prices as reported by the International Energy Agency it follows that the gas price increased in the early 1990s, however in 1995 it was lower than in 1989. Besides the electricity prices also increased and they were higher in 1995 than in 1989. Therefore the price differential between gas for electricity generation and electricity is considered as being conductive to the exploitation of CHP within the United Kingdom, though its interruptible supply (which hardly happened before) is considered being detrimental to the diffusion of CHP.

Table 8.1: United Kingdom, natural gas prices for electricity generation, and electricity prices for industry, in Pound Sterling (Source: International Energy Agency, i.e. IEA, "Energy prices and taxes, 2nd Quarter 2000").

Year	**Gas (£ per 10E7 kCal GCV)**	**Electricity (£ per kWh)**
1989	77.34	0.0373
1993	81.76	0.0455
1994	77.57	0.0438
1995	74.78	0.0434

On the contrary in Germany the price differential between fuel energy and electricity decreases, which endangers the diffusion of CHP within Germany. The decrease of the price differential follows from the prices regarding natural gas for electricity generation and electricity for industry as published by the IEA in "Energy prices and taxes, 2nd Quarter 2000". An increasing excise tax on natural gas (per 10 Gcal from DM 30.2 in 1990 to DM 41.9 in 1992) contributes to an increase by 3% of the price for natural gas for electricity generation, whenever the prices of 1989 and 1995 are compared (respectively DM 241.9 and DM 250.2 per 100 Gcal based on Gross Calorific Value). Besides the in general high electricity price slowly decreases in the period from 1989 to 1995 by 3.6%, from DM 0.1484 to DM. 0.1431 also including an excise tax to support the German coal industry, see also K.M. Weber (41, page 316).

According to an anonymous source the price ratio gas electricity within the Netherlands is conductive to diffusion of CHP around 1995. The favourable price differential is caused by a decision of the Gasunion and distribution companies to charge a special low price for the natural gas used to produce electricity in a CHP plant. Besides, from 1989 to 1995 also the electricity price for industry increases substantially by 33%, in real terms per kWh from Dfl. 0.0899 to Dfl. 0.1197, see the figures as published by the IEA in: "Energy prices and taxes, 2nd Quarter 2000".

Framework Convention on Climate Change: Rio Conference 1992

In this so-called Rio-Conference of 1992 the governments of developed countries as Member States of United Nations agreed to prevent the disturbance of the climate system caused by humans. They however made a voluntary agreement to stabilise the greenhouse gas emissions to the level of 1990 by 2000. In December 1997 this voluntary agreement made in Rio de Janeiro was substituted by the obligatory Kyoto Protocol. Though, according to the Dutch Energy report 2000, the Rio-Conference led to the implementation of a climate policy during the 1990s in almost all industrialised countries (12, page 74). With respect to CHP, K.M. Weber remarks that as an outcome of this Rio-Conference CHP started to figure prominently as an element of the United Kingdom's CO_2-reduction strategy (41, page 264). The Britsh government for example raised the target set for an installed CHP electrical capacity in 2000 from 4000 MWe to 5000 MWe (which is a relatively modest target compared to the Dutch target, see sub-section 8.1.2). The British government also refrained from substantial (financial) support for CHP, information requirements of users were regarded as a priority area, see also K.M. Weber (41, page 265).

From the elaboration in the previous paragraphs it follows that finally the three countries under study adopted an energy-efficiency policy, though from different contextual impulses. It also resulted in different (positive) stances towards CHP, or as mentioned in section 1.1 CHP is being considered as one of the very few technologies that can offer a significant short or medium term contribution to the energy efficiency issue. Whereas CHP was broadly supported in the Netherlands, including transfer of information and massive financial support, in Germany it was less (financially) supported, and in the United Kingdom the information supply about CHP was regarded most important. Moreover in the Netherlands the price differential between natural gas and electricity for industry is more conductive to the diffusion of CHP as in the United Kingdom and especially Germany. In Germany the price differential decreased, where this differential in the Netherlands and the United Kingdom increased. On the basis of the discussion in this sub-section and those in previous sub-sections in the following sub-sections the innovation features of CHP are summarised.

8.1.5 Innovation features

In section 2.3 the five most important characteristics were discussed to describe the different actor's perceptions of the technology. The objective of this sub-section is to capture these innovation features in a table (below) on the basis of the description in the previous sub-sections and with respect to the main alternative to CHP, as introduced in sub-section 8.1.1. Though as the macro economic features were not discussed or assessed, (even K.M. Weber remarks that they are difficult to determine) they are not taken into account in this sub-section.

Table 8.2: Innovation features of CHP

Innovation Features	CHP	Centralised power generation and individual heating
Technological	* Complex heterogeneous technology; * Requires high-grade co-ordination of production, due to simultaneous production of heat and power; * Incompatible with established infrastructure, due to decentralised generation; * Technically mature * Future development potential, e.g. introduction of CHP fuel cells.	* Mature and fully established; * Less complex (requires less , co-ordination), though heterogeneous; * Compatible with established infrastructure; * Future development potential, e.g introduction of fuel cells only producing electricity.
Micro-economic	Beneficial under right circumstances, as in the Netherlands	* Beneficial for large operators and utilities; * In monopolised structure not the least-cost option for consumers.
Environmental and Resource	* Higher efficiency; * Due to decentralisation, locally higher emissions, though lower global emissions;	* Lower efficiency; * Due to centralisation, locally lower emissions, though higher global emissions;
Organisational and power	* Difficult to co-ordinate actors; * Incompatible with organisational structures, as it requires horizontally integrated organisations (excluding the Netherlands); * Challenges present power positions.	* Requires less co-ordination; * Compatible with organisational structure

It is therefore concluded, in accordance with sub-section 8.1.1 that around 1995 CHP is a challenging technology, being heterogeneous, difficult to operate, incompatible with (infra-) structures (with exception of the Netherlands). Though, economically viable and environmental friendly under the right circumstances. In the following section decisions of the political actors are elaborated regarding CHP.

