Ecodesign Preparatory Study on Steam Boilers (ENTR Lot 7)

Presented by

PricewaterhouseCoopers EEIG's consortium
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www.eco-steamboilers.eu

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This consultation document contains preliminary information and conclusions on Tasks 1 to 7 of the Ecodesign Preparatory Study on Steam Boilers. Its content may be modified during the stakeholder process.

The information and views set out in this document are those of the authors and do not necessarily reflect the official opinion of the European Union.

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Introduction

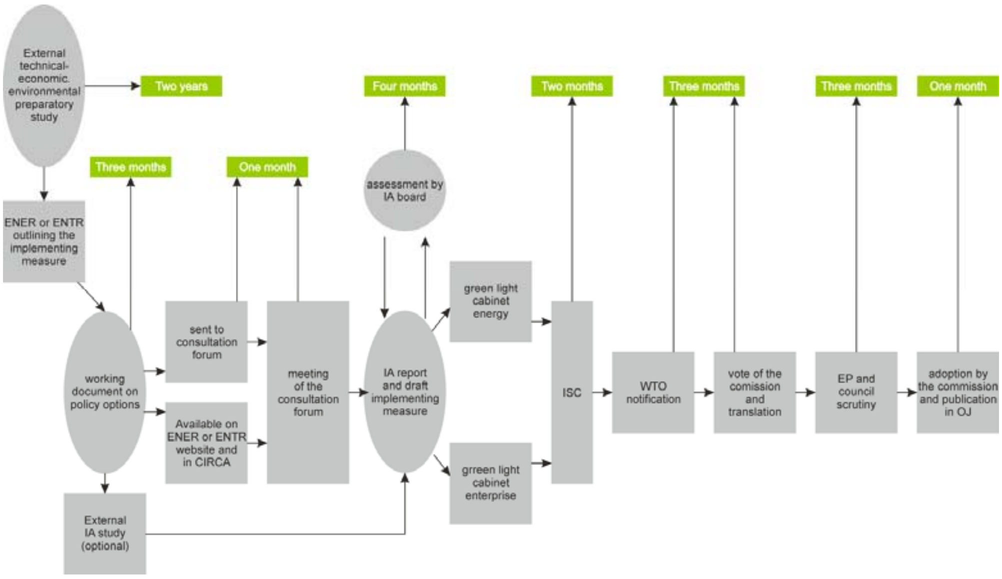
Introduction

The Ecodesign Directive (Directive 2009/125/EC) establishes a framework for the setting of Community Ecodesign requirements for energy-related products with the aim of ensuring the free movement of such products within the internal market. This preparatory study is carried out in the framework of this Directive. Its aim is to provide the European Commission with a technical, environmental and economic analysis of steam boilers according to Article 15 of the Ecodesign Directive.

1.1 Legislative process

The process of making Ecodesign Regulations for specific product groups is depicted in Figure 1.

Figure 1 - Process of making Ecodesign Regulations1



The first step in considering whether and which Ecodesign requirements should be set for a particular product, is a preparatory study recommending ways to improve the environmental performance of the product. The preparatory study provides the necessary information to prepare for the next phases in the policy process (to be carried out by the Commission) and in particular the impact assessment, the consultation forum, and the possible draft implementing measures laying down Ecodesign requirements for products.

Within the scope of this study are the technical properties of the product as well as the market data. This enables the determination of parameters like Best Available Technology (BAT) and Least Life Cycle Cost (LLCC) of the product.

The Commission then prepares a working document basing on the results of the preparatory study. Following the completion of the working document the Consultation Forum's first meeting is organised in which stakeholders are able to express their views on the working paper and the possible implementing measures presented in it. The Consultation Forum consists of representatives from member states, industry and NGOs. In parallel an external impact assessment study is prepared.

Afterwards, the final version of the proposed legislation is sent to the Regulatory Committee on the Ecodesign of Energy-related Products (EEP) that consists of

[1] Presentation by Paul Hodson: Introduction to Ecodesign, 13/04/2011 (modified).

officials from all member states. The committee is allowed to make adjustments to the proposal and should reach a qualified majority to allow the Commission to present the proposal to the EP and the Council. After voting by the EEP the European Parliament (EP) and the Council have three months to apply scrutiny, in which they can review the final proposal and potentially still block its introduction.

The World Trade Organization (WTO) is notified after 3 months and the implementing measure is accepted after publication in the Official Journal of the European Union.

1.2 Ecodesign evaluation

The effectiveness of the Ecodesign Directive and its implementing measures was reviewed and assessed, according to Article 21 of the Directive. In preparation for the review, an independent evaluation study[2] was carried out to examine the functioning of the Directive concluded in 2012, including the appropriateness of extending the scope of the Ecodesign Directive beyond energy related products.

The study concluded that, in general, the Ecodesign Directive achieves its policy objectives (free movement of goods and environmental protection) and that no revision of the Directive is deemed appropriate at the moment or necessary to increase its effectiveness and of its implementing measures.

The study has also indicated challenges faced at EU and Member States levels in the application of the Ecodesign Directive and its implementing measures, including:

- Complex and lengthy preparatory procedure;
- Unavailability of reliable data to inform policy decisions (e.g. market trends and technological changes, market data, performance data from market surveillance activities etc.);
- Insufficient coordination of Ecodesign measures with other pieces of the EU legislation, such as WEEE, RoHS or EPBD Directives;
- Lack of resources to deal with the increasing amount of the regulatory, communication and standardisation work;
- Question on the level of ambition of requirements, and especially in Tier-1;
- Remaining potential to further address non-energy related issues of energy related products (e.g. material efficiency, recyclability etc.);
- Delays in the elaboration of suitable harmonised standards;
- Insufficient and ineffective market surveillance.

The outcome of the study and the review of the Ecodesign Directive were discussed at a meeting of the Ecodesign Consultation Forum on 19 April 2012, on the basis of a Working Document.

The study concluded that, in general, the Ecodesign Directive achieves its policy objectives (free movement of goods and environmental protection) and that no revision of the Directive is deemed appropriate at the moment or necessary to increase its effectiveness and of its implementing measures.

After the 2012 review of the Ecodesign Directive, certain aspects of it are currently reassessed in the framework of an evaluation of the Energy Labelling Directive.[3]

[2] CSES (2012): Evaluation of the Ecodesign Directive (2009/125/EC). Final Report. http://cses.co.uk/ecodesign_evaluation/documents/

[3] Evaluation of the Energy Labelling Directive and Specific Aspects of the Ecodesign Directive. http://www.energylabelevaluation.eu/eu/documents/

Task 1: Scope

2 Task 1: Scope

2.1 Objectives

The main objective of this task is to determine a clear scoping for steam boilers according to the needs of the Ecodesign process. For this definition we take into account legal, normative and functional aspects relevant to the topic. These considerations will then serve as a basis for the whole study.

The product classification and definition is performed in close agreement with the commission after a stakeholder consultation. It is subject to constant review along the following tasks.

2.2 Product scope

2.2.1 General description and definition

The term "boiler" is generally used for any closed vessel in which water or other fluid is heated. The heated fluid does not have to boil necessarily. Boilers are used in various processes or heating applications, such as central heating, boiler-based power generation, cooking and sanitation.[4]

This preparatory study deals with boilers based on water for steam generation. The initial focus of this study according to the common Methodology for Ecodesign of Energy-related Products (MEErP) is to analyse boilers with a power output <50 MW. A definition of the term Steam Boiler within the context of this study is given in the conclusion of this Task (Chapter 1.5).

Steam boilers can be categorized in several ways. On typically used categorization is based on the way the water-steam medium is flowing through the boiler. Based on this distinction, fire tube and water tube boilers can be distinguished. Next to this categorization, other categorizations of steam boilers can be used as well.

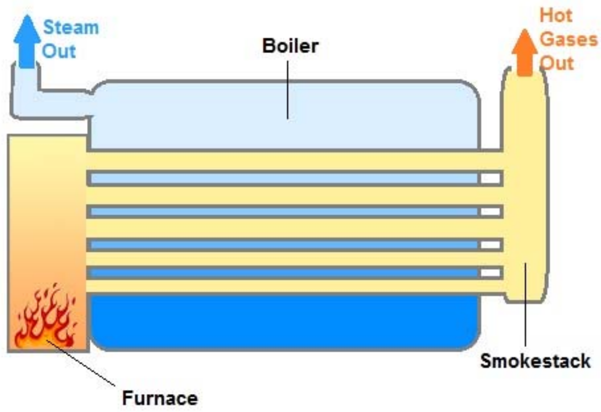
2.2.1.1 Fire tube boilers (Shell boilers)

In these boilers, hot gases pass through the tubes. Boiler feed water in the shell side is converted into steam (Figure 2, Figure 3). Fire tube boilers are generally used for relatively small steam capacities and low to medium steam pressures. As a guideline, fire tube boilers (shell boilers) are competitive for steam rates up to 28,000 kg/hour and pressures up to 30 bars.[5] Fire tube boilers are available for operation with oil, gas or solid fuels. For economic reasons, most fire tube boilers are nowadays of "packaged" construction (i.e. manufacturers shop erected) for all fuels.

[4] The preparatory study is only focusing on steam boilers. Hot water boilers are not part of the study. However in Task 2 the term super heated water boiler is mentioned several times. This is only an artefact due to the improper categorization of PRODCOM database. We assume that "super heated water boilers" are actually steam boilers as there is no such thing as superheated water.

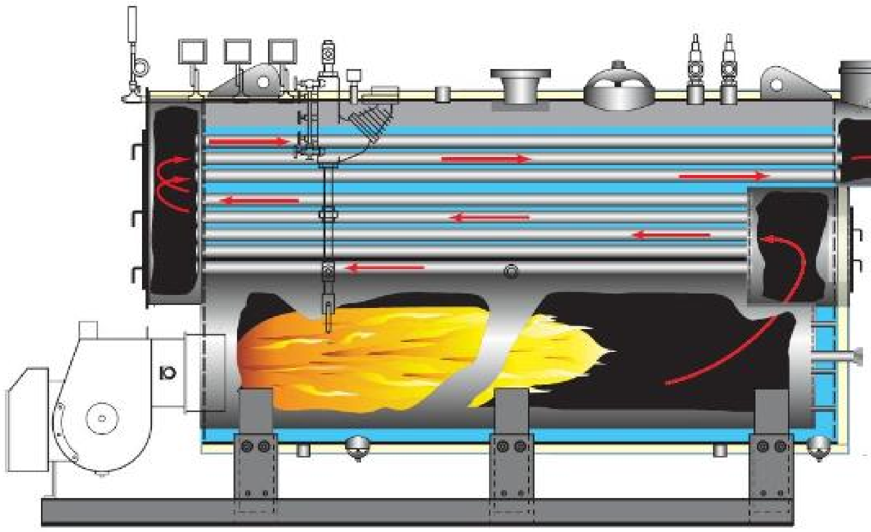
5 In a prior version of this report other values had been presented. These values had been updated in response to stakeholder comments from industry.

Figure 2 - Functional scheme of a fire tube boiler



Source: http://www.globalspec.com/

Figure 3 -Fire tube boiler



Source: http://www.wargaboiler.com/

The main advantages of fire tube boilers are:

- Relatively low cost
- Easy for cleaning
- Compact in size
- Easy to replace tubes
- Well suited for space heating and industrial process applications

Nevertheless fire tube boilers have also some limitation, the most important of which are presented below:

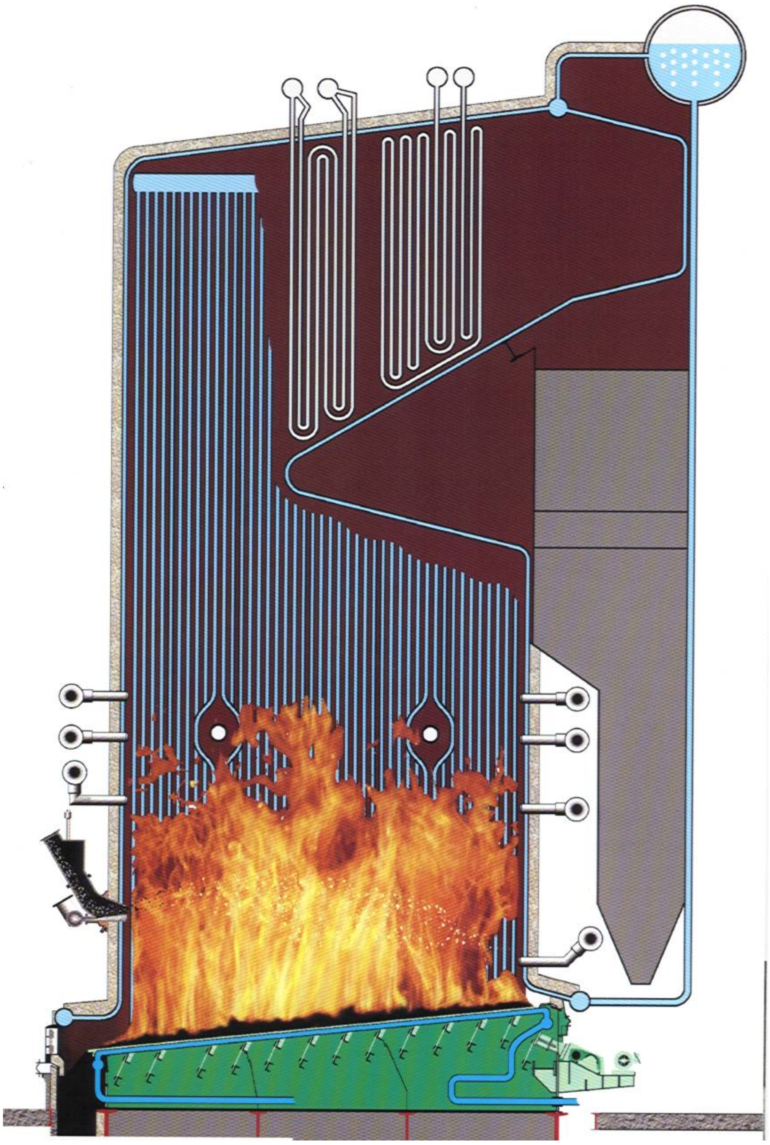
- Not suitable for high pressure applications higher than 25bar
- Limitation for high capacity steam generation

2.2.1.2 Water tube-Boilers

In common water tube boiler, boiler feed water flows through the tubes and enters the boiler drum (Figure 4). The circulated water is mainly heated by the combustion gases and converted into steam. These boilers are selected when the steam demand as well as steam pressure requirements are high.

Most modern water boiler tube designs are within the capacity range 4,500 – 120,000 kg/hour of steam, at very high pressures (supercritical boilers work in pressures above 350bar).

Figure 4 - Water tube boiler



Source: http://boilersarfi.com/our-products.html

Advantages of water tube boilers are:

- Available in sizes larger than the sizes of the fire tube design
- Able to handle higher pressures up to 250-260 bar
- Ability to reach at very high steam temperatures, up to 650 °C

Disadvantages of the water tube boilers:

- High initial cost
- More demanding cleaning procedures, due to the design
- No commonality between tubes

- Physical size

2.2.1.3 Other categorizations of boilers

Next to this often used distinction, other categorizations of boilers can be used, as well. They include the following categories:

2.2.1.3.1 Categories of boilers based on fuel

The heat for a boiler is provided by the combustion of any of several fuels, including solid (wood, coal), liquid (oil) and gaseous (natural gas) fuels. Other types of boilers (heat recovery steam generators) utilize the heat rejected from other processes such as gas turbines, while others operate by electricity and solar thermal power.

2.2.1.3.2 Superheated steam boilers

Superheated steam boilers, which are used to produce steam above saturation temperature, are a distinct category of boilers which are often called superheaters. They produce stream of much higher temperature, leading to increased overall efficiency of both steam generation and its utilization. Special care should be taken to ensure that no system component of the superheater fails, due to the dangerous nature of any escaping superheated stem. Depending on the dominant heat transfer mechanism, superheaters can be of the radiant or convection type, or a combination thereof.

2.2.1.3.3 Categories based on draught

The draught inside the boiler can be achieved either by natural or mechanical means. Because of the high sensitivity of natural draught to ambient external conditions, most boilers now depend on mechanical draught equipment in order to attain more reliability of operation. Mechanical draught can be induced, forced or balanced.

2.2.1.3.4 Other performance parameters

Next to these classifications, boilers can also be distinguished by other criteria. They include among others the boiler capacity, the output pressure or the type of generated steam (saturated, super-heated).

2.2.1.4 Boiler design considerations

Boiler design is subject to various considerations. Some of the main factors affecting the design procedure of a boiler include:

- Production of a maximum quantity of steam with minimal fuel consumption
- Economic feasibility of installation
- Minimal operator attention required during operation
- Capability for quick starting
- Conformity to safety regulations
- Heat source - the fuel to be burned and its ash properties or the process material from which the heat is to be recovered
- Capacity / steam output required, usually measured in tonnes per hour or kg/sec
- Steam condition - pressure, temperature, etc.
- Safety considerations
- Mechanical constraints
- Cost restrictions

- Monetary cost
- Tensile strength of material must be considered while using any joining processes

2.2.2 Specific definitions and characterizations

According to the MEErP methodology, product scoping should be discussed with regard to existing classifications. For this purpose, we briefly discuss the corresponding classifications according to the PRODCOM classification as well as according to other classifications.

2.2.2.1 PRODCOM classification

According to the MEErP methodology, the official European production statistics from the PRODCOM database should be used as a preferential data source for refining the scope of preparatory studies. PRODCOM consists of a survey of at least annual frequency, with the purpose of collecting and disseminating statistics on the production of various industrial (mainly manufactured) goods in the EU, mainly in terms of value and quantity. The word PRODCOM stands for the French "Production Communautaire". All products that are involved in the survey are listed in the PRODCOM lists and are given an eight-digit label. The first four digits refer to the equivalent class within the Statistical classification of economic activities in the European Community (NACE), while the subsequent two correspond to subcategories within the Statistical classification of products by activity (CPA). The PRODCOM survey results can be accessed on the Eurostat website in an extensive database containing annual production and economic data back from 1995.

The current PRODCOM labels for various boiler and heater types according to NACE Rev.2 (a revised classification developed from 2006) are listed in Table 1. The problem that occurs when using the PRODCOM data is that it does not provide details on the thermal capacity of the products. This complicates the comparison with the product scope of 1 to 50 MW power output. A more detailed analysis on the PRODCOM database is conducted in Task 2.