8.2 Event analysis: important changes

In the previous section the state of the PET-systems of the countries under study as well as the different actors' perceptions of CHP with respect to its main alternative around 1995 were described. It followed that especially the Dutch PET-system was very conductive for the diffusion of CHP, whereas the British system was less conductive and the conductivity of the German system decreased due to a decreasing price differential between gas and electricity. Though the diffusion of CHP in these countries in the period between 1995 and 1998 cannot be qualitatively analysed on the basis of this description only. After all the systems under study were conceptualised as evolutionary systems, which adapt to in- and external impulses over time. Therefore in this section an event analysis is made.

The event analysis concerns a description of the impact of events, i.e. decisions taken by important actors, on the PET-systems under study between 1995 and 1998. Though, it is not the objective of this section to discuss an exhaustive list of decisions, it is rather limited to those that are regarded to be most important to the diffusion of CHP within the PET-systems under study. This description is moreover limited to the decisions that concern CHP taken by the political actors in the PET-systems of the United Kingdom, Germany and the Netherlands. To take into account external impulses, also the impact of important decisions from the United Nations, especially the Kyoto Protocol, and of the European Union is discussed. In the following five sub-sections the Kyoto protocol and its consequences for CHP, and the decisions taken by the European Union, the United Kingdom, Germany and the Netherlands regarding the PET-systems under study are successively elaborated.

8.2.1 Kyoto protocol

In sub-section 8.1.4 it has already been mentioned that the agreement of Rio de Janeiro was substituted in December 1997 by the Kyoto Protocol, which contains obligatory targets for the reduction of greenhouse gases. It is the objective of this sub-section to assess the impact of the Kyoto Protocol on the governmental policies pursued during 1998 and whether it affects the diffusion of CHP in this year.
In the Dutch Energy Report 2000 these (obligatory) Kyoto targets set by the different industrialised countries are compared as well as the policies pursued to fulfil these targets set (12, page 73 ff). In this report it is concluded that the Netherlands, as well as e.g. Finland and Denmark, pursues an average to difficult target to be reached by 2010. The Dutch policy to reach this target is furthermore remarkable, because it has the objective to realise half of it, by buying foreign emission credits. On the contrary Germany and the United Kingdom are supposed to pursue a less difficult target. Though they aggravated their Kyoto targets with a domestic target, e.g. the United Kingdom set a domestic target to a 20% reduction in CO_2 emissions below 1990 levels by 2010, therefore they pursue an active domestic policy. However the most countries with emission reduction obligations, including the three countries under study presented an implementation plan of the Kyoto

obligation in the late nineties. It is therefore assumed that the Kyoto Protocol did not influence the diffusion of CHP in the period under study.

However in preparation to the Kyoto protocol the European Commission presented a Community strategy to promote CHP and to dismantle barriers to its development in October 1997 (13). In the next sub-section this strategy is discussed, as well as other important EU decisions.

8.2.2 European Union

Besides this strategy to promote CHP, this technology has also been affected by the implementation of the electricity single market directive from the EU of 1996, see e.g. the discussion in section 1.1. The EU directive for a single natural gas market that came into force in August 1998 is also of importance to CHP, which is expected to increase the availability of gas at more competitive prices and so contribute to the viability of CHP plants running on natural gas (13, item 10). Though regarding the time-span explored (1995 to 1998) in this research, the latter directive is not considered to be important. Therefore this sub-section is limited to a discussion of the Directive for a single electricity market and the Community strategy to promote CHP.

In December 1996 the European Parliament and the Council accepted "Directive 96/92/EC" concerning common rules for the internal electricity market, i.e. the generation, transmission and distribution of electricity. According to the Directive, establishment of the internal market in electricity is particular important in order to increase efficiency in the production, transmission and distribution of this product, while reinforcing security of supply and the competitiveness of the European economy and respecting environmental protection.

The internal market for electricity is established gradually, to enable industry to adjust in a flexible and ordered manner to its new environment and to take account of the different ways in which electricity systems are organised at present. Therefore the Directive requires from the EU Member States to liberalise at least:

(1) 26% of national electricity demand as from 19 February 1999. Furthermore consumers that use more than 100 GWh electricity per annum must be permitted to choose their supplier;

(2) 28% of national electricity demand as from 19 February 2000;

(3) 33% of national electricity demand as from 19 February 2003.

In the paper "Opening up to choice: The single electricity market", the European Commission remarks that most Member States are moving faster and will either open up their markets completely, or at least move a step further than the Directive requires (14, page 8). In addition to the United Kingdom in Germany the electricity markets will be completely opened by April 1998, this in contrast to the Dutch electricity market, which will be completely opened by October 2003.

However, one of the main objectives of the liberalisation of the Member States electricity markets and merging them into one, is to obtain lower prices for electricity. In the paper "Opening up to choice: the single electricity market" it is supposed that these lower electricity prices result in lower production prices for European industry, which in turn will result in lower prices for products (14, page 4). Though, in section 2.4 it has been discussed that the price differential between fuel energy and electricity is most important to the diffusion of CHP, and in this respect the liberalisation initiated by the EU seems to be detrimental to CHP's diffusion. Though the single electricity Directive offers the possibility to Member States to give priority to CHP plants when the system operator is dispatching generating installations (13, item 10).

By October 1997 in preparation to the Kyoto Conference (COP 3), it is recognised by the European Commission that the changing legal framework creates a new situation for CHP, where there is less price stability and increased environmental concerns (13, item 5). Since the European Commission considers CHP as one of the very few technologies that can offer a significant short or medium term contribution to the energy efficiency issue, it wants to propose a strategy that facilitates the diffusion of CHP. The European Commission therefore mentions that it is for the Member States to undertake the main financing efforts, though European Union programmes are reoriented emphasising CHP (13, item 33). The European Commission also considers for example negotiated agreements with industry and internalisation of external costs as important and conductive to the diffusion of CHP (13, chapter 4). In the following three sections changes in the British, German and Dutch policies towards CHP are discussed in the period under study.

8.2.3 The United Kingdom

Though the objective of this sub-section is to discuss changes in the British policy towards CHP during 1996 to 1998, no policy changes in this period have been traced. Only some minor changes are reported, K.M. Weber for example refers to the Private Finance Initiative (PFI) initiated in 1996, which he considers as an interesting initiative that facilitates the set-up of private-public partnerships for energy efficiency investment like community heating by providing extra funds to local authorities. He however also remarks that there are no special tariff arrangements or any kinds of taxation advantages for CHP foreseen in the regulatory and policy framework (41, page 266).

With respect to the energy supply structure, it has already been mentioned in sub-section 8.1.3, that in September 1998 the remaining part of the electricity market (i.e. customers with an electricity peak load lower than 100 kWe) is opened. Though, in the Digest of United Kingdom Energy Statistics 2000 it is remarked that this part of the market has been opened over a time-span from September 1998 to May 1999 (8, item 5.10c and 9.22 ff). Thus it follows from this sub-section that in the period under study no major changes occurred, i.e. policies were initiated in the United Kingdom that significantly affect the diffusion of CHP.

However, as well as in chapter 6 of the Digest of United Kingdom Energy Statistics 2000 and 2001 recent (from 1999 onwards) important policies initiated towards the diffusion of CHP in the United Kingdom are discussed. These policies were initiated in order to achieve the obligatory Kyoto goal, which the British government committed itself to and the domestic goal set regarding the reduction of greenhouse gas emissions, see also sub-section 8.2.1. The British government for example confirmed a new target of installed CHP electrical capacity of at least 10.000 MWe by 2010 as part of its Climate Change Programme, which also includes a climate change levy from which Good Quality CHP, see sub-section 5.1.3, is exempted.

In the following sub-section the German policies are discussed that are initiated in the period under study, and which affect the diffusion of CHP.

8.2.4 Germany

In Germany the PET-system under study was more dynamic than the British. First of all a special tax to support the German coal industry was dropped by the 1st of January 1996. Second, the energy supply industry was revolutionary reformed by the energy supply act that came into force in April 1998. The impact of these two decisions is discussed in this sub-section.

In sub-section 8.1.4 it has been discussed that in general the German electricity prices are high. One of the reasons for these high electricity prices was the excise tax levied to support the domestic coal industry, from the 1st of January 1994 to 31st of December 1995 the tax rate was 8.50% (Rates vary across regions, this is the federal average, source International Energy Agency). Since the 1st of January 1996 this tax was abolished, according to K.M. Weber, in response to a decision of the Federal Constitutional Court, leading to a corresponding decrease of electricity prices from 1996 onwards. As has been discussed decreasing electricity prices endanger the viability of CHP as the price differential between the fuel energy and electricity decreases.

In April 1998 the new electricity act finally passed. The Act is based on the principle of full competition in the electricity market. Thus since April 1998 the German electricity market has been completely liberalised. The consequences for CHP are briefly discussed in the "Shared Analysis Project, Economic Foundations for Energy Policy Volume No. 14" (19, page 65 ff). In this report P.E. Gronheit remarks that in Germany energy efficiency was often considered more important than economic efficiency, but within the protected local market. He subsequently states that much investment (large-scale or small-scale) may well be considered as stranded costs, facing the price of electricity that may emerge on the liberalised electricity market. He therefore remarks that some of the municipal utilities do perceive the liberalisation as a threat for their CHP activities and are looking for protection. In some cases already CHP units have even been closed down or "mothballed". Though the Electricity feed-in Act, as discussed in sub-section 8.1.3 remained in force after the new electricity Act of April 1998.

As electricity prices decreased, it seems that CHP did not benefit from the dynamics introduced in the German energy supply industry and especially that of electricity, In the following sub-section the impact of the Dutch policies initiated to their CHP exploitation is discussed.

8.2.5 The Netherlands

According to K.M. Weber and R.J.F. Hoogma the Dutch strategy operated before 1996 at all societal levels, including regulatory reform, targeted financial support schemes, information provision and the stimulation of co-operation agreements for CHP. Beyond 1996 the Dutch strategy has not been changed, in 1996 the so-called "Energy Regulatory Tax" (REB) was introduced. In 1997 the introduction of the "REB" was followed by specific subsidies for environmental friendly technologies (e.g. January 1997 introduction of Energy Investment Allowance of 40%) as well as non-obligatory agreements with the industry to use energy efficient technologies (see also the Energy Report 1999). Moreover, in 1997 a new electricity Act was prepared, which finally came into force at 1st of January 1999. Taking the time-span under study (1996 to 1998) in to account and it follows that the new electricity act does not have a major impact on the diffusion of CHP. Therefore in this sub-section only the impact of the Energy Regulatory Tax is elaborated.

January 1st, 1996 the "Energy Regulatory Tax" was introduced in order to stimulate energy saving behaviour. These tax incomes are refunded to the taxpayer by an overall tax decrease. Regarding electricity, the tax is initially limited to small and medium users only, see also table 8.3 below, in order to prevent undesirable effects on the international competitiveness of the Dutch manufacturing sector.