Table 1 - Steam or other vapour generating boilers; super-heated water boilers6

PRODCOM category	Description	External trade nomenclature reference for 2012(HS/CN)
25.30.11.10	Water tube boilers (excluding central heating hot water boilers capable of producing low pressure steam)	8402[.11+.12]
25.30.11.50	Vapour generating boilers (including hybrid boilers) (excluding central heating hot water boilers capable of producing low pressure steam, water tube boilers)	8402 [.19(.10+.90)]
25.30.11.70	Super-heated water boilers (excluding central heating hot water boilers capable of producing low pressure steam)	8402 20

[6] Prodcom list 2012, Eurostat. Please note that "Water tube boilers" is a clear definition. This is not the case for "Vapour generating boilers" because also other fluids than water might be vaporized. However this is the terminology used in PRODCOM.

2.2.2.2 Harmonized Commodity Description

Next to the PRODCOM classification, the HS 84.02 code refers to the Harmonized Commodity Description and Coding System, which is an international system of names and numbers for classifying traded products created by the World Customs Organization and used in determining tariffs on items shipped internationally. According to the HS database, the HS 84.02 code involves five different products (Table 2).

Table 2 - HS codes and respective product categories

HS Code	Product category
840211	Water tube Boilers With a Steam Production Exceeding 45t Per Hour
840212	Water tube Boilers With a Steam Production Not Exceeding 45t Per Hour
840219	Other Vapour Generating Boilers, Including Hybrid Boilers
840220	Super-heated Water Boilers
840290	Parts of Steam Generating Boilers and Super-heated Water Boilers

2.2.3 Performance parameters ("functional unit")

2.2.3.1 Boiler capacity

A primary performance parameter of the boiler is the (nominal) capacity of the boiler. The capacity can refer either to the amount of steam produced over a defined time unit, (i.e. t/hr), or in terms of heat duty produced under base load operation (in kW). It is evident that the base load of a boiler is not its actual load during operation, since the steam and heating requirements can vary greatly.

Another performance parameter of boilers is their efficiency, which is described next.

2.2.3.2 Boiler efficiency

Boiler efficiency may be indicated by:

- **Combustion efficiency** indicates a burner's ability to burn fuel and is measured by unburned fuel and excess air in the exhaust gas stream. The amount of excess air in modern conventional boilers is approximately 10-15% for complete combustion of the fuel.
- **Thermal efficiency**, which is used to rate the effectiveness of the transfer of the heat derived from the combustion process to the water or steam in the boiler, without taking into consideration radiation and convection heat losses. It is a measure of exclusively the heat exchanger of the boiler.
- **Fuel to fluid efficiency** is the overall efficiency of the boiler, taking into account radiation and convection losses.
- **Heat content of generated vapour** is expressed as the energy of the steam output of the boiler. It is a function of its pressure and temperature and determines the extent of usage capacity of the steam.

The boiler efficiency is equal to the amount of heat exported by the fluid (water, steam etc) divided by the heat provided by the fuel.

$$\eta_b = \frac{Q_{out}}{Q_f}$$

Another method to measure boiler efficiency is the heat loss method, which is based on accounting for all the heat losses. The actual measurement is performed by subtracting from 100 percent the total percent stack, radiation and convection losses. Furthermore losses due to enthalpy and unburned combustibles in ash and flue dust for solid fuels are subtracted for shell boilers (as per EN 12953-11:2003) or losses due to enthalpy and unburned combustibles in tap and flue dust are subtracted for water tube boilers (as per EN 12952-15:2003). The resulting value is the boiler's fuel-to-useful heat output efficiency.

$$\eta_b = \frac{Q_f - Q_{loss}}{Q_f}$$

The stack losses consist of the heat carried away by dry flue gases exiting the boiler and unburned combustibles in ash and flue dust for solid fuels. They are determined by the stack temperature, the temperature of the flue gases and reflect the energy that did not transfer from the fuel to the stream or hot water. Lower stack temperature means more effective heat transfer design and higher efficiency.

Radiation and convection losses represent heat radiating from the boiler and heat lost due to air flowing across the boiler. These losses are essentially constant throughout the firing range of a particular boiler, but vary between different boiler types, sizes and operating pressures.

An extensive discussion on the components and the measurement of the boiler efficiency can be found in the section of Task 4 of the Preparatory Study.

2.2.3.3 Pollutant emission factors

An additional parameter that can also be used for the evaluation of steam boilers regards the emission factors of various pollutants (NO_x, SO_x, particulate matter emissions etc). These can be expressed as the ratio between the quantity of an emitted pollutant (in a mass or volume basis) and the useful product (units of thermal energy/steam produced). These pollutant emission factors are strongly affected by the boiler efficiency which determines the fuel consumption rate and therefore the flue gases produced. However, they can also be dependent on other elements such as the type of the burners, the type of the fuel used and post-combustion pollutant control equipment. Another direct dependency exists between the boiler operating temperature and NO_x-emissions.

Considering the above, the fuel to fluid efficiency can be considered as the primary functional unit of the steam boiler, since it possess a more general field of application and has a significant impact on the economic and environmental evaluation parameters of the product. It expresses the actual overall energy behaviour of the boiler and represents the accumulated efficiency of all of its subsystems.

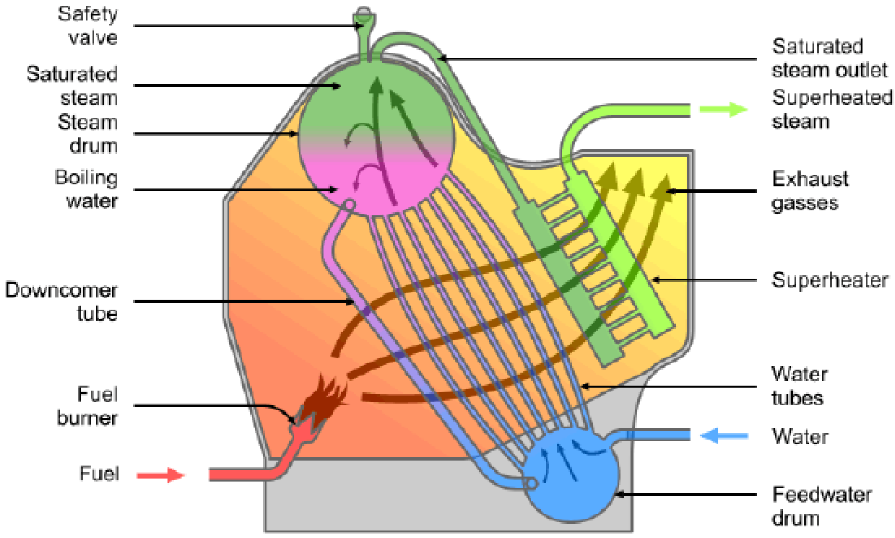
The boiler capacity, additional efficiency parameters, vapour energy content and pollutant emission factors can be regarded as secondary functional units which can be utilized as tools for further evaluations.

2.3 Test standards

2.3.1 European Standards

According to website of the Comité Européen de Normalisation (CEN), "A European Standard (EN) is a standard that has been adopted by one of the three recognized European Standardisation Organisations (ESOs): CEN, CENELEC or ETSI. It is produced by all interested parties through a transparent, open and consensus based process." European Standards are a key element of the Single European Market and are currently created not only for technical reasons, but as platforms to enable greater social interaction with technology and facilitate market exchange across industries.

Figure 5 - Marine type tube boiler for steam generation - steam generator (feedwater drum, steam drum, downcomer tube) and superheater



Source: Wikipedia images

At the very moment, the only EN standards applicable for the steam boiler product group are related with the manufacturing, the structural properties and the quality assurance of steam boilers. These are EN 12952 for water tube boilers, EN 12953 for shell boilers and EN 14222 for stainless steel shell boiler. They are introduced by the listed standards in the following table. In the table only general standards are mentioned – more specified standards affecting several fields of design can be derived from the content of the general documents.

Table 3 - EN standards for boilers and burners

Standard	Objective
EN 12952-1:2014	Water-tube boilers and auxiliary installations
EN 12953-1:2012	Shell boilers
EN 267	Forced draught burners for liquid fuels
EN 676	Automatic forced draught burners for gaseous fuels

No other standard relevant to energy efficiency of boiler is identified.

2.3.1.1 EN 12952-1-Water tube boilers and auxiliary installations - Part 1: General

This European Standard applies to water tube boilers with volumes in excess of 2 l for the generation of steam and/or hot water at an allowable pressure greater than 0,5 bar and with a temperature in excess of 110°C as well as other plant equipment.

More specifically, the purpose of EN 12952 is to ensure that the hazards associated with the operation of water tube boilers are reduced to a minimum and that adequate protection is provided to contain the hazards that still prevail when the water tube boiler is put into service. This protection is achieved by the proper application of the design, manufacturing, testing and inspection methods and techniques incorporated in the various parts of this standard. This standard refers to:

- The water tube boiler including all the pressure parts from the feed water inlet (including the inlet valve) up to and including the steam and/or hot water outlet (including the outlet valve or, if there is no valve, the first circumferential weld or flange downstream of the outlet header). All superheaters, reheaters, economizers, the associated safety accessories and interconnecting tubing are heated by means of the gases of combustion and are not capable of isolation from the main system by interposing shut-off valves. Additionally, the tubing that is connected to the boiler involved in services such as draining, venting, desuper-heating, etc., up to and including the first isolating valve in the tubing line downstream of the boiler. Reheaters which are heated by the flue gas or independently fired, and are separately provided with their safety accessories including all control and safety systems.
- isolatable superheaters, reheaters, economizers and related interconnecting tubing
- the heat supply or firing system
- the means of preparing and feeding the fuel to the boiler including the control systems
- the means of providing the boiler with feed-water including the control system
- the pressure expansion vessels and tanks of hot water generating plant.

Other plant equipment:

- the boiler supporting structural steelwork, the thermal insulation and/or brickwork and the casing
- the means of providing the boiler with air including the forced draught fans and air pre-heaters which are heated by the gases of combustion
- the facilities for moving flue gases through the boiler up to the stack inlet, including the induced draught fans and the air pollution reducing equipment located in the flue gas removal path
- all other equipment necessary for the operation of the boiler plant.

For steam generator shell boilers the certified steam capacity of the safety valves must exceed the allowable steam production. The calculation of the steam capacity of the safety valve for the steam conditions, for which no certified steam capacity is available, must comply with ISO 4126-1 and it must exceed the allowable steam production (EN 12953-8, Par 4.2.1).

2.3.1.2 EN 12953-1:2012-Shell boilers - Part 1: General

This European Standard applies to the generator, from the feed-water or water inlet connection to the steam or water outlet connection and to all other connections, including the valves and steam and water fittings. If welded ends are used, the requirements specified herein begin or end at the weld where flanges, if used, would have been fitted.

Similarly to the previous standard that was described, this European Standard applies to shell boilers with volumes exceeding 2 litres for the generation of steam and/or hot water at a maximum allowable pressure greater than 0,5 bar and with a temperature in excess of 110 °C. The boilers covered by this European Standard are intended for land use for providing steam or hot water. For Low Pressure Boilers less stringent requirements concerning design and calculation are acceptable. The rules of this standard equally apply for boilers operating at a pressure on the gas-side greater than 0,5 bar. However, it is generally considered that additional design analysis, inspection and testing may be necessary.

Where a particular boiler is a combination of shell and water tube design then the water tube standard series EN 12952 is used in addition to this European Standard. 1.2. It must be noted that this European standard does not apply to non-stationary boilers, e.g. locomotive boilers, thermal oil boilers or boilers where the main pressure housing is made of cast material.

2.3.1.3 EN 12952-15:2003-Water tube boilers and auxiliary installations - Part 15: Acceptance tests

This European Standard covers direct-fired steam and hot water generators, including the auxiliaries. A steam generator normally consists of the flue gas-heated evaporator, the superheater, the reheater, the feedwater heater, the air heater, the fuel heater, if any, and the fuel burning equipment. The term 'direct-fired' relates to equipment by means of which the chemical heat in the fuel of known composition is converted to sensible heat. Such equipment can involve stoker firing, fluidized-bed combustion or burner systems. The auxiliaries include the fuel feeders, the pulverizer, the FD (forced draught) fan, the ID (induced draught) fan, the facilities for removal of the refuse (combustion residues), the steam air heater, the main air heater, the fuel heater, if any, and the dust collector. For the purposes of this standard, steam and hot water generators are defined as vessels and piping systems in which 75% of the steam flow rate is at a pressure higher than atmospheric one and is generated for use external to the system. Accordingly, it includes cases where 75% of the water flow rate is heated to a temperature higher than the saturation temperature at atmospheric pressure for use external to the system.

2.3.1.4 EN 12953-11:2003-Shell boilers - Part 11: Acceptance tests

This Part of this European Standard specifies a concise procedure for conducting thermal performance tests, using the indirect (losses) procedure for boilers for steam or hot water. Test results are based on either the gross or net calorific value of the fuel. This concise procedure provides a convenient means for assessing boilers which thermodynamically simple, i.e. having a single major source of heat input and a simple circuit for water, steam or high temperature heat transfer fluid. An acceptance test may be required after the commissioning of a new plant or after the re-commissioning of a modified plant in order to verify compliance with a specification or contractual obligation. It can also be necessary whenever the user wishes to determine the current performance of the plant either on a route basis or due to change of load or other operating conditions or when a change of fuel or a modification to the plant is being considered. Finally acceptance tests are carried out whenever the user wishes to check combustion conditions. Regular tests in accordance with this European Standard help to monitor the boiler plant in normal operation for optimizing its efficiency and conserve fuel.

2.3.2 International Standards

According to www.iso.org, "ISO International Standards ensure that products and services are safe, reliable and of good quality. For business, they are strategic tools that reduce costs by minimizing waste and errors, and increasing productivity. They help companies to access new markets, level the playing field for developing countries and facilitate free and fair global trade. "The ISO standards available for boilers and pressure vessels are given in Table 4. They were retrieved from the ISO website. Standards regarding boilers and heaters can be found under the International Classification for Standards number 27 (Energy and heat transfer engineering).

Table 4 - ISO standards for boilers and burners

Standard	Objective
ISO 16528-1:2007	Boilers and pressure vessels -- Part 1: Performance requirements
ISO 16528-2:2007	Boilers and pressure vessels -- Part 2: Procedures for fulfilling the requirements of ISO 16528-1
ISO 22968:2010	Forced draught oil burners
ISO 22967:2010	Forced draught gas burners

2.4 Existing legislation

The MEErP methodology requires an identification and description of EU legislation, member state legislation and third country legislation relevant to the product group under consideration.

2.4.1 European legislation

The legal environment for steam boilers in the EU is directly and indirectly affected by various directives and regulations. In the following, the most relevant energy-related directives will be discussed with regard to their impact on the product definition.

2.4.1.1 Ecodesign Directive

The Ecodesign directive (Directive 2009/125/EC) is a framework directive defining the principles, conditions and criteria for setting environmental requirements for energy-related products. It makes no direct provision for mandatory requirements for specific products; this is done at a later stage for given products via implementing measures which will apply following consultations with interested parties and an impact assessment.

This study on boilers is carried out under the provisions of the Ecodesign directive. In the past, similar studies have been carried out for various product groups for heat supply as well as equipment that can be part of the auxiliary equipment used for steam boilers (Table 5).

With regard to studies dealing with boilers, the existing product study on boilers (ENER 1) deals with gas-fired, oil-fired and electric central heating (combi-) boilers. As it deals with small-scale water heating, it is thus not relevant for the present study on steam boilers. The same is valid for the product study on solid fuels small combustion installations (ENER 15). This study deals with combustion appliances used for direct and/or indirect indoor space heating fired by solid fuels and with a capacity below 500 kW. Other studies dealing with heat supply equipment are neither dealing with steam nor boiler and are thus not relevant for this study on steam boilers.

Various products covered by studies on motor and motor-driven equipment as well as transformers may be used as auxiliary equipment in conjunction with steam boilers. Regulations on this equipment will thus affect the environmental impact of the steam boilers indirectly. However, there is no relevant legislation based on the Ecodesign directive that directly addresses steam boilers.

Table 5 - Product groups covered by preparatory studies in the framework of the Ecodesign directive and related to steam boilers[7]

Application	Lot	Product groups

7 Based on information from www.eup-netzwerk.de.

Application	Lot	Product groups
Lighting	ENER 8	Office lighting
	ENER 9	Street lighting
	ENER 19	Domestic lighting part I “non-directional lamps”
	ENER 19	Domestic lighting part II “directional lamps”
Electronics	ENER 0	Simple set-top boxes
	ENER 3	PCs (desktops and laptops) and monitors
	ENER 4	Imaging equipment
	ENER 5	Consumer Electronics: TV
	ENER 6	Standby and off-mode losses
	ENER 18	Complex set-top boxes
	ENER 26	Networked standby losses of energy using products
	ENTR 3	Sound and imaging equipment
White goods	ENER 12	Commercial refrigerators and freezers
	ENER 13	Domestic refrigerators and freezers
	ENER 14	Domestic dish washers
	ENER 14	Domestic washing machines
	ENER 16	Household tumble driers
	ENER 17	Vacuum cleaner
	ENER 23	Domestic and commercial hobs and grills
	ENER 24	Professional washing machines, dryers and dishwasher
	ENER 25	Non-tertiary coffee machines
	ENTR 1	Refrigeration and freezing equipment
Motors and motor-driven equipment	ENER 11	Electric motors
	ENER 11	Circulators
	ENER 11	Fans
	ENER 11	Water pumps
	ENER 28	Wastewater pumps
	ENER 29	Clean water pumps (larger than those under lot 11)
	ENER 30	Motors and drives (outside scope of 640/2009)
	ENER 31	Compressors
Ventilation and air conditioning	ENER 10	Room air conditioning
	ENER 10	Comfort Fans
	ENER 10	Residential ventilation
	ENTR 6	Air-conditioning and ventilation systems
Heat supply	ENER 1	Boilers and comb boilers
	ENER 2	Water heaters
	ENER 15	Solid fuels small combustion installations
	ENER 20	Local room heating products
	ENER 21	Central heating products using hot air to distribute heat
	ENER 22	Domestic and commercial ovens
	ENTR 4	Industrial and laboratory furnaces and ovens
Others	ENER 0X	Medical imaging equipment

Application	Lot	Product groups
	ENER 7	Battery chargers and external power supplies
	ENER 27	Uninterruptible power supplies (UPS)
	ENTR 2	Transformers
	ENTR 5	Machine tools
Products for heat supply		Equipment possibly relevant as auxiliary equipment for steam boilers

2.4.1.2 Energy Labelling Directive

The Energy Labelling Directive (Directive 92/75/EC) provides a framework for the provision of product information related to energy consumption and use of other essential resources by household products. This should enable consumers to choose more energy efficient appliances. The focus of the Directive is on appliances whose aggregate use of energy is significant and which afford an adequate scope for increased efficiency.