Table 8.3: Energy Regulatory Tax on electricity from 1996 to 1998 in Dfl/kWh. (Source: International Energy Agency, Energy prices and taxes 2nd Quarter 2000)

	1996	1997	1998
0-800 kWh	**0**	**0**	**0**
801-10000 kWh	**0.0295**	**0.0295**	**0.0295**
10001-50000 kWh	**0.0295**	**0.0295**	**0.0295**
50001 kWh – 10 MWh	**0**	**0**	**0**
> 10 MWh	**0**	**0**	**0**

Since 1997 also the large energy users are subjected to the Energy Regulatory Tax, albeit only for their consumption below 170.000 m^3 natural gas (see table 8.4 on the next page) and 50.000 kWh electricity (see the table above). The extra tax income of this measure is used to finance the Energy Investment Allowance. According to the Energy Report 1999 this Energy Regulatory Tax stimulates energy savings, while energy generated with fossil fuels becomes much more expensive.

Table 8.4: Energy Regulatory Tax on Natural Gas from 1996 to 1998 in Dfl/m^3. (Source: International Energy Agency, Energy prices and taxes 2nd Quarter 2000)

	1996	1997	1998
0-800	**0.02155**	**0.02155**	**0.02155**
801-5000	**0.05355**	**0.08555**	**0.11685**
5001-170000	**0.05355**	**0.08555**	**0.11685**
170000- 1M	**0.02155**	**0.02155**	**0.02155**
1M-10M	**0.02155**	**0.02155**	**0.02155**
> 10 M	**0.01410**	**0.01410**	**0.01410**

The electricity generated and used on-site, e.g. in a CHP plant, is not subjected to this Energy Regulatory Tax. It is however remarked in the Energy Report 1999 that the supposed effects of the introduction of the Energy Regulatory Tax cannot be determined on short-term in order conclude on these effects. Besides, it is denoted that district heating is more viable, because the Regulatory Energy Tax on natural gas has raised the heat price (natural gas used in CHP plants is not subjected to the Regulatory Energy Tax). Thus the electricity prices are high, due to the Regulatory Energy Tax. Moreover CHP electricity used on-site and CHP natural gas fuel inputs are not subjected to the Regulatory Energy Tax. Therefore it is supposed that this measure and according prices are conductive to the diffusion of CHP within the Netherlands.

From this and the previous sub-sections regarding Germany and the Netherlands, it follows that in Germany especially the prices of electricity is influenced by policies initiated. In the Netherlands the natural gas as well as the electricity price are subjected to changes. Therefore in the following section development of the price differential between natural gas and electricity is discussed for the time-span and countries under study. The prices of natural gas are used in this analysis, because it is most commonly used in CHP plants in the countries under study, see e.g. figures from EUROSTAT.

8.3 Development of price differential natural gas-electricity

In this section the development of the price differential between electricity and natural gas is successively discussed for the United Kingdom, Germany and the Netherlands. As in sub-section 8.1.4 again the figures are used, as published by the International Energy Agency in “Energy prices and taxes, 2nd Quarter 2000”.

8.3.1 The United Kingdom

In table 8.5 the electricity and natural gas prices are depicted for the United Kingdom. It immediately follows from this table that from 1995 to 1998 the electricity price decreased, by 9%. In contrast to the electricity price the gas price increases from 1995 to 1998, by 2%. It is therefore concluded, with respect to 1995, that the viability of (gas-fired) CHP plants, decreases.

Table 8.5: United Kingdom, natural gas prices for electricity generation, and electricity prices for industry, in Pound Sterling (Source: International Energy Agency, i.e. IEA, "Energy prices and taxes, 2nd Quarter 2000").

Year	Electricity (£ per kWh)	Gas (£ per 10E7 kCal GCV)
1995	0.0434	74.78
1996	0.0419	73.04
1997	0.0395	75.25
1998	0.0392	76.29

8.3.2 Germany

In table 8.6 the electricity and natural gas prices are depicted for Germany. It immediately follows from this table that from 1995 to 1997 the electricity price significantly decreased, by 9.4%. This decrease was expected as in 1996 the special tax to support the German coal industry was abolished. In contrast to the electricity price the gas price increases, from 1995 to 1997, by 9.5%. It is therefore concluded, that with respect to 1995 the viability of (gas-fired) CHP plants decreased significantly.

Table 8.6: Germany, natural gas prices for electricity generation, and electricity prices for industry, in DM (Source: International Energy Agency, i.e. IEA, "Energy prices and taxes, 2nd Quarter 2000").

Year	Electricity (DM per kWh)	Gas (DM per 10E7 kCal GCV)
1995	0.1319	250.2
1996	0.1295	259.8
1997	0.1245	274.1
1998	0.1183	not available.

As the data for 1998 are not completely available, the table regarding the price indices for Germany as published by the International Energy Agency is very useful. From that table it follows that the gas price suddenly decreases during 1998 to a price level similar to that in 1995. Though the electricity price further decreases (by 11% with respect to 1995), probably under influence of the liberalised electricity market in April 1998, it follows that the viability of CHP is in 1998 slightly better than in 1997.

8.3.3 The Netherlands

In table 8.7 the electricity and natural gas prices are depicted for the Netherlands. It immediately follows from this table that, in contrast to the other two countries, the electricity price increases by 3.4% from 1995 to 1998, probably under influence of the introduced Regulatory Energy Tax in 1996 (see sub-section 8.2.5). As well as the electricity price, also the gas price increases in the period between 1995 and 1998, by 4.4%. Between 1995 and 1997 the gas price increases by almost 9%. However the electricity price increased and almost levels out the increase of the gas price. Moreover CHP plants are not subjected to the Energy Regulatory Tax for electricity (if it is used on-site) and natural gas (see also sub-section 8.2.5). It is therefore concluded, with respect to 1995, that the viability of (gas-fired) CHP slightly decreased. In the following section the inferences of the previous sub-sections are used to qualitatively explore the diffusion of CHP within the United Kingdom, Germany and the Netherlands from 1995 to 1998.

Table 8.7: Dutch, natural gas prices for electricity generation, and electricity prices for industry, in Dfl. (Source: International Energy Agency, i.e. IEA, "Energy prices and taxes, 2nd Quarter 2000").

Year	Electricity (Dfl. per kWh)	Gas (Dfl. per 10E7 kCal GCV)
1995	0.1197	231.5
1996	0.1205	231.3
1997	0.1228	252.2
1998	0.1238	241.7

8.4 Share of CHP electricity

In the previous sections the PET-systems of the United Kingdom, Germany and the Netherlands and their developments, due to governmental interventions, have been discussed. In this section a qualitatively analysis is made of the diffusion of CHP in the countries mentioned through a bi-variate analysis between 1994 and 1998. Though, before the developments in the indicators (for the share of CHP electricity in the electricity sector) are discussed. The shares of CHP electricity in the electricity production of the United Kingdom, Germany and the Netherlands are displayed in table 8.8, below. These data stem from EUROSTAT, see section 7.3 in which the choice for these data has been explained.

Table 8.8: CHP electricity shares in electricity production of the United Kingdom, Germany and the Netherlands (source: EUROSTAT).

	1994	1995	1996	1997	1998
the United Kingdom	0,037	-	0,054	0,056	0,058
Germany	-	0,090	0,068	0,067	0,075
the Netherlands	0,395	-	0,427	0,479	0,526

From this table three characteristics in the development of CHP in and between the different countries can be discerned:

(1) A very large difference between the penetration of CHP electricity in the Netherlands and the other two countries, that already exists around 1995;

(2) The penetration of CHP electricity was in the Netherlands in 1998 33% larger than in 1994, in the United Kingdom about 57%;

(3) A "parabolic" development of the penetration of CHP electricity in Germany.

The first characteristic concerns a very large difference in the diffusion of CHP around 1995. It can therefore not be explained on the basis of the developments described in sections 8.2 and 8.3 regarding the PET-systems of the United Kingdom, Germany and the Netherlands. However in sub-section 8.1 the differences were described that existed between the three countries under study around 1995. It followed from the elaboration in section 8.1, that especially the Dutch PET-system was very conductive to the diffusion of CHP, as well as the price difference between natural gas and electricity. This in contrast to the much lower conductivity of the PET-systems of the United Kingdom and Germany, as well as the price differential between natural gas and electricity.

Regarding the development of CHP in the Netherlands from 1995 onwards, the policies pursued by the Dutch government, such as the Energy Investment Allowance, the introduction of the Regulatory Energy Act as well as agreements on energy efficiency seem to be very conductive to the diffusion of CHP.

With respect to the development of CHP within the United Kingdom, which only slightly increases from 1995 onwards, which can be explained by a decreasing viability of CHP, see sub-section 8.3.1. In Addition Graham Meeks argues that CHP has benefited from the widespread availability of relatively cheap natural gas and the rapid advances in small-scale power generation technology, which have made small-scale on-site power generation an economic reality. These factors, more than liberalisation may have created the opportunity for an expansion of embedded generation under the right economic circumstances.

In Germany the sharp decrease in the share of CHP electricity in total German electricity production is remarkable. It coincides with the abolishment of the support tax for the German coal industry, and the emergence of lower electricity prices endangering the exploitation of CHP. From 1995 to 1997 also the natural gas prices increase, which even more threats the diffusion of CHP. As by 1998 the natural gas prices for electricity generation drop to the level of 1995, German CHP plants immediately produce more electricity.

8.5 Chapter summary and conclusions

In this chapter the development of the indicator for the share of CHP electricity in the total electricity production of the United Kingdom, Germany and the Netherlands. Therefore the framework, i.e. the PET-system approach of K.M. Weber, discussed in chapter 2 has been applied. Though as a longitudinal survey could not be conducted within the context of this research, first the differences between the PET-systems under study were described as they were around 1995 (mainly on the basis of inferences of K.M. Weber and R.J.F. Hoogma). Second to take the system dynamics into account, the development of these systems of the United Kingdom, Germany and the Netherlands was described, especially regarding the impact of governmental decisions.

Around 1995 there are major differences in the PET-systems of the United Kingdom, Germany and the Netherlands. Though differences in all elements of the PET-systems have been described, most important are those between the structures of the Energy Supply Industry (ESI) and the viability of CHP in the countries under study. In the United Kingdom the ESI was revolutionary transformed, though with the objective to obtain more competition and initially with a minor interest in energy efficiency, which changed after the Rio-Conference. In the Netherlands the ESI was also reformed, but the distribution companies were obliged to buy electricity from independent power producers. In Germany such a reform has not taken place around 1995, though district heating was relatively common. In Germany CHP became less viable due to a decreasing price differential between natural gas and electricity. In the Netherlands this price differential increased, and was conductive to the diffusion of CHP in the Netherlands. While in the United Kingdom "interruptible" gas became interruptible it is considered to be detrimental to the diffusion of CHP.