A revised directive on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products (2010/30/EU) was introduced in 2010. This expanded the possible introduction of labelling requirements beyond the area of domestic appliances to energy related products with significant direct or indirect impact on the consumption of energy. Under this directive the Commission has delegated power to set the labelling requirements for specific products. Both directives do not provide any specific regulations for steam boilers or related equipment[8].

2.4.1.3 Energy Efficiency Directive

The Energy Efficiency Directive (2012/27/EU) introduces new instruments to foster energy efficiency in Europe significantly. Among the further development of measures laid down in the Energy Services Directive (2006/32/EC) like the national reporting on energy efficiency efforts in the National Energy Efficiency Action Plans (NEEAP), the Directive introduces some new instruments which are relevant in the context of Energy using and Energy related products.

The main new instrument is the (mandatory) introduction of energy saving obligation schemes within the member states as laid down in Article 7. This instrument is supposed to deliver additional savings equivalent to 1.5 % of the annual energy consumption of the member states in a reference period. The Ecodesign directive is quoted directly as a mandatory baseline for these savings, so the savings accounted to the 1.5 % target must exceed the minimum requirements for the products under coverage of the directive.

Instruments such as the mandatory energy audits for larger enterprises may lead to an increased demand for efficient technologies. However there are no regulations in the Energy Efficiency that directly affect steam boilers.

8 Nevertheless labels for other heat generating product exist. An example is Commission Delegated Regulation (EU) No 811/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device. Another example is Commission Delegated Regulation (EU) No 812/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device. However both examples refer to household appliances. Industrial steam boilers are business-to-business products. Sometimes the value generated for the customer by industrial steam boilers is not the heat but the steam itself – which is used e.g. as carrier for chemical substances/reactions. This is introduced in Task 3. Thus these regulations cannot be used as patterns for industrial steam boiler without modification.

2.4.1.4 Emission Trading Directive

The Emission Trading Directive (2003/87/EC) establishes a scheme for trading greenhouse gas emission within the European Union. The aim of this trading scheme is to reduce green-house gas emissions in a cost-effective manner. The directive introduces a system of tradable permits. Operators of certain installations as defined in Annex I of the directive have to hold a sufficient number of permits for operating their installations.

Based on the list of activities provided in the directive (Table 6), steam boilers are covered by the directive in two cases: either as combustion installations or as part of other production activities. For the combustion installations, the minimum threshold for inclusion into the directive is a total rated thermal input of 20 MW. If steam boilers are considered as a functional part of other activities defined in Annex I, they may also be subject to the directive, e. g. as part of paper production installations with a capacity exceeding a stipulated threshold value of 20 tons per day. Thus, larger steam boilers installations or those included in other industrial activities are subject to the regulation of the ETS directive.

Table 6 - Simplified overview of activities in Annex I of the Emission Trading Directive (for details and threshold values, see the Directive)

Category	Activity
Energy activities	Combustion installations
	Refining of mineral oil
	Production of coke
Production and processing of metal	Metal ore
	Production of pig iron or steel
	Production or processing of ferrous metals
	Production of primary and secondary aluminium
	Production of non-ferrous metals
Mineral industry	Production of cement clinker
	Production of lime, calcination of dolomite or magnetite
	Manufacture of glass including glass fibre
	Manufacture of ceramic products
	Manufacture of mineral wool insulation material
	Drying or calcination of gypsum and related products
Paper industry	Production of pulp
	Production of paper or cardboard
Chemical industry	Production of carbon black
	Production of nitric acid
	Production of adipic acid
	Production of glyoxal and glyoxylic acid
	Production of ammonia
	Production of bulk organic chemicals
	Production of hydrogen
	Production of soda ash and sodium bicarbonate
Carbon capture and storage	Capture of greenhouse gases
	Transport of greenhouse gases
	Geological storage of greenhouse gases
Aviation	Aviation

2.4.1.5 Industrial Emissions Directive

The directive on industrial emissions 2010/75/EU of 24 November 2010 (Industrial Emissions Directive –IED) replaces seven existing directives including the IPPC Directive:

- Directive 78/176/EEC on titanium dioxide industrial waste,
- Directive 82/883/EEC on the surveillance and monitoring of titanium dioxide waste,
- Directive 92/112/EEC on the reduction of titanium dioxide industrial waste,
- Directive 1999/13/EC on reducing emissions of volatile organic compounds,
- Directive 2000/76/EC on waste incineration,
- Directive 2008/1/EC concerning integrated pollution prevention and control (IPPC Directive),
- Directive 2001/80/EC on the limitation of emissions of certain pollutants from large combustion plants.

The IED lays down rules on integrated prevention and control of pollution arising from industrial activities. Its aims to achieve a high level of protection of the environment as a whole by preventing and reducing emissions into air, water and land and the generation of waste. The regulations of IED cover a range of different industrial activities and installations including combustion plants, waste incineration plants, installations using organic solvents, installations producing titanium oxide as well as industrial activities defined in Annex I of the directive. The industrial activities defined in Annex I of the IED concern:

- Energy industries including the combustion of fuels in installations with a rated thermal input of 50 MW or higher,
- Production and processing of metals,
- Mineral industry,
- Chemical industry,
- Waste management,
- Other activities.

Several of these activities are only covered by the regulations if they meet certain capacity thresholds.

Article 3 of the IED describes installations as stationary technical units where any of the activities in Annex I are carried and "any other directly associated activities on the same site which have a technical connection with the activities listed [there] and which could have an effect on emissions and pollution." In consequence, steam boilers are likely anchored twice in the list of activities provided in Annex I of IED: On the one hand, as combustion installations if they have a rated thermal input of >= 50 MW. An on the other hand, used in conjunction with activities specified in Annex I (e.g. steam boilers for paper production).

Furthermore, Article 3 of the IED defines a combustion plant as "any technical apparatus in which fuels are oxidized in order to use the heat thus generated". As steam boilers provide steam by burning fuels, they can be considered as combustion plant and are thus furthermore subject to the regulations on combustion installations (Table 7).

Table 7 - Coverage of combustion plants in the IED

Capacity <> Activity	Annex I	Combustion installations
(>= 50 MW)	Covered by "combustion of fuels" (Annex I)	Covered by Subject to limit values set out in Parts 1 or 2 in Annex V
(< 50 MW)	Covered if part of other activities listed in Annex I	If two or more combustion plants add up and use or could use a common stack AND if the individual rated thermal input power is above (15 MW) (Art. 29)
Exceptions	Permit shall not include regulation on direct emissions of green-house gases if the installation is covered by EU ETS (threshold for combustion there 20 MW or included in Annex I of ETS directives)	

Thus both the activities listed in Annex I as well as the regulations concerning combustion plant of the directive may apply to steam boilers.

Article 11 of the directive sets out general obligations for actives according to Annex I operators of installations performing these activities are required to:

- Take preventive measures against pollution
- Apply best available techniques
- Avoid significant pollution
- Prevent the generation of waste
- Re-use, recycle, recovery waste if possible, or to dispose of it while avoiding or minimizing impact on the environment
- Use energy efficiently
- Take measures to prevent accidents and limit their consequences
- Avoid any risk of pollution and assure remediation upon cessation of activities.

Article 15 of the directive binds permits for operating such installations to the emission levels as defined in the Best Available Techniques (BAT) reference documents.

2.4.1.6 Proposal for a directive on the limitation of emissions of certain pollutants into the air from medium combustion plant

The Commissions aims to complement existing regulation on combustion plants with a regulation for medium combustion plants. A draft of this directive from December 2013 aims to limit emissions of certain pollutants into the air from medium combustion plants. The new directive is to fill a regulatory gap as large combustion plants are covered by the Industrial Emissions Directive while small combustion installations not regulated on European level in terms of emission of certain pollutants (refer to section 1.4). They may be regulated by specific provisions of the Ecodesign Directive.[9]

[9] Both forms of regulations are not comparable directly as the Ecodesign Directive covers not only the limitation of emissions of certain pollutants into the air. Within the methodology of the Ecodesign Directive a strong focus lies on the energy consumption and thus the energetic modeling of the product

The Directive covers combustion plants with a rated thermal input from 1 to 50 MW irrespective of the type of fuel used.

Table 8 - Overview on proposed emission limit values for medium combustion plants in mg/Nm³ (excluding engines and gas turbines)

	Existing plants (for plants > 5 MW from 2025 and other plants from 2030)			New plants		
Pollutant	SO2	NO_X	PM	SO2	NO_X	PM
Solid biomass	200	650	30(1)	200	300	20(2)
Other solid fuels	400	650	30	400	300	20
Liquid fuels other than heavy fuel oil	170	200	30	170	200	20
Heavy fuel oil	350	650	30	350	300	20
Natural gas	-	200	-	-	100	-
Gaseous fuels other than natural gas	35	250	-	35	200	-
(1) 45 mg/Nm³ for plants with a thermal input below or equal to 5 MW						
(2) 25 mg/Nm³ for plants with a thermal input below or equal to 5 MW						

With regard to the Ecodesign directive, the directive shall not apply to "energy related products which are covered by implementing measures adopted in accordance with Directive 2009/125/EC where those implementing acts are setting emission limit values for the pollutant listed in Annex II of this Directive" (Art. 2).

Thus, if there are no specific Ecodesign requirements, products will be subject to the requirements of this Directive. Emission limit values from the Directive are provided in Annex II of the Directive. They cover sulphur dioxide, nitrogen oxides and particulate matter (PM). The limit values are distinguished by existing and new plants (Table 8). Member states may decide to exempt combustion plant from these values if the annual operating hours are below 500 hours per year.

2.4.1.7 Other directive and regulations

Next to the directives and regulations shown above, there are further items of EU legislation potentially affecting the design, installation and operation of steam boilers. For the product definition they have little importance and are thus only provided for information without addressing them in detail here:

- Gas Applicance Directive (2009/142/EC)
- Pressure Equipment Directive (97/23/EC)
- Simple Pressure Vessels Directive (2009/105/EC)

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in scope. Furthermore energetic improvements can increase the emission of pollutants in certain cases. This will be discussed more in detail in Task 6. The modeling of these interdependencies is not trivial. This problem can only be solved by prioritization of the goals by the European Commission. E.g. when emission values are fixed industry can respond whether the anticipated energy efficiency improvements in the study are realistic with the background of the anticipated pollutant limits.

- Construction Products Directive (89/106/EEC)
- Low Voltage Directive (73/23/EEC, 93/68/EC)
- Machinery Directive (2006/42/EC)
- WEEE Directive (2012/19/EC)
- RoHS Directive (2011/65/EC)
- National Emission Ceiling for Pollutants Directive (2001/81/EC)
- Energy Taxation Directive (2003/96/EC)

2.4.2 Member state legislation

In this section national laws and ordinances are described, which are binding for manufacturer and user of industrial steam boiler in terms of environmental pollution and energy efficiency. Laws and ordinances going back to EU Directives are only referenced and not described. The following countries have been reviewed in detail: Germany, France, the Netherlands, the USA and China.

2.4.2.1 Germany

In Germany there are three implemented ordinances for different categories of fire places directly relevant for industrial steam boiler. They go back to the "Bundesemissionsschutzgesetz (BImSchG)". Which one of the four ordinances applies depends among other things on the thermal capacity of the firing place, used fuel and risk assessment factors. An overview which ordinance for which constellation applies is given in Table 9. Please keep in mind that this is just an overview as it does not include exceptional rules, which can apply from case to case. Furthermore there are other ordinances relevant for limiting pollutants. However they refer to whole facilities/plants, so that they do not affect industrial steam boiler directly as the pollutant limits in there are achieved by facilities cleaning the flue gas (such as Selective Catalytic Reduction (SCR)) or by specific boiler and burner design.

Table 9 - Extract of relevant laws for firing places in Germany

Fuel	1.BImSchV (small and medium sized firing places)	4.BImSchV (firing places with official approval procedure)	IED implementation-> 13.BImSchV (large-scale combustion plants)
Heating oil (type EL), vegetable oil, ethanol, methanol, etc.	< 20 MW	≥ 20 MW < 50 MW	≥ 50 MW
Natural gas, liquid gas, gases from public grid, etc.	< 20 MW	≥ 20 MW < 50 MW	≥ 50 MW
Biogas, digester gas, mine gas, etc.	-	≥ 10 MW < 50 MW	≥ 50 MW
Heating oil (except type EL), etc.	-	≥ 1 MW < 50 MW	≥ 50 MW
Coal, coke, wood, etc.	-	≥ 1 MW < 50 MW	≥ 50 MW

2.4.2.1.1 1. BImSchV

The 1.BImSchV applies for firing places with a thermal output equal or larger than 4 kW (Table 10 and Table 11). Thus there are mainly small and medium sized firing places such as gas fired condensing boiler in scope of the ordinance. Enacted in 1987, the 1.BImSchV has been revised last time in 2010. The law only applies, when no individual official approval procedure for operating according 4.BImSchV is necessary. For products, where the 1.BImSchV applies a type acceptance certificate procedure has to be carried out by the manufacturer. This shall guarantee that the product meets the emission limits as set in the ordinance. The scope of the law goes up to a net rated thermal input of 20 MW. Therefore heating devices for the residential sector as well as industrial steam boiler are affected. Flue gas losses for these ranges are listed in Table 12. The regulations for residential heating devices have already been discussed in Task 1 of the preparatory study on Eco-design of CH-Boilers (2007). Therefore in the following spreadsheets only regulations, which are valid for industrial steam boiler, are presented. The relevant passages for industrial steam boiler can be found in §§7–11. As §11 affects firing places with a net rated thermal input greater than or equal 10 MW, passages §§7-9 are relevant for a net rated thermal input lower than 10 MW in reverse.

Passages §§7-9 and §11 set limits for pollutants. However in this paragraphs it is cross-referenced to §10, where limits for flue gas losses are set, which are at least an energy efficiency criteria by neglecting other losses.

Table 10 - Pollutant limits Germany for industrial steam boiler <10 MW in Germany (when not in scope of 4. BImSchV)

Technology (classified according used technology, 1.BImSchV §§7– 9)	**Oil-fired firing places with vaporizing burner (§7)** (1)	**Oil-fired firing places with forced draught burner (§8)** (1)	**Gas-fired firing places (§9)** (1)
net rated thermal input [MW]	< 10 (as ≥ 10 in §11)		
carbon monoxide CO [mg/kWh]	1300	1300	(2)
Nitrogen Oxides NOx [mg/kWh]	(2)	(2)	250
smoke spot number	≤ 2	≤ 1	-
For dual fuel steam boiler the NOx limit is 250 [mg/kWh] for all boiler operating temperatures, if the operating hour with heating oil is lower than 300 h per year and they are usually fired with gas.			
(1) Flue gas losses according §10 has to be fulfilled. (2) Not specified in this paragraph, therefore standard values from section 4 apply: • nitrogen oxides NOx for plants erected after 22nd of March 2010: 0,6 [g/mn³] • nitrogen oxides NOx for plants erected after 31st of December 2014: 0,5 [g/mn³] • carbon monoxide CO: 0,25 [g/mn³] • dioxins and dibenzofurans (PCDFs): 0,1 [ng/mn³]			
.			

Source: "Verordnung über kleine und mittlere Feuerungsanlagen vom 26. Januar 2010 (BGBl. I S. 38)", national legislation from Germany

Table 11 - Pollutant limits for industrial steam boiler ≥ 10 and < 20 MW in Germany (when not in scope of 4. BImSchV)

Fuel (classified according used fuel, 1.BImSchV §11)		**Heating oil, vegetable oil, ethanol, methanol, vegetable oil methyl esters***	**Natural gas, liquid gas**(1)	**Other gases**(1)
net rated thermal input [MW]		≥ 10 < 20	≥ 10 < 20	≥ 10 < 20
(2) carbon monoxide CO [mg/m_n^3]		80	80	80
(2) nitrogen oxides NO_x [mg/m_n^3]	boiler operating temperature [°C]			
	< 110	180	100	200
	≥ 110 ≤ 210	200	110	200
	> 210	250	150	200
	smoke spot number	≤ 1	-	-
For dual fuel steam boiler the NO_x limit is 250 [mg/m_n^3] for all boiler operating temperature, if the operating hour with heating oil is lower than 300 h per year.				
(1) Flue gas losses according §10 has to be fulfilled. (2) CO- and NO_x are referred to 3% O2-contents.				
Flue gas losses according §10 for different below:				

Nominal thermal capacity in kilowatt	Limiting value for flue gas losses in percent
≥ 4 ≤ 25	11
> 25 ≤ 50	10
> 50	9

Source: "Verordnung über genehmigungsbedürftige Anlagen vom 2. Mai 2013 (BGBl. I S. 973, 3756)", national legislation from Germany

2.4.2.1.2 . BImSchV

The 4.BImSchV applies in general for firing places/facilities where an official approval procedure for operating is necessary. The affected firing places/facilities are listed in Annex 1 of the ordinance. Therefore it applies also for some firing places with a net rated thermal input equal or larger than 1, 10 or 20MW depending on the used fuel. Please refer to Table 9 to see the relevant cases. The pollutant limits prescribed by the ordinance are listed in the linked administrative directive "TA-Luft", where limits for NOx, SOx, CO, dust and dioxins are set. The "TA-Luft" sets general pollutant limits for the protection of human health as per Source: Verordnung über kleine und mittlere Feuerungsanlagen vom 26. Januar 2010 (BGBl. I S. 38)", national legislation from Germany.

Table 13. However these values can deviate or are more specific for industrial steam boiler in dependence of used fuel. An extract of the limits is shown in Source: " Erste Allgemeine Verwaltungsvorschrift zum Bundes–Immissionsschutzgesetz (Technische Anleitung zur Reinhaltung der Luft – TA Luft), vom 24. Juli 2002", administrative fiat from Germany.

Table 14.

2.4.2.1.3 13. BImSchV

The 13.BImSchV applies in general for plants with a net rated thermal input larger than 50 MW, respectively large combustion plants. However the limits set in there fulfil at least the IED (EU-level) requirements. Furthermore the technical standard according BREF for Large Combustion Plants (EU-level) has to be fulfilled.

Table 12 - Allowed flue gas losses for industrial steam boiler < 20 MW in Germany according to the 1. BImSchV

Thermal output [kW]	Limits for flue gas losses [%]
≥ 4 ≤ 25	11
> 25 ≤ 50	10
> 50	9

Source: Verordnung über kleine und mittlere Feuerungsanlagen vom 26. Januar 2010 (BGBl. I S. 38)", national legislation from Germany.