From 1995 onwards to 1999 most remarkable are the realisation of the Kyoto Protocol (December 1997), the market reforms of the German ESI (April 1998) and Dutch ESI (January 1999), and the introduction of the Regulatory Energy Tax in the Netherlands (1996). Although in Germany also the abolishment of the support tax for the German coal industry on electricity was of importance. These interventions mainly influence the energy prices and therefore they have been used to explore the share of CHP electricity in the United Kingdom, Germany and the Netherlands.

In the United Kingdom from 1995 to 1998 the share of CHP electricity in the total electricity production increased by 7%, although the price differential between natural gas and electricity decreased. Though, according to Graham Meeks, CHP has benefited from the widespread availability of relatively cheap natural gas and the rapid advances in small-scale power generation technology, which have made small-scale on-site power generation an economic reality. In the Netherlands CHP benefited from an increasing price differential between natural gas and electricity. This in contrast to Germany, where CHP suffered from a decreasing price differential between natural gas and electricity, due to the abolishment of the support tax of the German coal industry.

9 Conclusions and Recommendations

In chapter one the goal and problem proposition of the research that underlies this report were formulated. They in essence concerned two parts. First the development of Combined Heat and Power (CHP) indicators for the ODYSSEE database and their implementation in that database. Second the interpretation through a qualitative analysis of the indicator for the share of CHP electricity in the total electricity production of the United Kingdom, Germany and the Netherlands. Though, have the objectives been fulfilled and has the problem proposition been answered? The objective of this chapter is to answer this question.

The targets set with respect to the development and the interpretation of the indicators were reached. First, standard ODYSSEE indicators for CHP can be defined, if new branches for CHP heat and electricity are created, i.e. whenever CHP heat and electricity are separated from the branches of respectively fossil thermal heat and electricity. The standard ODYSSEE indicators include besides the respective shares in the sector output, also the efficiency and it reverse. The efficiency is defined as the ratio of the process output and input.

Second, as CHP is a process that produces from one fuel energy input, two energy outputs (viz. heat and electricity), the input has to be allocated to both outputs. An allocation method has been chosen that allocates the CHP inputs according to the respective share fossil thermal means would have used to produce heat and electricity. Such an allocation allows for an unambiguous assessment of the efficiency indicators with respect to those of fossil thermal heat and electricity.

Third, it has been possible to explore the diffusion of CHP within the United Kingdom, Germany and the Netherlands, through a qualitatively analysis of the indicator for the share of CHP electricity in the total electricity production of these countries. Thus indicators for CHP have been developed that fit into the current system of indicators, and allow for a qualitative analysis and future assessment of CHP's contribution to energy savings and the reduction of CO_2 emissions.

Conclusion 1: ***The objective to develop indicators for CHP and interpret the indicator for the share of CHP electricity in the total electricity production of a country has been reached.***

Though with respect to the implementation of the indicators still some problems remain. First, in order to implement the indicators for CHP, as proposed and developed, into the ODYSSEE database, the data for CHP and fossil thermal heat and electricity have to be separately available. Currently, they can only be derived for the United Kingdom from data published in the Digest of United Kingdom Energy Statistics. For Germany and the Netherlands these data are not available, nor can they be derived from the data available from EUROSTAT.

Conclusion 2: ***On the basis of the data used in this report, the indicators adapted for fossil thermal heat and electricity and those developed for CHP cannot yet be implemented for Germany and the Netherlands, they can only be implemented for the United Kingdom.***

Moreover, as the heat available for other purposes of some CHP plants is not entirely used, the electricity accordingly produced cannot be denoted as CHP electricity. This electricity is denoted as condensed electricity and should be stored in the branch of fossil thermal electricity. To separate CHP electricity from condensed electricity, it is necessary to adopt a transparent method throughout Europe with which the condensed electricity produced by CHP plants can be determined and subsequently be allocated to the proposed branch of fossil thermal electricity. If such a common method is not adopted, it is not possible to compare the ODYSSEE indicators for CHP and fossil thermal electricity of different countries with each other. On the basis of this observation, a recommendation to EUROSTAT and the EU Member States national Statistics Offices is formulated:

Recommendation 1: ***Provide separate data for CHP and fossil thermal heat and electricity on the basis of a transparent common methodology, such as used by EUROSTAT in the survey of CHP data in 2000.***

If these data are available it is recommended to the Fraunhofer Institutes for Systems and Innovation research to:

Recommendation 2: ***Implement these data as well as the indicators developed into the ODYSSEE database.***

Recommendation 3: ***To use the allocation method as proposed in chapter 6, to allocate the CHP inputs to the outputs to be able to make an unambiguous assessment of the indicators for CHP in comparison to those of fossil thermal heat and electricity.***

With respect to small-scale CHP-plants, i.e. CHP-plants with an electrical capacity of 1 MWe or smaller, it has been concluded in chapter 5 that if it is necessary to follow their diffusion in the respective countries it is necessary to introduce an extra branch for small-scale CHP plants regarding their electricity production.

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Appendix

A1 ODYSSEE Indicators: techno-economic ratios and energy savings indicators for the transformation sector

The following text is a copy of the sections 2.3.1 and 2.3.2 from the document "*Methodology and calculation of indicators on the supply side and in the transformation sector for the ODYSSEE database*", which discusses the techno-economic ratios and energy savings indicators for the transformation sector".