Table 13 - Pollutant limits for the protection of human health according TA Luft in general

Pollutant	Concentration [µg/m³]	Averaging period	Permissible Annual Frequency of Exceeded Values
Benzene	5	Year	-
Lead	0,5	Year	-
Fine sulphur powder (PM)	40	Year	-
	50	24 hours	35
SO2	50	Year	-
	125	24 hours	3
	350	1 hour	24
NO2	40	Year	-
	200	1 hour	18
PERC	10	Year	-

Source: " Erste Allgemeine Verwaltungsvorschrift zum Bundes–Immissionsschutzgesetz (Technische Anleitung zur Reinhaltung der Luft – TA Luft), vom 24. Juli 2002", administrative fiat from Germany.

Table 14 - Extract of pollutant limits for industrial steam boiler when in scope of 4.BImSchV (respectively TA-Luft)

Fuel (classified according used fuel, TA-Luft, Paragraph 5 ff.)		**Heating oil, vegetable oil, ethanol, methanol, vegetable oil methyl esters**	**Other fluid fuels**	**Gas fuels (natural gas, liquid gas, etc.)**
(1) carbon monoxide CO [mg/m_n^3]		80	80	80
(1) nitrogen oxides NO_x [mg/m_n^3]	boiler operating temperature [°C] (or over-pressure range [MPa])			
	< 110 (< 0,05)	180	350	100
	≥ 110 ≤ 210 (≥ 0,05 ≤ 1,8)	200		110
	> 210 (>1,8)	250		150
smoke spot number* or dust**		≤ 1*	50**	5-10**

[mg/ m_n^3]			
(1) CO- and NO_x are referred to 3% O2-contents.			

2.4.2.2 France

The framework for air pollution control in France is going back to the Air Pollution Control and Odour Abatement, which has been launched in 1961. Specific requirements of this legislation have been set out in decrees, orders and instructions. The EU Directive 2001/81/EC prescribing limitations on emissions of certain air pollutants from large combustion plants and national emission ceilings for certain air pollutants has been implemented by updating the existing order for combustion boilers with a capacity greater than 20 MWth. Furthermore the order on new or upgraded boilers with a capacity greater than 20 MWth has been updated. These two orders were revised last time in 2004 (Orders of 13 July 2004: NOR: DEVP0430214A and NOR: DEVP0430215A).[10]

Table 15 - Extract of Relevant laws for (Industrial) Fireplaces in France

French Law	EU Directive	Boiler Rating	Amendments	Remarks
NOR: DEVP0320297A	2001/81/EC	> 20 MWth	July 2004 as NOR: DEVP0430214A	Applicable on Existing boilers
NOR: DEVP0210222A	2001/81/EC	> 20 MWth	July 2004 as NOR: DEVP0430215A	Applicable on new or upgraded boilers

Source: MURE Database, 2011

Table 16 - Emission Limit Values France Boilers

Fuel	Boiler Rating [MWth]	Emission Limit Values (mg/m3)			Remarks
		SO2	NO_x as NO_2	CO	
Coal-fired	20 ≤ P < 50	2000	600	300	Existing Boilers
	50 ≤ P < 100	2000	600	300	
Coal-fired	20 ≤ P < 50	850 (1) (Area A(2))	550	200(3)	New, modified or Extended Boilers
		1700 (Area B(2))			
	50 ≤ P < 100	850	400	200(3)	
(1) When coal and natural gas or liquefied petroleum gas or biomass are burned simultaneously, the emission limit value for coal fired boilers shall apply if the coal is used predominantly (2) Area A refers to cities or towns of more than 250,000 habitants, and Area B refers to an area with inhabitants under 250,000. (3) An emission limit value of 100 mg/m³ applies to pulverized coal boilers.					

Source: IEA Clean Coal Center, Database on emission standards, values for the UK downloaded from http://www.iea-coal.org.uk/site/2010/database-section/emission-standards, on the 1st of August 2013

[10] Mure (2011): FRA5 - Minimum energy performances of boilers, downloaded from http://www.muredatabase.org/, downloaded on the 1st of August, 2013

Efficiency criteria for boiler are also common in France. The first efficiency criteria for boiler have already been set in 1975. The most up to date legislation relating to energy efficiency is to going back to the decree of March 22, 2007. The operator of a boiler with a power between 400 kW and 50 MW has to fulfil efficiency criteria as per Table 17. The criteria are valid for boiler, which has been brought into service after September 14, 1998. During operation the operator has to calculate the characteristics of the boiler each time restarting or at least every three months for the period of operation. Finally the boiler (400 kW – 50 MW) has to undergo a periodic inspection every two years by an accredited body which meets requirements of the ISO standard 17020 "General Criteria for the Operation of Various Types of Bodies Performing Inspection". The report has to be sent to the local authorities after 2 months and has to be kept for control purpose five years. Additionally advices in terms of energy efficiency are given by the French Environment and Energy Management Agency. (MURE Database, 2011) (Roger Marie-Christine, 2011).

Table 17 - Boiler efficiency limits in France for boiler > 400 kW and < 50 MW

Fuel type	**Output (%)**
Domestic fuel	89
Heavy fuel	88
Gaseous fuel	90
Coal or lignite	86

Source: Mure (2011): FRA5 - Minimum energy performances of boilers, downloaded from http://www.muredatabase.org/, downloaded on the 1st of August, 2013

2.4.2.3 The Netherlands

The Netherlands agreed such as other countries to comply with the EU National Emission Ceilings (NEC) Directive (2001/812/EC). In order to achieve these limits for the industry several regulations has been enacted by the Dutch government as shown in Table 20 (NEC Report 2006 The Netherlands, 2006). For the case of steam boiler especially two regulations have to be highlighted as they directly affect pollutants caused by the combustion process within the steam boiler.

Table 19 shows the emission limits for boilers in the Netherlands according the law for large heating systems in non-residential buildings (BEMS), which has been enacted in April 2010.

Furthermore there has been an additional mechanism putting pressure on operator and therefore also on manufacturer of industrial steam boiler in recent years. In order to achieve the NEC ceiling for NO_x emissions the Netherlands established a NO_x emissions trading program in 2005. This trading program is based on a Performance Standard Rate (PSR) that is defined as grams of NO_x per unit of energy (GJ) used within a facility. The number of NO_x emission allowances of a combustion plant is determined by multiplication the PSR during a calendar year with the total fuel input. Having sufficient allowances a facility may cause NO_x emissions that exceed this performance standard. This can be achieved by buying additional NO_x allowances. On the other hand NO_x allowances can be sold by a facility when less emissions has been caused during a year than permitted by received NO_x allowances. From 2005 to 2010 the PSR became more stringent every year as shown in Table 18. However the Netherlands did not achieved the NEC emission limit for NO_x until 2010. The limit value has been finally achieved two years later in 2012. As a consequence the Dutch government announced to repeal the trading scheme in 2014. The reason why the Dutch NO_x trading scheme did not worked out to be cost effective is that many of the installations taking part on the NO_x trading scheme already had to comply with the emissions limits based on BAT prescribed by the IPPC-Directive. As a consequence the number of emission allowances the companies could buy for their installations to exceed the PSR standard was very limited. Furthermore the application of BAT by many firms leads to on an oversupply of NO_x emission allowances. Thus the application of BAT can be seen as main driver that the Netherlands achieved the ceiling in 2012, which lead to the conclusion that it is more cost effective to repeal the NO_x trading scheme.[11]

Table 18 - Performance standard rate for combustion plants with thermal capacity larger than 20 MWth (Annex II, Decree on Emission Allowance Trading)[12]

Year	2005	2006	2007	2008	2009	2010
PSR g/GJ	68	63	58	52	46	40

Table 19 - Emission-regulations for boilers in the Netherlands according BEMS[13]

Fuel	**Boiler Rating**	**Emission Limit Values [mg/m³]**			**Oxygen in Flue**
		NO_x	PM	SO_2	
Solid (s), Liquid (l)	≥ 1 MWn	100	5	200	6 vol% (s), 3 vol% (l)
Biomass	< 5 MWth	200	20	200	6 vol%
	≥5 MWth	145	5	200	
Gas	≥ 1 MWn	70		200	3 vol%
MWn: Nominal heat output in MW; MWth: Thermal input rate in MW					

Table 20 - Policy mechanisms to reduce pollutants in the Netherlands (Ministry of Infrastructure and the Environment, the Netherlands, 2010)

Sector	Sub-stance	Policy
Industry, energy and refineries; waste treatment	NO_x	• NOx emissions trading for companies larger than 20 MWth (combustion emissions: 40g/GJ by 2010, process emissions: 46% reduction by 2010 relative to 1995 level), • BEES for companies smaller than 20 MWth • Dutch Emissions Guidelines (NER) (ovens and dryers) • IPPC-BAT

11 Hujbers (2013), Press article wit title: NOx Emissions Trading Scheme Repealed in the Netherlands - Global Impacts?, downloaded on the 1st of August 2013 from: http://ehsjournal.org/http:/ehsjournal.org/marlies-huijbers/nox-emissions-trading-scheme-repealed-in-the-netherlands-global-impacts/2013/.

12 IEA Clean Coal Center, Database on emission standards, values for the UK downloaded from http://www.iea-coal.org.uk/site/2010/database-section/emission-standards, on the 1st of August 2013.

13 Public note from the Ministry of Infrastructure and the Environment, The Netherlands. Title: BEMS sets new emission standards on combustion plants, downloaded from http://www.infomil.nl/english/subjects/air/combustion-plants/bems-sets-new, on the 1st of August of 2013.

Industry, energy and refineries; waste treatment	SO_2	• IPPC-BAT • BEES for combustion plants and refineries NeR for non-BEES plants (iron and steel production)
Chemicals and base metal	SO_2	Integrated Environmental Target (IMT): 90% reduction by 2010 relative to 1985 level
Refineries	SO_2	Transition from oil fired to gas fired in 2007
Refineries	PM10	Transition from oil fired to gas fired in 2007 (with SO2)
Industry, energy and refineries; waste treatment; trade, services and government; construction	NMVOC	All measures – save those for refineries – from the National NMVOC Reduction Plan for industry, trade, services, government, and construction. The Solvents Decree and the Voluntary Agreements on Working Conditions
Trade, services and government	NO_x	• Type approval for central heating installations • BEES
Consumers	NO_x	Type approval for central heating installations

2.4.3 Third country legislation

2.4.3.1 USA

The United States have a long history setting limits for pollutants going back to the year 1963, where the Clean Air Act (CAA) has been enacted. The National Emission Standard (NSPS) is the most up to date law limiting Industrial Emissions in the U.S. on national level. An extract for emission limits of industrial boiler and process heater is shown in Table 24 to indicate the range of limits for carbon monoxide and particulate matter (PM). However as the U.S. has a federal structure in terms of environmental legislation stricter requirements on state level are possible. Therefore these limits have just to be seen as minimum values.

2.4.3.2 China

In 2012 the emission limits for thermal power plants has been tightened in China. The most up to date law is the Emission Standard of Air Pollutants for Thermal Power Plants (GB 13223-2011). It also applies for industrial steam boiler and it sets emission limits for SO2, NOx and soot in dependence of used fuel and location as per Table 25.

Due to environmental concerns there are more strict limits for pollutants in key regions as per Table 21. Additionally efficiency criteria for industrial steam boiler are common in China. They are listed in GB 24500-2009. In this document minimum energy efficiency limits are set in dependence of volume flow respectively capacity, energy consumption, net rated thermal input, technology and used fuel. Furthermore the values vary in dependence of the achievable grade. There are three grades, where the numeric first one is the most energy efficient. However as this document is only available in Chinese language just the scheme of the structure is show in Table 22.

Table 21 - Emission limits for boiler in China for key regions (key regions" refer to the three rivers (Huaihe, Liaohe and Haihe)

Boiler Type	**Pollutant**	**Limits [mg/ m³]**	**Emission Control Equipment**
Coal-fired	Soot	20	Stack or Flue
	SO_2	50	
	NOx (NO_2)	100	
	Mercury and mercury compounds	0,03	
Oil-fired	Soot	20	
	SO_2	50	
	NOx (NO_2)	100	
Gas-fired	Soot	5	
	SO_2	35	
	NOx (NO_2)	100	
Coal-, oil, - or gas-fired	Smoke Degree (Ringelmann Smoke Chart)	1	Stack vent

Table 22 - Structure of limits for industrial boiler efficiency in China according GB 24500-2009

Type: e.g. fire tube boiler						
Grade	Fuel		Consumption, Q [kJ/kg]	Capacity C, [t/h] (Net rated thermal input, P [MW])		
				C < 1 P < 0,7	1 ≤ C ≤ 2 0,7 ≤ P ≤ 1,4	Etc.
				To achievable boiler efficiencies in %		
1	soft coal	I	17.700 ≤ Q ≤ 21.000	79	82	...
		II	≥ 21.000	81	84	...
2		I	17.700 ≤ Q ≤ 21.000	76	79	...
		II	≥ 21.000	78	81	...
3		I	17.700 ≤ Q ≤ 21.000	73	76	...
		II	≥ 21.000	75	78	...

2.4.3.3 Other countries

Legislations within other European countries in our research are mainly limited to the implementation of existing EU Directives for pollutants. Limits for pollutants in Italy, Poland, Spain, Sweden and the UK are mainly based on the implementation of the Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants. Table 23 shows exemplary the implementation for coal-fired power plants in Italy.

Table 23 - Extract of emission standards for coal-fired power plants in Italy

Boiler Rating (MWth)	Emission Limit Values (mg/m3)		
	SO_2	NOx as NO_2	Dust/PM
> 0.15 to ≤ 3	200	500	100
> 3 to ≤ 6		500	30
> 6 to ≤ 20		400	30
> 20 to < 50		400	30

Table 24 - Extract of NSPS limits for steam boiler in the U.S. (U.S. Environmental Protection Agency, 2013)

Fuel	Boiler Type	Rating (MMBtu/hr) **	Emission Limit Values*	
			CO***	PM
			ppm	lb/MMBtu
Coal, Biomass, Oil, Gas	all	< 10	No numeric Emission limits	
Coal	New Pulverized injection	≥ 10	320	0,0011
	New Fluidized-Bed		230	0,0011
	New Fluidized-bed with Heat exchanger		150	0,0011
Biomass	New Fluidized-Bed		310	0,0098
	New Suspension Burner		2000	0,03
	New Dutch oven/Pile Burner		520	0,0032
Heavy Liquid	New large		130	0,013
Light Liquid	New large		130	0,0011
Gas 2 (other)	New large		130	0,0067
Coal	Existing pulverized Injection		320	0,04
	Existing Fluidized-Bed		230	0,04
Biomass	Existing Fluidized-Bed		310	0,11
	Existing Suspension Burner		2000	0,051
	Existing Dutch oven/Pile Burner		520	0,28
Heavy Liquid	Existing large		130	0,062
Light Liquid	Existing large		130	0,0079
Gas 2 (other)****	Existing large		130	0,0067
Coal	New	≥ 30	420	0,03
Biomass	New		-	0,03
* at 3% O2 Flue				

** 1 MMbtu/hr = 293,1 kW

*** Rule of thumb: the value in mg/m^3 can be calculated by multiplying the ppm value with 1,13 (assuming an atmospheric pressure of 101.325 Pa and an ambient Temperature of 25 °C).

**** "Gas 2 (other) Gases" are gaseous fuels other than natural gas and/or refinery gas

ppm: parts per million, usually by volume
lb: pounds

Table 25 - Emission limits for boiler in China as per GB 13223-2011 (Finamore)

Type of boiler	Pollutant	Remarks	Limits [mg/m^3]	Emission Control Equipment
Coal-fired boilers	Soot	All	30	Stack or Flue
	SO_2	New Boiler	100	
			200 [1]	
		Existing Boiler	200	
			400 [1]	
	NOx (NO_2)	All	100	
			200 [2]	
	Mercury and mercury compounds	All	30	
Oil-fired boilers	Soot	All	30	
	SO_2	New Boiler	100	
		Existing Boiler	200	
	NOx (NO_2)	New Boiler	100	
		Existing Boiler	200	
Gas-fired	Soot	Natural gas boilers	5	
		Other gas fired boilers	10	
	SO_2	Natural gas	35	
		Other gas	100	
	NOx (NO_2)	Natural gas	100	
		Other gas	200	
Coal-, oil-, or gas-fired boilers	Smoke Degree (Ringelmann Smoke Chart)	All (remark: unit not in mg/m^3)	1	stack vent

(1) to be located in Guangxi Zhuang Autonomous Region, Chongqing Municipality, Sichuan Province and Guizhou Province, where the limits will be implemented with coal-fired boilers.

(2) Implementing limits on W-type thermal power generation boilers or furnace chamber flame boilers, circulating fluidized bed (CFB) boilers, and boilers put into operation as of December 31, 2003or through the construction project's environmental impact report's approval of coal-fired power boilers.

2.4.3.4 Summary and conclusion on the review on national legislations for industrial steam boiler

The first outcome of the review on national legislations is that the structure of laws limiting emissions of pollutants differs within the EU. In any case basically two dimensions are being used in order to set limits for pollutants of firing places, respectively industrial steam boiler. Therefore in any structure the net rated thermal input and the used fuel are dimensions in order to categorize these limits. However there are also more complex laws using additional dimensions such as technology and operation parameter. One example is the German administrative directive "TA-Luft" setting different NO_x emission limits in dependence of the boiler operating temperature. That is why finally a direct comparison of national emission limits for industrial steam boiler is not possible without overloading the capacity of this task massively. However the presented extract of the national legislations indeed indicate countries with more ambitious legislations compared to other countries within our research. Let us assume an industrial steam boiler with a net rated thermal input of 15 MW, which is fuelled with natural gas from the public grid having an operating temperature of 150 °C. Then the emission limit for NO_x is 110 mg/m³ in Germany, whereas the emission limit for the same is 70 mg/m³ in the Netherlands (both referred to 3% O_2 content in the flue gas). However such considerations just have to be seen as rough orientation as there is no complete overview on national legislations given. Presupposing that emissions of pollutants have a large stake on the environmental performance of industrial steam boiler a more detailed comparison of national pollutant laws is worth consideration.

The second outcome of the review on national legislations is that legal binding energy efficiency criteria for industrial steam boiler (with at least a capacity of higher than 400 kW) are quite rare within our research. Therefore binding energy efficiency criteria has been found only for France and Germany within the EU and in China for other countries. Furthermore no efficiency criteria for part load behaviour of industrial steam boiler have been found.

This leads us to the conclusion, that there are gaps in legislation on national level within the EU affecting the environmental balance of industrial steam boiler during the utilization phase.

2.5 Conclusions for product scoping

Based on the analysis of the provided documents, we use the following scoping for the subsequent analysis. The scope of this study focuses on steam boilers that are used to generate steam by heating water with the following characteristics[14]:

- The minimum nominal thermal input power is of 1 MW or above[15].
- We exclude smaller steam boilers as according to the VHK study as 60 to 90% of the energy consumption is caused by larger boilers.
- The maximum nominal thermal input is below 50 MW.
- We exclude larger boilers as they are already covered by the requirements of the IED.
- We exclude boilers driven by waste heat as the use of waste heat should not be penalized by regulatory means.[16]

[14] As Task 1 is only a preliminary scoping tasks, the details of the scoping will not be treated before Task 3 as stipulated in the MEErP methodology.

[15] The underlying nominal thermal input for the scope definition is based on the lower heating value (LHV, respective net calorific value (NCV)). However, in the further course of this study thermal efficiencies will be based on acceptance test standards for shell and water tube boilers. These standards allow evaluating the efficiency based on the LHV as well as on the higher heating value (HHV).

- We exclude steam boilers using waste as a fuel as such boilers are subject to different environmental legislation, as they appear less relevant in terms of capacity, as they have to fulfil different technical requirements and because one of their main functions is to appropriately dispose of waste.
- We exclude electrical steam boilers from the scope[17].
- We exclude marine boilers as these boilers are regulated differently[18].

For these types of boilers, we do only consider carbon dioxide as an effluent as other emissions are or will likely be covered by existing regulation as well (especially IED and draft directive on medium combustion plants). The term Steam boiler is defined as follows within the context of this study:

Within the context of this study Steam Boiler:

a) Means a device -

   i. Most of which is an arrangement of pressure containment parts;

   and

   ii. The purpose of which is to generate steam at temperatures above 100°C

      (A) By the use of a directly applied combustion process; or
      (B) By the application of heated gases; and

b) Includes any of the following:

   i. Boiler piping (within the system boundary from feed water inlet up to steam outlet)

   ii. Combustion equipment

   iii. Combustion management systems

   iv. Controls

   v. Economisers

   vi. Fans

   vii. Feed and circulating pumps

   viii. Pressure fittings

   ix. Reheaters

c) The Combustion equipment is within the context of this study necessary part of a Steam boiler. The fuel of the Combustion equipment is Natural Gas or Heating Oil. We exclude all solid fuels[19].

16 From technological point of view waste heat boiler might be state of the art as they should be mainly dominated by the heat exchanger. However we assume that the market diffusion of this technology might be at the beginning. An ecodesign regulation might dampen further market diffusion. We do not want to create this risk.

17This is based in the fact that we assume the useful heat output of electric steam boiler to be lower than 0.3 MW. Furthermore we assume that the efficiency of electric steam boiler ranges between 90% and 98% (within that efficiency figure the used electrical energy is being set into relation to the generated useful heat output). Finally we assume that the production of 1 MW electricity consume 2.5 MW thermal input on average in Europe. This means that the accountable thermal input for electric steam boiler is lower than 1 MW together with the above named assumptions.

18 Information provided by EHI.

19 The definition is inspired by the definition from "The Design, Safe Operation, Maintenance and Servicing of Steam Boilers" published by the Occupational Safety and Health Service, Department of Labour, Wellington, New Zealand, from 2004, p 16-17, ISBN 0-477-03629-5. We adjusted the definition to the needs and content of this study.

Task 2: Markets

3 Task 2: Markets

3.1 Objectives

The objective of this task is to properly describe the EU market for steam boilers as defined in Task 1. This analysis provides the base for further tasks to consider the market perspective in their analyses. Specifically, the objectives of this task include:

- to place the Lot 28 product groups within the overall context of EU industry and trade;
- to provide market and cost input (sales and installed stock) for the assessment of EU environmental impacts of the product group;
- to provide insights into the latest market trends to indicate the market structures and on-going trends in product design. This will serve as an input for the subsequent tasks such as improvement potentials;
- to provide the dataset which can be a basis for the Lice Cycle Cost calculation.

3.2 Issues related to data collection

Due to the specific conditions of this market, the analysis dealt with the following statistical issues, which is worth mentioning as guidance, for a better understanding of the analysis itself.

1. **Eurostat data are gathered taking into account confidentiality and market relevance.**

According to the document "*PRODCOM Statistics on the production of manufactured goods*"[20] data are available for each Member State (MS) and EU aggregated data. The aggregations are constructed as follows:

- EU27: from the EU25 total shown, plus the sum of the "EU2" countries rounded to the base given in the BASE indicator;
- EU25: from the EU27 total shown, minus the sum of the "EU2" countries rounded to the base given in the BASE indicator;
- EU15 from the EU25 total shown, minus the sum of the "EU10" countries rounded to the base given in the BASE indicator.

The aggregation calculations are based on BASE indicators for two main reasons:

- **Confidentiality of data**. If only a small number of enterprises produce a product in the reporting country, there is a risk that information regarding an individual enterprise might be revealed. If the enterprise does not agree to this the reporting country declares the production figures confidential. They are transmitted to Eurostat but not published. However if several countries declare their production for a heading to be confidential, an EU total can be published because the data for an individual country cannot be inferred.
- **Data estimation**. The data is estimated, because no figures were supplied by the reporting country.

Data in some cases are not available for a number of reasons: the reporting country does not survey the heading; the reporting country has reason to doubt the

[20] http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/Annexes/prom_esms_an1.pdf

accuracy of the data and suppresses it; or the reporting country uses the wrong volume unit or the wrong production type, which means that the data is not comparable with other countries and is suppressed by Eurostat. Eurostat makes estimates for missing data, but only uses them in EU totals.

If data is missing for one or more MSs the corresponding EU total cannot be calculated and is also marked as missing. In these cases, Eurostat makes estimates for the missing data. For some headings reporting countries are unable to supply the data, normally because of non-response of the enterprises they have surveyed. If data for one or more countries is missing, Eurostat is unable to calculate EU totals for that heading. In order to avoid this situation, Eurostat makes estimates for missing data. These are not included in the published national data, but are used in aggregating individual country data to obtain EU totals.

Eurostat data used in the following analysis related to the Prodcom code 25.30.11.10 are in a preliminary version. Such figures will be made public around mid of March.

2. **Considering such limits, which have a relevant weight in the steam boilers sector, a market operators' consultation has been carried out in order to countercheck statistical data with information directly coming from the field**.

   Pursuant to formal and informal contacts with the European Heating Association (EHI), the German Association for Efficiency and Renewable Energies (BDH) and some market operators, selected data have been provided taken into account of the confidentiality limit of the market research. The preliminary results of such contacts show that:

   - There are only a limited number of steam boilers in the European market and only a few manufacturers.
   - Even if aggregated at European level, collected data on the thermal capacity of individual steam boilers or the industry utilising them, would inevitably be leading to its manufacturers thus revealing individual companies' market share and other sensitive information.
   - There is no "average steam boiler", as each boiler is custom made or at most produced in very limited numbers.
   - Steam boilers are designed for and in conjunction with the customer to meet very specific requirements.
   - Such complexities cannot be reduced even looking at destination markets.
   - In fact, the energy loss of such plants is dominated by the exhaust gas temperature and oxygen content, which is always in direct correlation to the necessary temperature level of the industrial process. Customers would thus be reluctant to disclose information on steam boilers that would shed a light on their industrial processes.

3.3 Generic economic data EU27

Eurostat database is the official source for EU policy, using PRODCOM categorization and as such are a valuable to the policy makers. Thus, tables and figures recalled below provide PRODCOM data for the EU production of steam boilers for the period 1995-2012.

The following PRODCOM codes have been considered:

- Code: 25.30.11.10

  Water tube boilers (excluding central heating hot water boilers capable of producing low pressure steam)

- Code: 25.30.11.50

Vapour generating boilers (including hybrid boilers) (excluding central heating hot water boilers capable of producing low pressure steam, water tube boilers)

- Code: 25.30.11.70

  Super-heated water boilers (excluding central heating hot water boilers capable of producing low pressure steam)

For each PRODCOM code considered, data on **Production (Y)**, (**value and quantity**), **Export and Import** (**X** and **M**, **value and quantity**) in the Eurostat Database, available **from 1995 to 2012**, has been analysed.

Since Eurostat PRODCOM codes includes all the Steam boilers in the scope of work without differentiating by power output, market operators have been asked to provide, based on direct experiences, the power range related to each category, as reported below.

Range	Product	Uses	PRODCOM
<20/25 MW	Fire tube Boilers	Industrial Processes	25.30.11.50
25-50 MW	Water tube Boilers	Industrial Processes	25.30.11.10
>50 MW	Water tube Boilers	Specific industrial applications/Power generation	25.30.11.10

Since steam boilers are designed as per client's specifications, the preliminary assumptions are listed below:

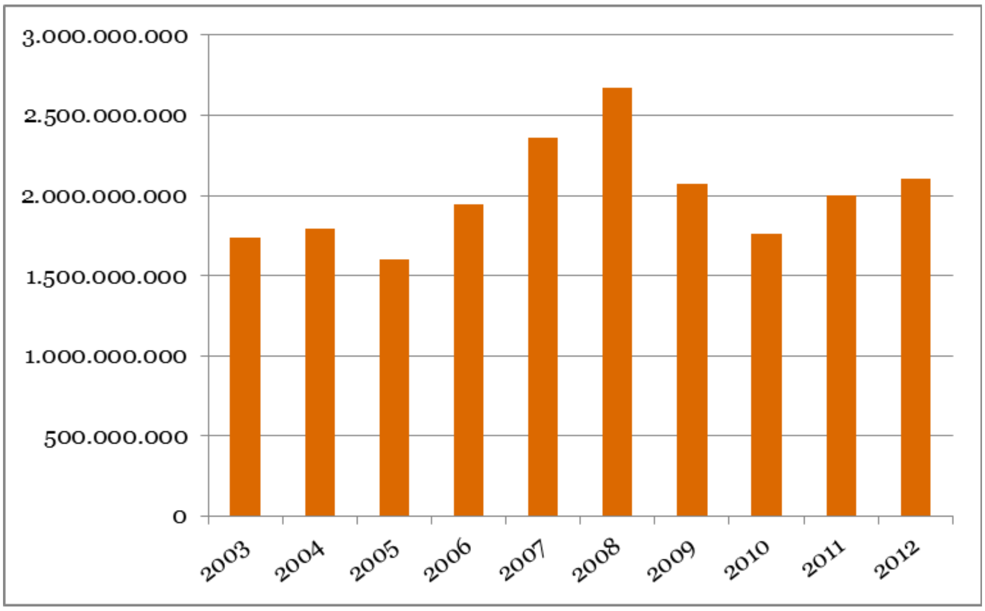
1. **EU Sales -** The EU sales of European producers are assumed equivalent to the difference between the overall production value and the export values. The overall sales of steam boilers in the EU are obtained adding imported steam boilers to that figure.
2. **Warehouse stock -** Since products are designed as per client's specifications, it has been assumed that each boiler produced is sold. A part of the production in the lower power range output can be considered as warehouse stock but not significant to the analysis purposes.
3. **Market trends -** Steam boilers production trends follow the served industries market trend (e.g. food processing, pulp and paper, chemical manufacturing, etc.). In the analysis which is presented in paragraph 3.7 detailed assumptions on market trends drivers are made.

As showed in a Figure 6 **significant growth of the production** of **steam boilers** is observed for the **2008**. Notwithstanding the decrease in 2009-2010, in the last two years (2011 and 2012) production confirms a positive trend.

As to the production of steam boilers in terms of units, in Figure 7 it can be noted a continuous decrease of units produced at EU level, with stable values between 2009 and 2012 for the first time below the threshold of 40.000 units.

In 2012 a total of **29.567 steam boilers** were produced in Europe for a total of **2.104.475.049 Euro**, of which **1.706.112.229 Euro** sold in EU27.

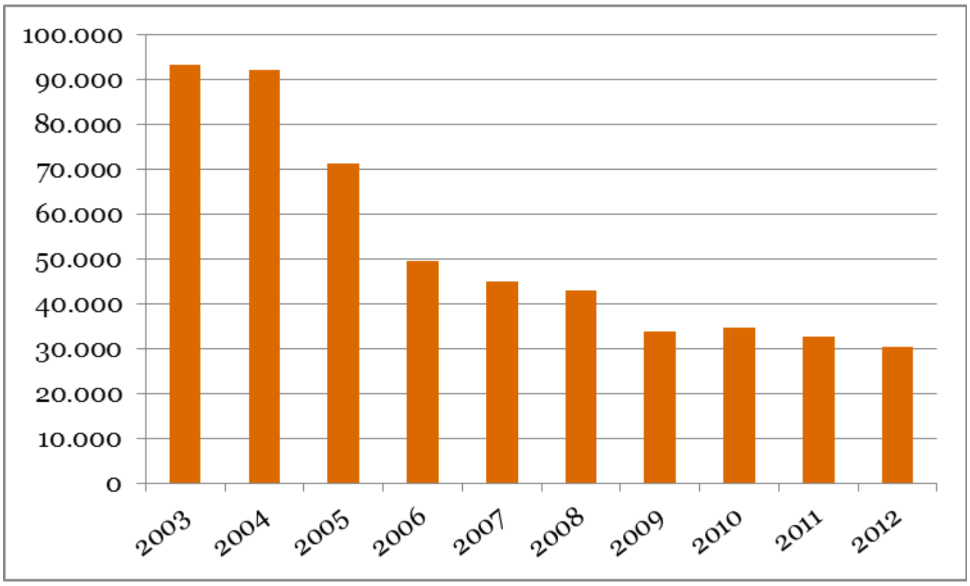
Figure 6 - Production of steam boilers of EU27 - 2003-2012* (values, Euro)



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

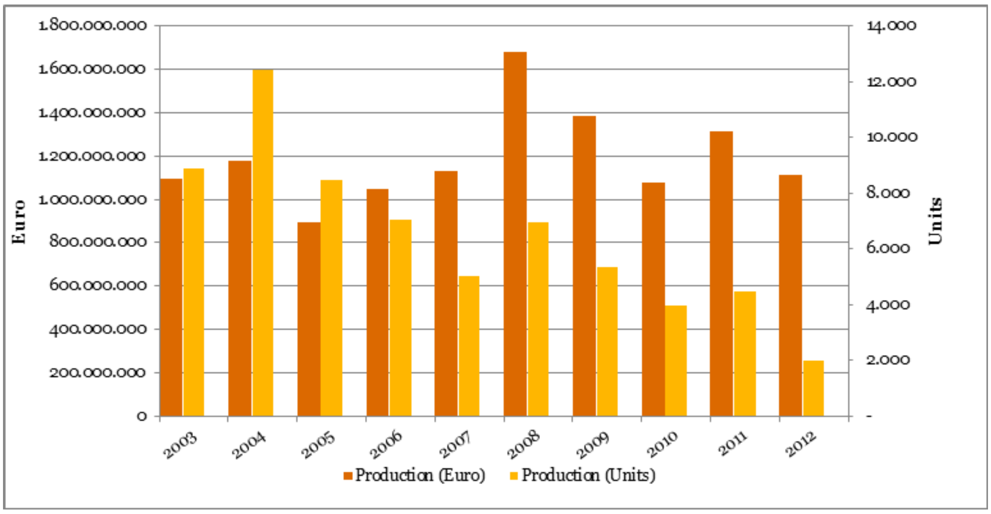
Figure 7: Production of steam boilers of EU27 - 2003-2012* (Units)



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

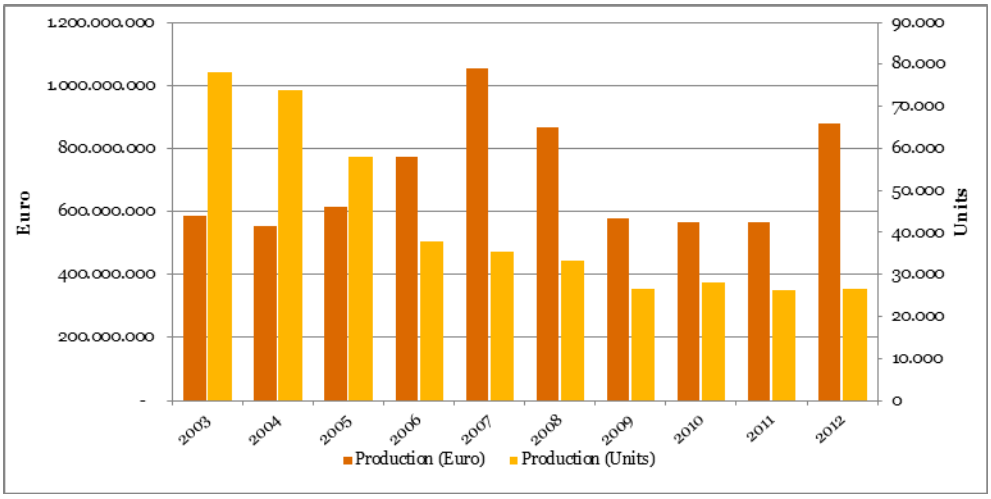
Figure 8 - Water tube boilers Production EU27 - 2003-2012*



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

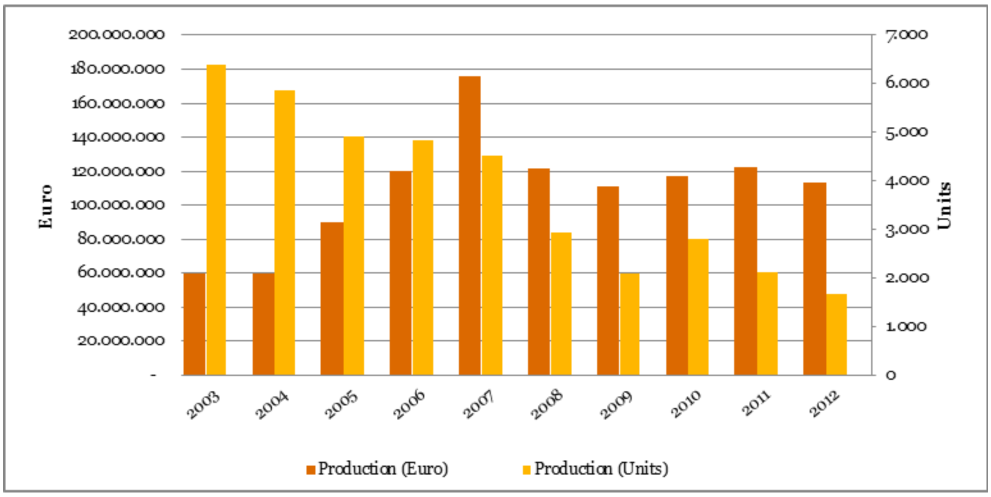
Figure 9 - Vapour-generating boilers production EU27 - 2003-2012*



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

Figure 10 - Super-heated boilers Production EU27 - 2003-2012*



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

The **geographical distribution** of the **Steam Boilers Production**, looking at the Table 26 (Water tube boilers), Table 27 (Vapour generating boilers) (Fire tube boilers) and Table 27.