2.3.1 Indicators in the transformation sector as a whole (1st level)

The most general indicator is the gross transformation unit consumption (cutrf) or - equivalent- gross transformation efficiency (rdtrf),

$cutrf = intrf / pdtrf = \Sigma_k\, shxxx_k\, cuxxx_k$
$= cutel*shtel+cutvp*shtvp+cutpe*shtpe+cutco*shtco$

intrf: gross transformation input
pdtrf: gross transformation output
k: summation index for different subsectors;
sh: share of subsector output in total gross transformation output
cu: gross input/output of each transformation subsector (rd = 1/cu)

and
$rdtrf = 1/cutrf = 1/(\Sigma_k\, shxxx_k\, cuxxx_k)$

Note 1: rdtrf is often substantially higher than the more global rdtfc (which includes foreign trade and primary energy carriers in end-use). At the first view, this is surprising, since cutfc also includes the "high efficiency" routes of primary energy carriers in end-use and of foreign trade (in case of imports) without substantial losses. The reason is the gross consideration of transformation (closer to a technical conversion efficiency) in rdtrf in contrast to the implicit net consideration of transformation in the context of final/primary energy consumption and rdtfc. Net transformation efficiency is lower than gross efficiency, since transformation internal consumption and output is not relevant to the primary or final energy balance and not included in the net transformation concept ("reuse and loss effect", for details see Landwehr, Jochem 1997).

Note 2: heat production (pdtvp) includes uncombined district heat as well as heat production in CHP plant. The respective input for CHP heat can be calculated according to the convention used in international statistics (see shaded box below in the text) if the CHP fuel inputs are available and not included in overall thermal electricity inputs. In international statistics there are substantial data problems that do not distinguish fuel inputs into CHP and uncombined generation. Furthermore very often district heat inputs have been omitted or included in a "electricity and heat" sector. Though it would be preferable to have all data separated, it depends largely on the country whether data are available or not. As a consequence, interpretations of electicity and heat production efficiencies across countries are have take into account these flaws in data availablility.

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[7] In contrast to earlier versions.

Since the shares of different subsectors in transformation output varies strongly over time, structural effects obscure actual efficiency progress in transformation as a whole. The transformation unit consumption can be calculated for frozen structure (reference year 1985). The corrected unit consumption cutrfse reflects the structural differences in transformation in 1985 but reflects the efficiency progress in transformation over time.

cutrfst= cutelst*shtel(1985)+cutvp*shtvp(1985)+cutpe*shtpe(1985)+cutco*shtco(1985)

> cutelst: electricity unit consumption at constant technology structure (definition below)
> cu..., sh... unit consumption and shares in transformation output of the transformation subsectors tvp, tpe, tco (see figure 2)

rdtrfst = 1/ cutrfst

Techno-economic effects:
transformation input can be calculated as:
$intrf = \Sigma_k\, pdtrf_i * shxxx_{k,i} * cuxxx_{k,i}$

As activity indicator of transformation the gross transformation output (pdtrf) is used. The changes in gross output (activity, structure, other include. efficiency) of four transformation subsectors (index k) are analysed with regard to the entailed changes in input in the transformation sector.
Three different effects can be discerned:

1. effect due to the transformation output pdtrf ("activity or quantity effect"): Under the assumption of frozen[8] share and and frozen efficiency[9] of each subsector, the impact (eftrfqt) of changes in total transformation output on transformation input is calculated

$$eftrfqt_{m,0} = \sum_k cutxxx_{k,0} \cdot shtxxx_{k,0} \cdot (pdtrf_m - pdtrf_0)$$

or in relative terms

$$ifeftrfqt_{m,0} = eftrfqt_{m,0} / intrf_0$$

This effect reflects the transformation input changes because of changing demand on (domestic and foreign) transformation output.

2. Effect of changing shares of converted energy carriers shtxxx ("structural effect"): Under the assumption of frozen[5] output and frozen efficiency of each subsector, the

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[8] frozen meaning constant at the value of the reference year (index 0)

[9] correct: unitary consumption

Currently this second way of inlcuding the residual effect in eftrfcu is not not used in the calculations!

ion

input can be calculated

$$eftrfse_{m,0} = eftelse + \sum_k \cdot cutxxx_{k,0} \cdot pdtrf_0 \cdot (shtxxx_{k,m} - shtxxx_{k,0})$$

eftelse: calculated below

or in relative terms

$$ifeftrfse_{m,0} = eftrfse_{m,0} / intrf_0$$

This "structural" effect includes substitution among the converted energy carriers of the transformation sector considered and includes structural changes within the electricity subsector[10].

3. Other effects incl. energy efficiency cutxxx („unit consumption effect“): Under the assumption of frozen output and frozen shares of each subsector, the impact (eftrfcu) of changes in unitary energy consumption on total transformation input is calculated by

$$eftrfcu_{m,0} = eftelcu + \sum_k \cdot shtxxx_{k,0} \cdot pdtrf_0 \cdot (cutxxx_{k,m} - cutxxx_{k,0})$$

eftelcu: calculated

k: here only tpe, tvp and tco; tel is excluded!

$$ifeftrfse_{m,0} = eftrfse_{m,0} / intrf_0$$

This effect evaluates changes in unitary consumption for each subsector. While eftelcu combines unit consumption changes in each electricity subsector (2nd level of disaggregation) for the other sectors only the unit consumption changes in the subsector as a whole are evaluated. It therefore might include some structural changes (product mix etc.) within each of the subsectors, that are not further disaggregated.

The approach leaves a residual amount if the total change of primary energy consumption is explained by the sum of the three effects calculated above. The alternative approach, without a residue, would be:

$$eftrfcu_{m,0} = (intrf_m - intrf_0) - eftrfqt_{m,0} - eftrfse_{m,0}$$

Relative change:

$$ifeftrfcu_{m,0} = eftrfcu_{m,0} / intrf$$

Currently this second way of inlcuding the residual effect in eftrfcu is not not used in the calculations!