3.3.1 Water tube boilers (Prodcom: 25.30.11.10)

In 2012**, Finland**, **Italy**, **Germany** and **Spain** have been the majors markets in terms production of water tube boilers. The four Member States count together for **Euro 920 million** and **1.389 boilers produced** on a total **EU27 of Euro 1.112.229.307** and **1.196 units produced.**

Table 26 - Water tube boilers (excluding central heating hot water boilers capable of producing low pressure steam) Code: 25.30.11.10 - 2012 data

MS	Production (units)	Production (Euro)
Finland	109	550.673.335
Italy	748	201.185.000
Germany	382	100.682.327
Denmark	3	88.629.579
Spain	150	69.658.529
Croatia	30	29.853.246
Austria		0
Belgium		0
Bulgaria	0	0

MS	Production (units)	Production (Euro)
Cyprus	0	0
Czech Rep.		0
Estonia	0	0
France		0
Greece		0
Hungary		0
Ireland		0
Latvia	0	0
Lithuania	0	0
Luxemburg	0	0
Malta	0	0
Netherlands	0	0
Poland	33	0
Portugal		0
Romania	0	0
Slovakia	0	0
Slovenia	0	0
Sweden		0
UK	0	0
EU27	1.196	1.112.229.307

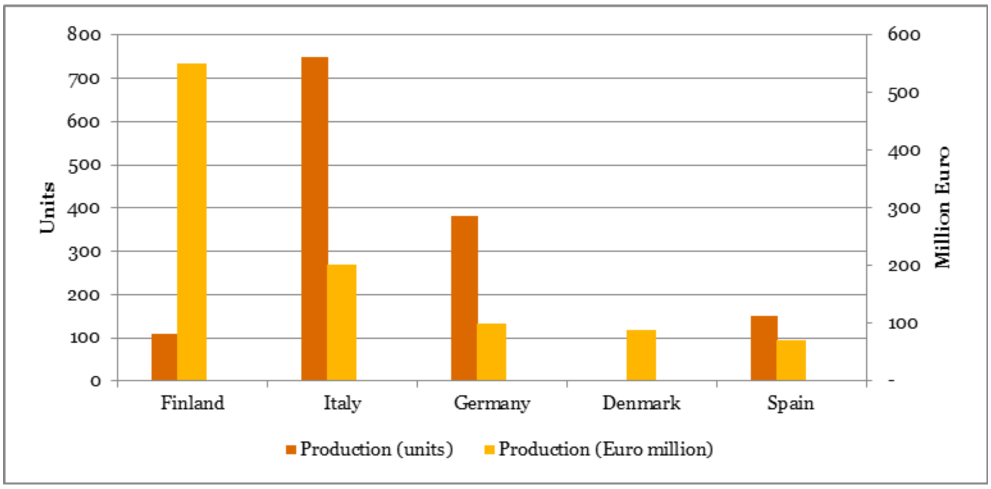
Source: Eurostat

Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.

Possible values are blank (data is available), ':' data is not available, ':O' data is not available but this is an optional heading, ':C' data is confidential, ':E' data is estimated, '-' not applicable.

Some EU totals are unsafe to publish because they would reveal confidential national data that they are composed of. Rounding is used to introduce some uncertainty to such totals, so that a figure can be given without disclosing the underlying confidential data. A set of flags is used to indicate rounded totals.

Figure 11 - Production of Water tube boilers Top 5 MSs in 2012*

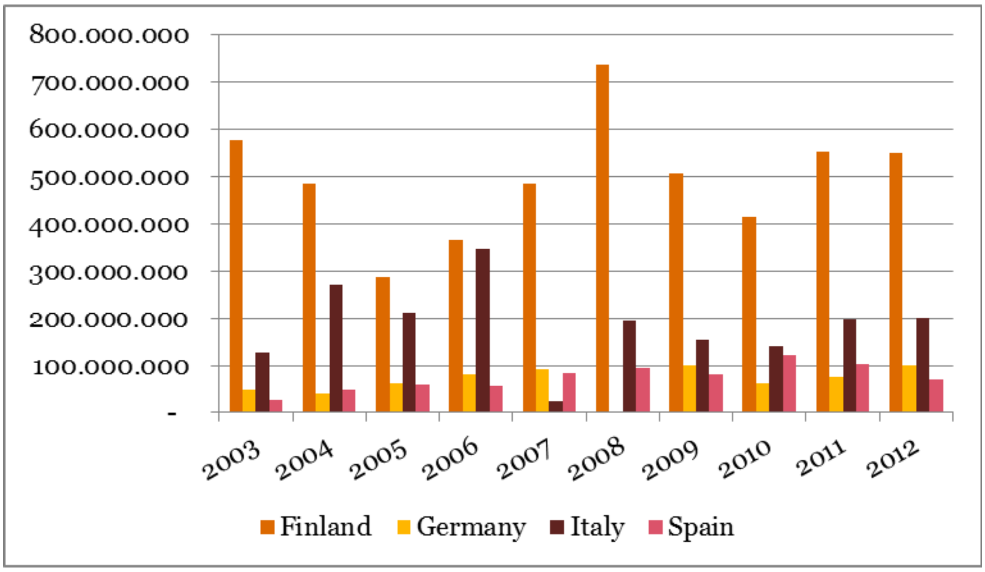


**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

Finland appears as the first market (with a production of 550 million Euro for a total of 109 boilers produced), representing the 50% of the total EU27 production. **Italy** follows with a total of 201 million Euro and 748 boilers, representing a share of 18% of the EU27 overall production. Finally, **Germany** (100 million Euro and 382 units) and **Spain** (70 million Euro and 150 boilers produced) close the top ranked producers in the water tube boilers market.

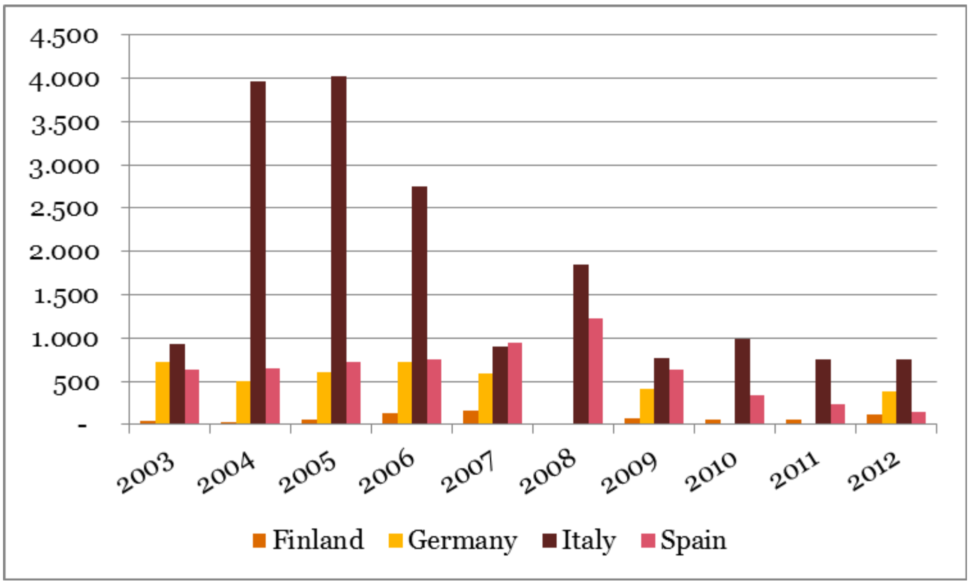
Figure 12 - Production of Water tube boilers* (Prodcom: 25.30.11.10) in main countries 2003-2012 (Euro)



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

Figure 13 - Production of Water tube boilers* (Prodcom: 25.30.11.10) in main countries 2003-2012 (units)



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

It can be observed that in some cases the highest production values do not correspond to the highest number of units produced, due to a number of factors depending on product technical features (thermal capacity MW, fuel, raw materials etc.) and as well as on specific market conditions (number of operators, etc.). Italy confirms its leading role in terms of units produced.

3.3.2 Vapour generating boilers (Prodcom: 25.30.11.50)

Germany and **Italy** dominate the Vapour generating boilers market in Europe with a total production value of **480 million Euro** with a total of **11.600 boilers** produced in 2012. The two Member States represent more than the 50% of the total EU27 production (**879.255.735 Euro and 26.689 units).**

Table 27 - Vapour generating boilers (including hybrid boilers) (excluding central heating hot water boilers capable of producing low pressure steam, water tube boilers) Code: 25.30.11.50 - 2012 data

MS	Production (units)	Production (Euro)
Italy	8.614	348.848.000
Spain	766	24.499.367
UK	629	38.543.786
Croatia	61	2.895.040
Estonia	5	565.534

MS	Production (units)	Production (Euro)
France	306	25.330.205
Portugal	30	1.968.523
Germany	3.040	131.085.245
Greece	279	790.252
Finland	217	42.428.159
Hungary	16	758.793
Poland	152	:
Bulgaria	113	628.387
Austria	:	:
Belgium	:	:
Czech Rep.	:	:
Latvia	:	:
Netherlands	:	:
Romania	:	:
Sweden	:	:
Cyprus	-	-
Denmark	-	-
Ireland	-	-
Lithuania	-	-
Luxemburg	-	-
Malta	-	-
Slovakia	-	-
Slovenia	-	-
EU27	26.689	879.255.735

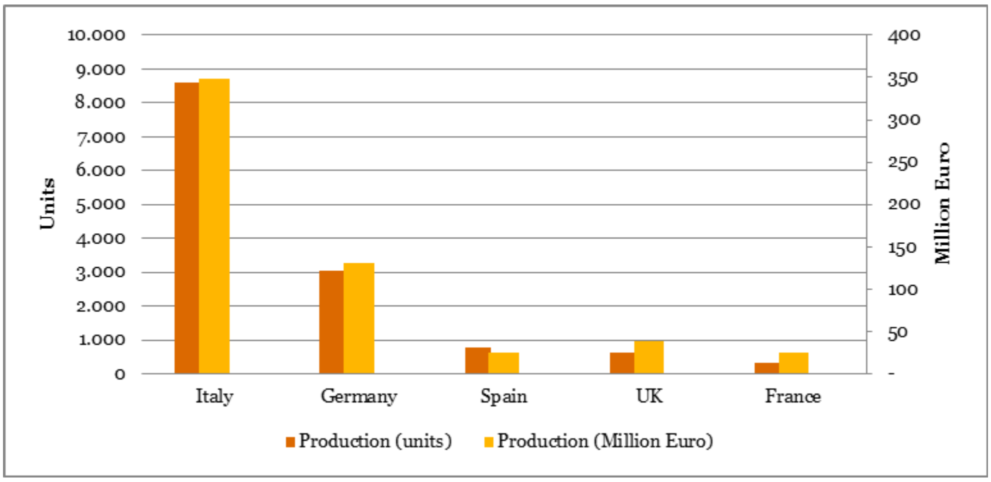
Source: Eurostat

Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.

Possible values are blank (data is available), ':' data is not available, ':O' data is not available but this is an optional heading, ':C' data is confidential, ':E' data is estimated, '-' not applicable.

Some EU totals are unsafe to publish because they would reveal confidential national data that they are composed of. Rounding is used to introduce some uncertainty to such totals, so that a figure can be given without disclosing the underlying confidential data. A set of flags is used to indicate rounded totals.

Figure 14 - Production of Vapour generating boilers Top 5 MSs in 2012*

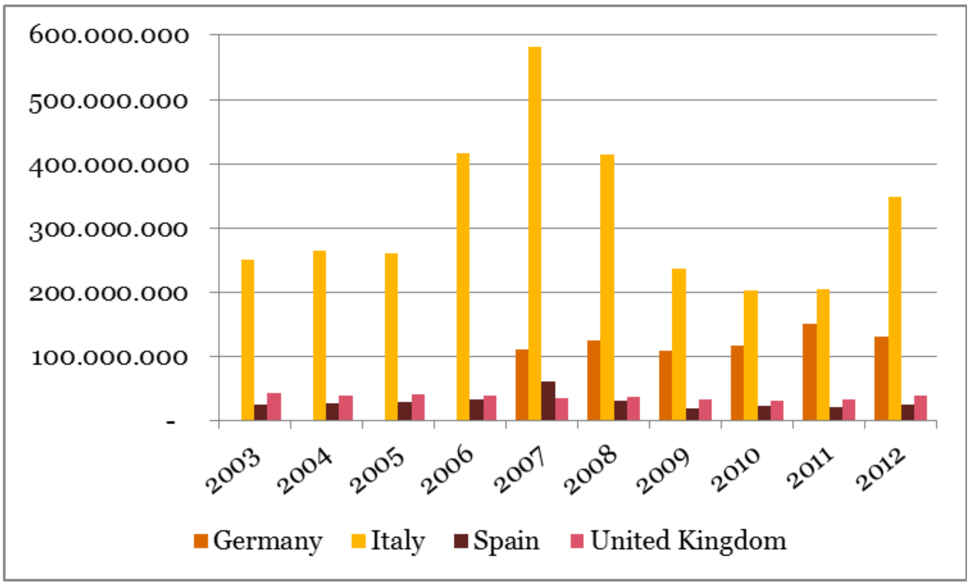


**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

With lower values, UK and Spain appear in the ranking with a total of 38 million Euro and 629 boilers in UK, and 25 million Euro and 766 boilers produced in Spain.

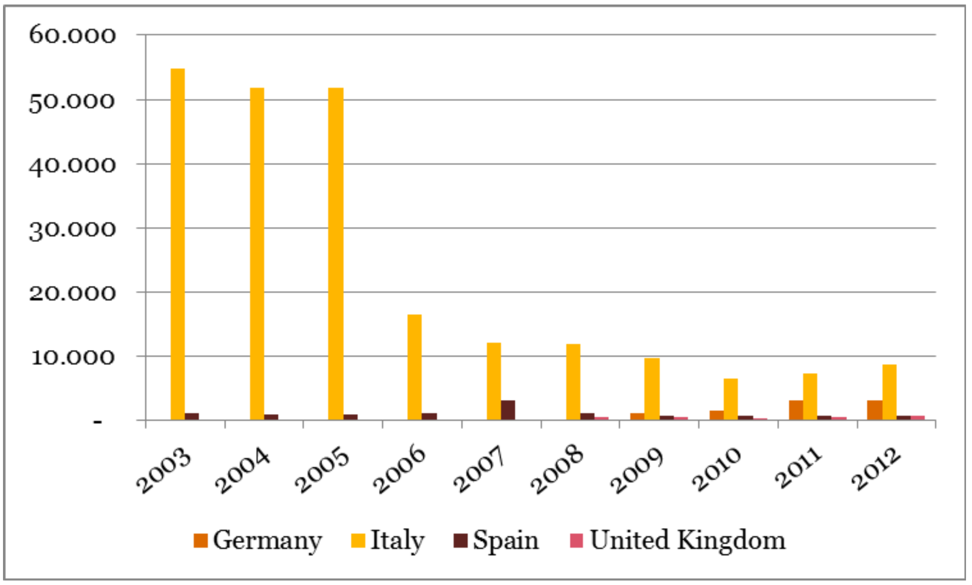
Figure 15 - Production of Vapour generating boilers* (Prodcom: 25.30.11.50) in Germany, Italy, Spain and UK 2003-2012 (Euro)



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

Figure 16 - Production of Vapour generating boilers* (Prodcom: 25.30.11.50) in Germany, Italy, Spain and UK 2003-2012 (units)



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

The higher number of Vapour generating boilers produced in Europe (**26.689**) comparing to the water tube boilers produced (**1.196**), indicates different industrial uses.

Figure 16 shows the dramatic decrease in terms of units produced of Italy, by going from a total of more than 50.000 Vapour generating boilers produced in 2003 to less than 20.000 boilers produced in 2006. The figure displays, as well, the leading role played by the Italian producers comparing to the other major markets.

3.3.3 Super-heated boilers (PRODCOM: 25.30.11.70)

Finland and **Spain** lead the Super-heated boilers market in EU with a total production value of **49 million Euro with** a total of **338 boilers** produced in 2012 on a total of **EU 27 of 112 million Euro.**

Italy follows with a total of roughly **5 million Euro** for a total of **183 boilers** produced in 2012.

Table 28 - Super-heated water boilers (excluding central heating hot water boilers capable of producing low pressure steam) Code: 25.30.11.70 - 2012 data

MS	Production (units)	Production (Euro)
Spain	318	21.763.285
Italy	183	4.997.000
Germany	131	:

MS	Production (units)	Production (Euro)
Poland	31	2.207.661
Finland	20	27.846.172
Austria	0	-
Belgium	0	-
Bulgaria	0	-
Croatia	0	-
Cyprus	0	-
Czech Rep.	0	-
Denmark	0	-
Estonia	0	-
Iceland	0	-
Ireland	0	-
Latvia	0	-
Lithuania	0	-
Luxemburg	0	-
Malta	0	-
Netherlands	0	-
Norway	0	-
Portugal	0	-
Romania	0	-
Slovakia	0	-
Slovenia	0	-
UK	0	-
France	:	:
Greece	:	:
Hungary	:	:

MS	Production (units)	Production (Euro)
Sweden	:	:
EU27	1.682	112.990.007

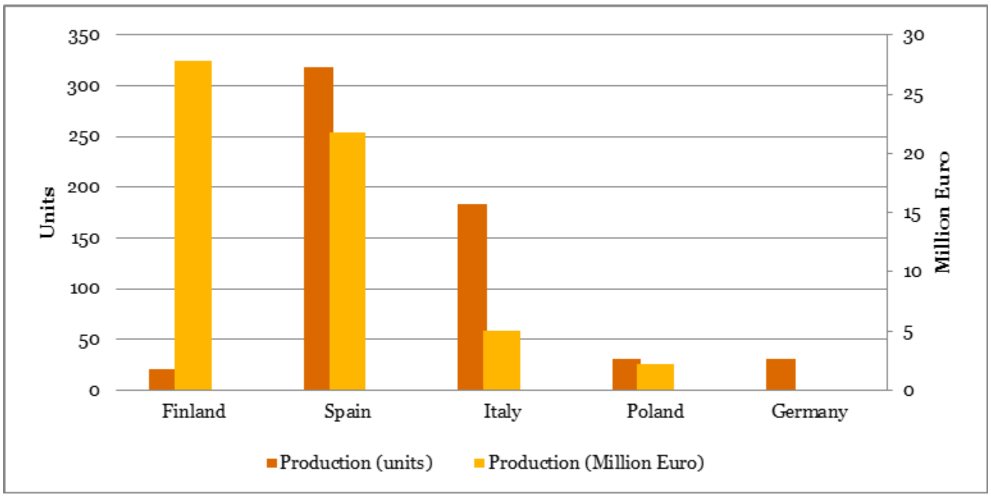
Source: Eurostat

Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.

Possible values are blank (data is available), ':' data is not available, ':O' data is not available but this is an optional heading, ':C' data is confidential, ':E' data is estimated, '-' not applicable.

Some EU totals are unsafe to publish because they would reveal confidential national data that they are composed of. Rounding is used to introduce some uncertainty to such totals, so that a figure can be given without disclosing the underlying confidential data. A set of flags is used to indicate rounded totals.

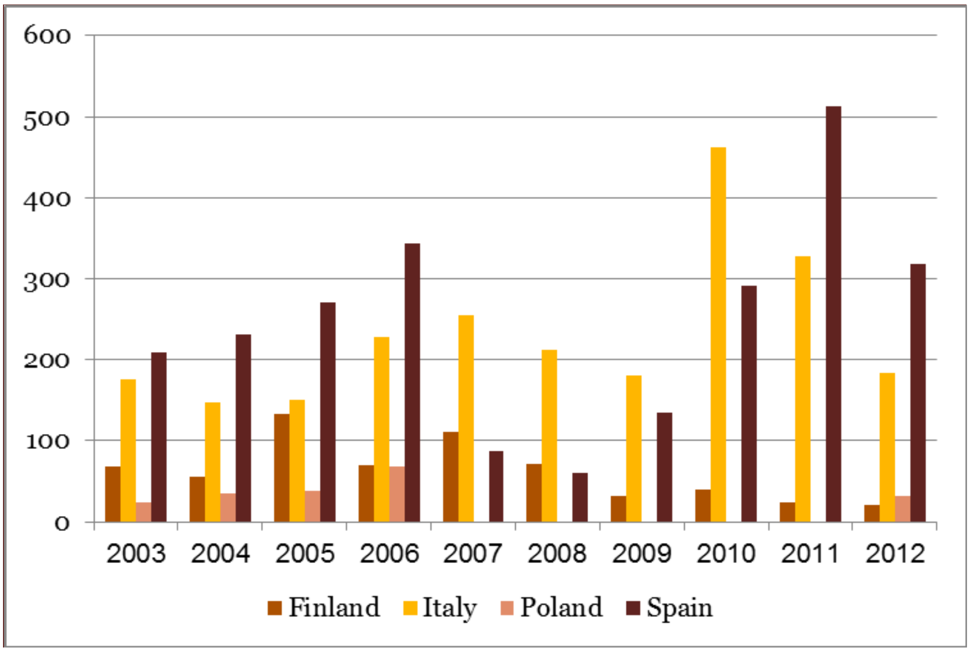
Figure 17 - Production of Super-heated water boilers Top 5 MSs in 2012*



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

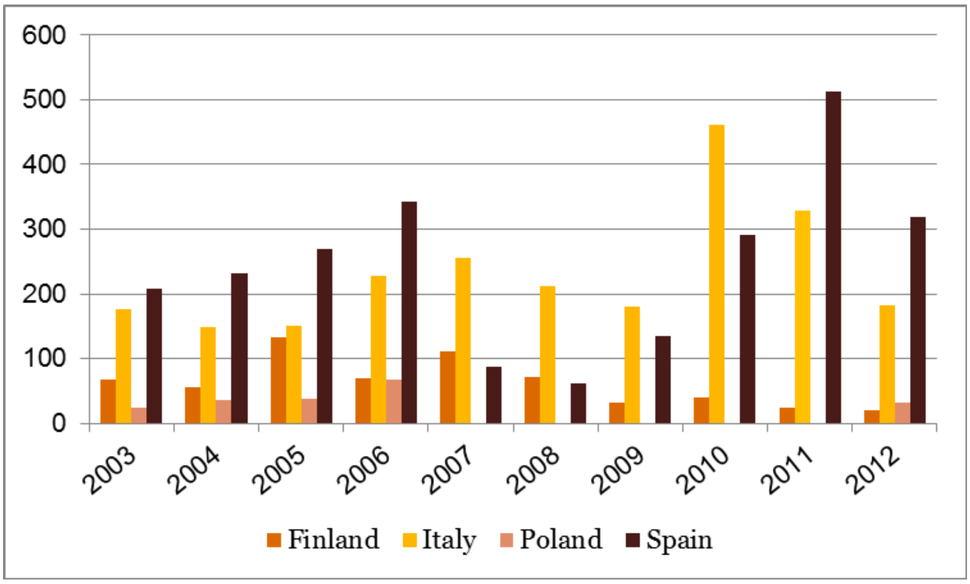
Figure 18 - Production of super-heated tube boilers* (Prodcom: 25.30.11.70) in Finland, Italy, Poland and Spain 2003-2012 (Euro)



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

Figure 19 - Production of super-heated tube boilers* (Prodcom: 25.30.11.70) in Finland, Italy, Poland and Spain 2003-2012 (units)



**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: PwC on Eurostat

New figures on steam boilers production are presented in paragraph 2.6.

Table 29 - Production value of Water tube boilers (excluding central heating hot water boilers capable of producing low pressure steam) Code: 25.30.11.10 - (Euro and number of units) – continued

25.30.11.10*	1995		1996		1997		1998		1999		2000		2001		2002		2003	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
AT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HR	-	-	-	-	-	-	-	-	-	-	-	-	5.533.296	55	-	-	-	-
CY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CZ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DK	49.547.489	-	49.920.916	-	54.568.924	-	71.948.849	-	74.212.975	-	43.541.147	164	14.831.898	33	16.864.150	23	28.760.990	9
EE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FI	392.269.558	-	297.023.781	-	310.444.342	-	276.722.106	-	332.761.323	83	361.150.243	82	372.538.939	-	440.084.477	32	576.359.397	48
FR	-	-	9.553.211	-	14.996.371	-	55.309.025	-	54.430.301	-	42.503.964	-	-	-	133.674.000	-	13.981.000	215
DE	-	-	-	-	-	-	-	-	165.587.995	575	64.791.000	623	50.949.000	690	48.211.000	619	48.388.000	717
EL	1.159.610	50	359.118	40	837.679	70	290.871	50	436.859	50	-	-	-	-	-	-	-	-
HU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT	187.920.043	145	173.421.611	1.297	189.302.338	842	183.099.395	891	273.232.039	-	206.242.415	1.375	365.150.005	1.356	282.803.534	1.138	125.878.000	926
LV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NL	-	-	-	-	23.084.404	-	-	-	-	-	-	-	-	-	-	-	-	-
PL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PT	-	-	-	-	642.714	33	778.120	43	1.139.264	53	1.264.338	57	885.921	48	204.919	17	195.959	16
RO	-	-	-	-	-	-	-	-	-	-	-	-	846.396	21	-	-	-	-
SK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

25.30.11.10*	1995		1996		1997		1998		1999		2000		2001		2002		2003	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
SL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SP	65.481.098	382	66.769.733	243	114.002.984	437	94.181.686	339	130.647.627	912	34.590.000	267	14.499.000	461	21.952.321	410	25.573.388	639
SE	-	-	11.030	151	5.046	58	5.700.939	60	217.996	18	174.182	11	275.067	21	285.961	22	-	-
UK	-	-	65.127.796	4.054	4.534.161	268	347.428	17	3.186.580	180	-	-	-	-	-	-	2.819.393	-
EU 15 (Eurostat)	1.556.389.202	13.927	1.492.365.169	21.616	1.277.964.230	23.498	1.055.563.898	18.126	1.495.651.688	28.123	1.022.694.528	25.037	1.401.861.363	20.611	1.348.798.453	20.152	1.062.300.232	8.850
EU 25 (Eurostat)	-		-		-		-		-		-		-		-		1.092.308.232	8.865
EU 27 (Eurostat)	-		-		-		-		-		-		-		-		1.092.908.232	8.898

**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: Eurostat

25.30.11.10*	2004		2005		2006		2007		2008		2009		2010		2011		2012	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
AT	-	-	-	-	-	-	-	-	-	-	3.985.000	209	2.408.900	52	-	-	-	-
BE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HR	-	-	-	-	-	-	10.805.179	63	-	92	62.193.289	83	88.717.759	43	40.591.030	56	29.853.246	30
CY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CZ	-	-	-	-	-	-	-	-	-	-	2.739.663	26	1.424.419	24	766.287	-	-	-
DK	28.388.688	19	36.772.458	19	67.539.650	13	126.199.098	25	57.181.465	7	102.490.801	12	2.647.268	4	439.293	11	88.629.579	3
EE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FI	484.189.075	34	286.213.750	61	365.045.790	132	485.401.204	163	738.369.645	-	506.807.583	69	413.873.498	58	554.120.113	64	550.673.335	109
FR	4.738.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DE	41.125.000	504	62.253.203	611	80.710.367	722	93.013.967	592	-	-	100.874.317	413	61.300.610	-	76.468.548	-	100.682.327	382
EL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IR	-	-	-	-	-	-	-	-	2.519.000	26	-	-	-	-	-	-	-	-
IT	271.148.000	3.968	211.708.000	4.021	347.409.000	2.746	23.371.000	897	193.984.000	1.850	154.079.000	773	141.035.000	993	197.460.000	747	201.185.000	748
LV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PL	-		-	-	-	-	-	-	-	31	-	-	-	36	-	27	-	33
PT	169.600	14	178.362	15	215.351	17	-	-	-	7	-	-	-	-	-	-	-	-
RO	1.172.439	-	1.375.733	-	1.293.762	20	-	-	-	-	-	-	-	-	-	-	-	-
SK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

25.30.11.10*	2004		2005		2006		2007		2008		2009		2010		2011		2012	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
SL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SP	47.937.500	653	58.518.644	730	57.960.490	749	83.092.927	942	95.133.191	1.220	81.275.763	630	122.477.835	333	101.660.628	228	69.658.529	150
SE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UK	-	-	-	-	-	-	-	-	-	-	2.469.302	-	-	-	-	-	-	-
EU 15 (Eurostat)	1.175.210.899	12.412	859.090.463	8.419														
EU 25 (Eurostat)	1.176.846.978	12.417	891.090.463	8.466	1.045.573.578	7.039	1.127.792.726	4.984	1.683.267.593	6.966	1.386.001.320	5.330	1.078.678.187	3.967	1.316.355.094	4.450	1.112.229.307	1.996
EU 27 (Eurostat)	1.178.636.978	12.453	893.066.196	8.489	1.048.067.339	7.064	1.128.292.726	5.014	1.683.327.593	6.936	1.386.001.320	5.330	1.078.678.187	3.967	1.316.361.094	4.450	1.112.229.307	1.996

**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

- It indicates data are confidential or not provided.

Source: Eurostat

Table 30 - Production value of Vapour generating boilers (including hybrid boilers) (excluding central heating hot water boilers capable of producing low pressure steam, water tube boilers) Code: 25.30.11.50 - (Euro and number of units) – continued

25.30.11.50*	1995		1996		1997		1998		1999		2000		2001		2002		2003	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
AT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BE	-	-	-	-	-	-	-	-	16.544.067	641	44.417.413	2.505	-	-	-	-	-	-
BG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CZ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.999.755	-
DK	1.758.597	25	1.835.229	26	1.660.832	27	1.468.404	24	765.103	13	496.123	25	494.245	26	757.868	22	6.965.571	15
EE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FI	14.465.894	-	23.294.842	-	19.132.231	227	16.469.870	96	26.072.792	-	34.387.709	328	74.711.559	-	63.545.600	-	56.834.441	15.088
FR		-	44.022.178	-	42.044.884	-	38.760.414	-	33.882.096	-	30.856.302	-	-	-	25.914.000	-	24.830.000	-
DE	137.692.390	1.228		-	105.006.618	517	138.503.885	526	130.636.568	1.703	103.166.000	1.334	89.547.000	1.245	75.193.000	-	-	-
EL	1.856.952	640	2.627.461	830	4.109.611	950	4.442.127	1.130	5.011.515	1.350	3.511	1	2.825	1.455	2.599.501	1.393	1.990.437	823
HU	-	-	-	-	-	-	-	-	-	-	-	-	2.822.646	101	1.588.367	70	1.639.249	70
IR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT	20.050.325	80.427	187.438.233	2.264	-	-	-	-	116.827.199	-	86.661.984	3.724	102.973.242	7.037	118.792.317	8.153	250.781.000	54.772
LV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	180	1.334.059	155
PT	15.350.083	57	3.061.968	77	2.863.245	74	4.168.299	66	3.893.033	67	3.800.161	64	3.226.924	66	3.747.230	57	2.472.616	48
RO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SK	-	-	-	-	-	-	-	-	-	6	794	9	-	-	-	-	-	-

25.30.11.50*	1995		1996		1997		1998		1999		2000		2001		2002		2003	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
SL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SP	15.136.589	4.316	15.730.143	5.685	17.244.028	5.384	19.841.552	8.405	29.201.399	10.453	26.397.000	7.982	70.306.000	6.404	78.004.199	1.307	25.498.032	1.155
SE	-	-	9.292	5.480	27.257	-	37.274.083	-	46.261.368	-	12.663.288	-	7.160.044	-	32.724.033	-	52.723.134	-
UK	42.401.062	-	57.160.236	-	38.029.756	-	32.767.593	-	45.976.924	-	36.287.121	-	46.251.025	-	53.348.646	-	42.780.780	-
EU 15 (Eurostat)	333.829.600	89.500	540.278.403	19.250	491.459.832	12.687	577.588.595	16.457	470.606.310	20.868	385.000.000	19.620	480.000.000	26.410	488.776.078	22.508	580.035.895	77.693
EU 25 (Eurostat)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	585.185.895	78.023
EU 27 (Eurostat)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	585.185.895	78.023

**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: Eurostat

25.30.11.50*	2004		2005		2006		2007		2008		2009		2010		2011		2012	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
AT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BG	-	-	-	-	-	-	-	-	-	-	596.687	58	-	-	751.099	123	628.387	113
HR	-	-	-	-	-	-	-	-	2.810.674	26	686.963	12	1.980.997	20	3.629.306	32	2.895.040	61
CY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CZ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DK	1.118.563	25	1.886.792	25	1.432.076	55	2.161.302	97	2.698.900	93	1.034.890	35	1.089.388	69	1.842.670	90	-	-
EE	-	-	-	-	-	-	-	-	-	-	-	-	138.433	163	133.416	1	565.534	5
FI	49.065.138	13.068	62.748.116	13.068	32.218.254	7.503	40.281.080	5.486	98.025.687	6.161	48.010.242	4.007	34.324.349	4.423	30.610.669	1.273	42.428.159	217
FR	32.469.000	-	34.327.000	-	65.701.440	155	72.157.000	185	45.446.000	159	74.240.000	144	61.962.000	257	24.066.230	142	25.330.205	306
DE	-	-	-	-	-	-	111.042.925	-	124.017.004	-	109.194.175	1.209	116.334.248	1.589	151.052.953	3.112	131.085.245	3.040
EL	4.991.272	2.790	4.221.534	2.790	2.548.784	1.488	2.661.591	1.307	2.712.212	1.122	1.318.575	611	981.342	380	870.331	310	790.252	279
HU	2.418.183	54	2.650.772	54	1.600.208	120	2.319.073	91	6.468.180	38	1.463.090	27	2.348.098	32	1.426.592	20	758.793	16
IR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT	263.895.000	51.751	261.062.000	51.751	417.204.000	16.490	581.344.000	11.998	414.852.000	11.862	236.692.000	9.711	202.610.000	6.529	204.191.000	7.209	348.848.000	8.614
LV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PL	-	-	485.657	-	1.203.522	25	8.794.778	112	-	187	2.908.887	90	2.458.057	-	12.066.908	-	-	152
PT	2.768.231	48	2.394.172	48	1.577.762	34	1.565.065	34	2.176.324	35	-	-	-	-	2.340.965	15	1.968.523	30
RO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

25.30.11.50*	2004		2005		2006		2007		2008		2009		2010		2011		2012	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
SP	27.609.887	853	28.380.139	853	33.521.467	1.171	61.142.739	3.063	31.697.485	1.017	19.116.161	770	23.521.774	786	20.737.305	711	24.499.367	766
SE	26.609.055	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UK	38.879.557	-	41.003.217	-	38.207.208	-	34.164.304	-	36.652.936	489	33.691.382	422	31.516.367	396	32.458.404	499	38.543.786	629
EU 15 (Eurostat)	546.558.223	73.684	609.616.242	57.841	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EU 25 (Eurostat)	554.680.739	73.867	614.809.113	57.991	774.353.556	37.720	1.053.789.706	35.478	867.183.240	33.226	577.106.631	26.451	565.455.691	28.064	563.591.395	26.177	878.253.735	26.557
EU 27 (Eurostat)	555.280.739	73.888	615.409.113	58.009	774.593.556	37.726	1.054.289.706	35.505	868.183.240	33.266	577.806.631	26.523	566.061.101	28.100	564.791.395	26.322	879.253.735	26.689

**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

- It indicates data are confidential or not provided.