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[10] Electricity is included "twice": in the changing shares of fuel carriers and with regard to electricity sector internal structural changes

2.3.2 Effect in the electricity producing subsector (2nd level)

The average indicator for total electricity transformation is

$\text{cutel} = \Sigma_k \, \text{shyyy}_k \, \text{cuyyy}_k$
$= \text{cuehy*shehy+cuenu*shenu+cuethtx*shethtx+ cuethtw*shethtw+ cuedv*shedv}$

k: summation index for different electricity subsectors;
sh: share of subsector output in total gross electricity output
cu: gross input/output of each electricity subsector (rd = 1/cu)

and
$\text{rdtel} = 1/\text{cutel} = 1/(\Sigma_k \, \text{shxxx}_k \, \text{cuxxx}_k)$

In addition to the indicators averaging total electricity:

The changes in gross output of the different electricity branches is analysed with regard to the entailed gross input consumption of the electricity sector. The methodology employed is equivalent to that in chapter 2.3.1, but is nevertheless given explicitly for reasons of transparency. yyy denotes the codification for electricity branches used in the database.
The effects eftelse (structure) and eftelcu (unit consumption - efficiency) are already included in the 1st level effects eftrfse and eftrfcu respectively.

Three different effects can be discerned:

1. effect of the electricity production output ("activity or quantity effect"): Under the assumption of frozen share and and frozen efficiency of each electricity subsector, the impact (eftelqt) of changes in total electricity production on the total energy demand of the electricity branch is calculated

$$\text{eftelqt}_{m,0} = \sum_k \text{cueyyy}_{k,0} \cdot \text{sheyyy}_{k,0} \cdot (\text{pdtel}_m - \text{pdtel}_0),$$

or in relative terms

$\text{ifeftelqt}_{m,0} = \text{eftelqt}_{m,0} / \text{intel}_0$

This effect identifies the changes of total energy input into the electricity subsector due to changing (domestic and foreign!) demand on electricity production output.

2. effect of changing shares of electricity production technologies ("structural effect"): Under the assumption of frozen output and frozen efficiency of each electricity branch, the impact (eftelse) of changes in shares of electricity produced by different technologies on the energy input is calculated:

$$\text{eftelse}_{m,0} = \sum_k \text{cueyyy}_{k,0} \cdot \text{pdtel}_0 \cdot (\text{sheyyy}_{k,m} - \text{sheyyy}_{k,0})$$

or in relative terms

$\text{ifeftelse}_{m,0} = \text{eftelse}_{m,0} / \text{intel}_0$

This structural effect includes, besides the different efficiencies of thermal power or cogeneration plants, some kinds of fuel substitution on the input side of electricity (e.g. nuclear for fossil fuels).

3. other effects incl. energy efficiency ("unit consumption effect"): Under the assumption of frozen output and frozen shares of each electricity branch, the impact of changes (eftelcu) in specific energy consumption of each branch on total fuel input is calculated

$eftelcu_{m,0} = \Sigma_k \, shexxx_{k,0} \, pdtel_0 \, (cuexxx_{k,m} - cuexxx_{k,0})$

Relative change:

$$ifeftelcu_{m,0} = \frac{eftefcu_{m,0}}{intel_0}$$

This implies that the residual effect is not included in the "other effects" and not explicitly calculated.

This effect evaluates changes in specific consumption for each electricity production technology. These changes can be due to

- fuel substitution and change of shares of different technologies within the individual electricity branches, e.g. capacity changes of thermal power stations, changed steam demand from cogeneration plants, structural changes among renewables,
- improved efficiencies.

Note 3: The disaggregation chose for electricity production into different subsectors is decisive for the content of either structural or "other effects including efficiency". If fossil thermal electricity production can be broken down into CHP and non-CHP generation, an increase of CHP in share would be considered as structural effect. This is *not* the case in the current calculations in Odyssee due to missing data in the underlying databases: Since fossil thermal electricity production includes CHP and non-CHP electricity generation an increase in CHP shows as lowering of cueth (unit consumption of total thermal) or increase in rdeth (average efficiency of total thermal electricity production). A similar situation arises within transformation if district heat is not separated from electricity production (see Note 2 above).

A2 ODYSSEE Indicators: CO_2 emission factors

The following text is a copy of Annex 5 from the "*Cross country comparison on energy efficiency indicators (The ODYSSEE project phase 6; Final report Vol 1: Methodology)*", which discusses the CO_2 emission factors for the transformation sector".

5 Transformation sector

The transformation sector is not based on national information but rather on international statistics (IEA statistics with some modifications). This allows to carry out the calculation of overall carbon emission for each country according to the **IPCC reference approach** (for which a detailed step by step procedure is described in OECD/IEA 1997 including a datasheet for the calculations). This procedure delivers the full **national** carbon emissions not only the emissions at the final demand. It is based on apparent consumption (production + imports - exports - international bunkers - stock change). It **excludes imported electricity!**). The steps to be carried out in the reference approach are:

- Estimate apparent fuel consumption in original units
- Convert to common energy unit
- Multiply by emission factors to compute the carbon content
- Compute carbon stored (feedstock, lubricants, bitumen and coal tars)
- Compute carbon unoxidised (a slight fraction of 1-2% of the carbon is not oxidised
- Convert Carbon oxidised to CO2-emissions

This calculation procedure could be carried out on the information available in the database for the transformation sector, but the calculation procedure is not yet implemented. Instead, the sectoral approach was chosen. Currently the calculations yield at the same time the emission factors for electricity and heat generation in terms of emissions per kWh generated by considering the emissions from the power and heat generation sector (combined heat and power generation might pose a separation problem). The information is obtained in form of time series which can be used to calculate changes in emission from changes in the power and heat production mix.

An alternative approach would be that each country provides this information for electricity and heat, but it would be a pity not to use the information available on the transformation sector in ODYSSEE.