Source: Eurostat

Table 31 - Production value of Super-heated water boilers (excluding central heating hot water boilers capable of producing low pressure steam) Code: 25.30.11.70 - (Euro and number of units) – continued

25.30.11.70*	1995		1996		1997		1998		1999		2000		2001		2002		2003	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
AT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CZ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FI	7.878.114	-	-	-	-	-	-	-	1.967.640	50	8.005.113	28	16.005.686	136	18.048.501	435	14.476.447	68
FR	-	-	-	-	247.391.495	-	168.769.503	-	206.540.490	-	66.349.930	-	-	-	19.221.000	-	25.046.000	-
DE	11.187.427	67	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-
EL	1.426.334	2.370	2.921.670	3.730	2.660.794	3.970	53.454	20	63.381	20	128	-	1.083	165	3.483.807	4.277	3.249.354	4.174
HU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT	370.398	38	1.958.692	71	-	-	-	-	990.048	-	4.938.361	132	8.081.001	232	7.576.939	221	6.452.000	176
LV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	978.843	78	2.163.866	24
PT	-	-	-	-	164.057	6	-	-	-	-	192.546	7	-	-	-	-	-	-
RO	-	-	-	-	-	-	-	-	-	-	133.809	320	437.371	815	-	791	-	-
SK	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-

25.30.11.70*	1995		1996		1997		1998		1999		2000		2001		2002		2003	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
SL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SP	8.568.417	136	31.923.041	127	2.917.462	143	13.169.592	1.793	13.434.574	1.431	1.995.000	283	1.486.000	145	3.307.262	221	4.090.647	209
SE	-	-	1.069	20	1.450	14	2.627.441	20	987.227	15	791.337	12	2.156.965	10	1.446.502	16	-	-
UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EU 15 (Eurostat)	-	3.235	248.491.869	10.000	291.669.926	14.788	255.157.354	10.881	280.310.514	13.035	151.275.088	3.242	129.711.193	3.301	9.004.4171	5.987	60.000.000	5.457
EU 25 (Eurostat)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60.000.000	5.482
EU 27 (Eurostat)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60.000.000	6.400

**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: Eurostat

25.30.11.70*	2004		2005		2006		2007		2008		2009		2010		2011		2012	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
AT	-	-	-	-	-	-	-	-	19.281.600	87	-	-	-	-	-	-	-	-
BE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CZ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FI	14.933.681	56	10.288.683	133	5.096.685	69	7.628.828	111	14.933.863	72	12.404.693	31	7.125.511	39	9.774.304	24	27.846.172	20
FR	34.027.000	-	21.295.000	721	62.463.790	455	80.371.510	547	-	-	-	-	-	-	-	-	-	-
DE	-	-	-	-	-	43	-	33	-	-	-	-	-	-	-	84	-	131
EL	2.387.177	3.911	1.971.980	3.493	1.981.789	3.542	1.974.176	3.386	1.805.636	2.298	-	-	-	-	-	-	-	-
HU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT	3.938.000	148	3.746.000	150	5.518.000	228	6.558.000	255	5.935.000	212	5.242.000	180	11.589.000	462	9.174.000	328	4.997.000	183
LV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LT	-	-	-	-	-	-	-	-	-	-	3.707	27	5.532	27	1.245	9	-	-
LU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PL	-	35	1.210.788	38	3.467.722	68	-	-	-	-	-	-	-	-	-	-	2.207.661	31
PT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

25.30.11.70*	2004		2005		2006		2007		2008		2009		2010		2011		2012	
MS	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.	Euro	n.
SP	4.668.912	231	5.322.020	270	6.724.969	343	4.394.129	87	4.731.364	61	14.595.765	135	21.842.690	292	38.671.596	513	21.763.285	318
SE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UK	-	-	-	-	-	-	-	-	85.397	-	-	-	-	-	192.423	6	-	-
EU 15 (Eurostat)	60.000.000	5.500	88.789.212	4.877	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EU 25 (Eurostat)	60.000.000	5.566	900.00.000	4.915	120.292.371	4.840	176.184.235	4.513	121.830.216	2.945	110.897.783	2.100	116.877.209	2.800	122.237.523	2.110	112.990.007	1.682
EU 27 (Eurostat)	60.000.000	5.866	900.00.000	4.920	120.304.371	4.834	176.184.235	4.513	121.830.216	2.945	110.901.383	2.100	116.877.209	2.800	122.237.523	2.110	112.990.007	1.682

**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

- It indicates data are confidential or not provided.

Source: Eurostat

3.4 Import-export values per country

The Import-Export Eurostat data combine **Prodcom data** with **Import and Export data from the Foreign Trade** database. In most cases the Prodcom code corresponds to one or more CN[21] codes, so the data for all corresponding CN headings is aggregated to get the import and export data for the Prodcom code.

The analysis is based on the Prodcom codes and HS[22] Codes categorization. The values reported in the two databases (Prodcom and Foreign trade) are coherent.

Table 32 - HS codes within the Prodcom codes

25 30 11 10 Water tube boilers (excluding central heating hot water boilers capable of producing low pressure steam)
HS Codes of Heading 8402 Steam or other vapour generating boilers (other than central heating hot water boilers capable also of producing low pressure steam): Superheated water boilers Steam or other vapour generating boilers HS Codes 8402 11 Water tube Boilers With a Steam Production Exceeding 45t per Hour HS Codes 8402 12 Water tube Boilers With a Steam Production Not Exceeding 45t Per Hour
25 30 11 50 Vapour generating boilers (including hybrid boilers) (excluding central heating hot water boilers capable of producing low pressure steam, water tube boilers)
HS Codes 840219 Other vapour generating boilers including Hybrid boilers HS Codes 8402 19 10: Fire tube horizontal (Lancashire) boilers HS Codes 840219 90 Others
25 30 11 70 Super-heated water boilers (excluding central heating hot water boilers capable of producing low pressure steam)
HS Codes 8402 20 Super-heated Water Boilers HS Codes 8402 20 Parts of Steam Generating Boilers and Super-heated Water Boiler

[21] Combined Nomenclature

[22] Harmonised System

Source:http://www.cybex.in/HS-Codes/Steam-Vapour-Generating-Boilers-Central-Heading-8402.aspx

For each Prodcom code considered, data on **Export and Import** (**value and quantity**) in the Eurostat Database has been analysed.

On this basis, the data below report:

- **Imports**: the value or volume of imports derived from the Foreign Trade statistics
- **Exports**: the value or volume of exports derived from the Foreign Trade statistics

The indicators Imports and Exports are always blank for countries that are not EU Member States. If data for a country/period have not been loaded, all the indicators are blank.

For individual Member States all external trade is considered, i.e. the sum of the trade with all Intra-EU and all Extra-EU partners. While, for EU totals (EU27) the values are related to the trade leaving and entering the EU as a whole, so the sum of trade with all Extra-EU partners is displayed.

Table 33 - Import-export Water tube boilers (excluding central heating hot water boilers capable of producing low pressure steam) Code: 25.30.11.10 - 2012 data

MS	Export (Euro)	Import (Euro)	X-M (Euro)
Austria	6.699.570	466.150	6.233.420
Belgium	269.410	3.515.950	-3.246.540
Bulgaria	146.000	1.027.290	-881.290
Croatia	:	:	-
Cyprus	:	:	-
Czech Rep.	1.588.040	:	-
Denmark	12.931.160	35.480	12.895.680
Estonia	:	:	-
Finland	6.165.160	855.160	5.310.000
France	679.200	23.986.630	-23.307.430
Germany	43.796.380	2.665.720	41.130.660
Greece	321.210	:	-
Hungary	647.370	1.031.620	-384.250
Ireland	:	1.592.620	-
Italy	50.356.780	2.856.990	47.499.790

MS	Export (Euro)	Import (Euro)	X-M (Euro)
Latvia	:	54.620	-
Lithuania	:	110.360	-
Luxemburg	:	:	-
Malta	:	:	-
Netherlands	1.745.090	1.835.830	-90.740
Poland	2.045.190	:	-
Portugal	146.840	:	-
Romania	1.386.930	2.458.600	-1.071.670
Slovakia	:	:	-
Slovenia	:	:	-
Spain	124.736.140	1.535.200	123.200.940
Sweden	745.410	2.829.140	-2.083.730
UK	7.709.120	3.131.330	4.577.790
EU27	191.771.270	6.879.280	184.891.990

Source: Eurostat

Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.

Possible values are blank (data is available), ':' data is not available, ':O' data is not available but this is an optional heading, ':C' data is confidential, ':E' data is estimated, '-' not applicable.

Some EU totals are unsafe to publish because they would reveal confidential national data that they are composed of. Rounding is used to introduce some uncertainty to such totals, so that a figure can be given without disclosing the underlying confidential data. A set of flags is used to indicate rounded totals.

Table 34 - Import-Export Vapour generating boilers (including hybrid boilers) (excluding central heating hot water boilers capable of producing low pressure steam, water tube boilers) Code: 25.30.11.50 - 2012 data

MS	Export (Euro)	Import (Euro)	X-M (Euro)
Austria	52.101.590	3.292.350	48.809.240
Belgium	12.454.500	5.253.860	7.200.640

MS	Export (Euro)	Import (Euro)	X-M (Euro)
Bulgaria	548.570	757.640	-209.070
Croatia	:	:	-
Cyprus	:	:	-
Czech Rep.	2.905.980	2.400.280	505.700
Denmark	7.776.640	919.580	6.857.060
Estonia	482.070	1.301.000	-818.930
Finland	14.534.000	2.845.930	11.688.070
France	8.729.970	9.858.040	-1.128.070
Germany	83.869.890	9.849.880	74.020.010
Greece	243.090	873.710	-630.620
Hungary	201.090	1.752.520	-1.551.430
Ireland	587.400	991.180	-403.780
Italy	115.540.500	12.254.880	103.285.620
Latvia	1.137.370	:	1.137.370
Lithuania	1.807.010	2.419.080	-612.070
Luxemburg	14.940	:	14.940
Malta	:	:	-
Netherlands	15.485.450	2.009.870	13.475.580
Poland	5.301.890	2.567.900	2.733.990
Portugal	23.035.000	2.383.430	20.651.570
Romania	3.582.640	6.026.320	-2.443.680
Slovakia	1.573.320	:	1.573.320
Slovenia	876.740	1.016.470	-139.730
Spain	11.365.900	14.301.010	-2.935.110
Sweden	4.840.740	1.426.090	3.414.650
UK	10.108.570	8.161.100	1.947.470

MS	Export (Euro)	Import (Euro)	X-M (Euro)
EU27	194.519.990	11.490.770	183.029.220

Source: Eurostat

Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.

Possible values are blank (data is available), ':' data is not available, ':O' data is not available but this is an optional heading, ':C' data is confidential, ':E' data is estimated, '-' not applicable.

Some EU totals are unsafe to publish because they would reveal confidential national data that they are composed of. Rounding is used to introduce some uncertainty to such totals, so that a figure can be given without disclosing the underlying confidential data. A set of flags is used to indicate rounded totals.

Table 35 - Import-export Super-heated water boilers (excluding central heating hot water boilers capable of producing low pressure steam) Code: 25.30.11.70 - 2012 data

MS	Export (Euro)	Import (Euro)	X-M (Euro)
Austria	4.217.650	:	4.217.650
Belgium	109.750	1.032.900	-923.150
Bulgaria	:	89.980	-89.980
Croatia	:	:	-
Cyprus	:	55.140	-55.140
Czech Rep.	808.740	:	808.740
Denmark	3.749.790	1.193.010	2.556.780
Estonia	:	:	-
Finland	:	1.130.480	-1.130.480
France	1.049.140	20.614.410	-19.565.270
Germany	10.223.080	1.202.170	9.020.910
Greece	9.590	91.210	-81.620
Hungary	:	:	-
Iceland	:	:	-
Ireland	:	:	808.740
Italy	10.185.670	46.510	10.139.160

MS	Export (Euro)	Import (Euro)	X-M (Euro)
Latvia	234.000	:	234.000
Lithuania	3.651.090	:	3.651.090
Luxemburg	:	:	-
Malta	:	:	-
Netherlands	519.610	1.410.500	-890.890
Poland	162.990	426.210	-263.220
Portugal	:	:	-
Romania	53.080	1.320.030	-1.266.950
Slovakia	:	:	-
Slovenia	:	94.260	-
Spain	2.366.050	:	2.366.050
Sweden	1.926.580	3.050.100	-1.123.520
UK	838.760	4.198.830	-3.360.070
EU27	34.729.990	4.290.380	30.439.610

Source: Eurostat

Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.

Possible values are blank (data is available), ':' data is not available, ':O' data is not available but this is an optional heading, ':C' data is confidential, ':E' data is estimated, '-' not applicable.

Some EU totals are unsafe to publish because they would reveal confidential national data that they are composed of. Rounding is used to introduce some uncertainty to such totals, so that a figure can be given without disclosing the underlying confidential data. A set of flags is used to indicate rounded totals.

Table 36 - EU Sales in 2012 per MS (Euro) Production + Imports – Exports

MS	Water tube	Vapour generating	Super-Heated
AT	-6.233.420	- 48.809.240	-4.217.650
BE	3.246.540	-7.200.640	923.150
BG	881.290	837.457	89.980

MS	Water tube	Vapour generating	Super-Heated
HR	29.853.246	2.895.040	-
CY	-	-	55.140
CZ	-1.588.040	- 505.700	-808.740
DK	75.733.899	- 6.857.060	-2.556.780
EE	-	1.384.464	-
FI	545.363.335	30.740.089	28.976.652
FR	23.307.430	26.458.275	19.565.270
DE	59.551.667	57.065.235	- 9.020.910
EL	-321.210	1.420.872	81.620
HU	384.250	2.310.223	-
IR	1.592.620	403.780	-
IT	153.685.210	245.562.380	-5.142.160
LV	54.620	-1.137.370	-234.000
LT	110.360	612.070	-3.651.090
LU	-	- 14.940	-
MA	-	-	-
NL	90.740	-13.475.580	890.890
PL	- 2.045.190	-2.733.990	2.470.881
PT	- 146.840	-18.683.047	-
RO	1.071.670	2.443.680	1.266.950
SK	-	-1.573.320	-
SL	-	139.730	94.260
SP	- 53.542.411	27.434.477	19.397.235
SE	2.083.730	-3.414.650	1.123.520
UK	- 4.577.790	36.596.316	3.360.070
EU27	927.337.317	696.224.515	82.550.397

MS	Water tube	Vapour generating	Super-Heated

Source: Eurostat

Assumption :

Steam boilers production is equivalent to the sales. Overall steam boilers sales in EU can be calculated from Production + Imports – Exports (Y+M-X), representing the apparent consumption. EU27 total 2012 sales (Y+M-X) have been 1.706.112.229 Euro.

3.5 Intra-Extra EU Trade

According to Eurostat classification, Import and Export data related to a single country represent commercial exchanges of that country with any other inside and outside EU, while Import and Export totals show respectively incoming and outgoing flows to and from EU.

Given the assumption that the steam boilers production is equivalent to the sales, overall steam boilers sales in EU can be calculated from Production + Imports – Exports (Y+M-X), representing the apparent consumption.

Table 37 shows that the total **2012 EU27 exports** of steam boilers to third countries is **421.021.250 euro (21%** of the total production)**,** of which **191.771.270 euro** of Water tube boilers (**17%** of the production of water tube boilers) and **194.519.990 euro** of Vapour generating **boilers** (**22%** of the production of Vapour generating boilers).

EU27 total 2012 sales (Y+M-X) have been 1.706.112.229 Euro (all the steam boilers).

As already stated above, for individual Member States all external trade is considered, i.e. the sum of the trade with all Intra-EU and all Extra-EU partners. While, for **EU totals (EU27)** the values are related to the trade **leaving and entering the EU as a whole**, so the sum of trade with all Extra-EU partners is displayed.

Table 37 - Production , Import and Export per Prodcom 2012 data (euro)

	25.30.11.10*					25.30.11.50*					25.30.11.70*				
	Production	Import	Export	X-M	EU sales (Y+M-X)	Production	Import	Export	X-M	EU sales (Y+M-X)	Production	Import	Export	X-M	EU sales (Y+M-X)
AT	-	466.150	6.699.570	6.233.420	-6.233.420	-	3.292.350	52.101.590	48.809.240	- 48.809.240	-	-	4.217.650	4.217.650	-4.217.650
BE	-	3.515.950	269.410	-3.246.540	3.246.540	-	5.253.860	12.454.500	7.200.640	-7.200.640	-	1.032.900	109.750	- 923.150	923.150
BG	-	1.027.290	146.000	-881.290	881.290	628.387	757.640	548.570	- 209.070	837.457	-	89.980	-	- 89.980	89.980
HR	29.853.246	-	-	-	29.853.246	2.895.040	-	-	-	2.895.040	-	-	-	-	-
CY	-	-	-	-	-	-	-	-	-	-	-	55.140	-	- 55.140	55.140
CZ	-	-	1.588.040	1.588.040	-1.588.040	-	2.400.280	2.905.980	505.700	- 505.700	-	-	808.740	808.740	-808.740
DK	88.629.579	35.480	12.931.160	12.895.680	75.733.899	-	919.580	7.776.640	6.857.060	- 6.857.060	-	1.193.010	3.749.790	2.556.780	-2.556.780
EE	-	-	-	-	-	565.534	1.301.000	482.070	- 818.930	1.384.464	-	-	-	-	-
FI	550.673.335	855.160	6.165.160	5.310.000	545.363.335	42.428.159	2.845.930	14.534.000	11.688.070	30.740.089	27.846.172	1.130.480	-	-1.130.480	28.976.652
FR	-	23.986.630	679.200	- 23.307.430	23.307.430	25.330.205	9.858.040	8.729.970	-1.128.070	26.458.275	-	20.614.410	1.049.140	- 19.565.270	19.565.270
DE	100.682.327	2.665.720	43.796.380	41.130.660	59.551.667	131.085.245	9.849.880	83.869.890	74.020.010	57.065.235	-	1.202.170	10.223.080	9.020.910	- 9.020.910
EL	-	-	321.210	321.210	-321.210	790.252	873.710	243.090	- 630.620	1.420.872	-	91.210	9.590	- 81.620	81.620
HU	-	1.031.620	647.370	- 384.250	384.250	758.793	1.752.520	201.090	- 1.551.430	2.310.223	-	-	-	-	-
IR	-	1.592.620	-	-1.592.620	1.592.620	-	991.180	587.400	- 403.780	403.780	-	-	-	-	-
IT	201.185.000	2.856.990	50.356.780	47.499.790	153.685.210	348.848.000	12.254.880	115.540.500	103.285.620	245.562.380	4.997.000	46.510	10.185.670	10.139.160	-5.142.160
LV	-	54.620	-	- 54.620	54.620	-	-	1.137.370	1.137.370	-1.137.370	-	-	234.000	234.000	-234.000
LT	-	110.360	-	- 110.360	110.360	-	2.419.080	1.807.010	- 612.070	612.070	-	-	3.651.090	3.651.090	-3.651.090
LU	-	-	-	-	-	-	-	14.940	14.940	- 14.940	-	-	-	-	-
MA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NL	-	1.835.830	1.745.090	- 90.740	90.740	-	2.009.870	15.485.450	13.475.580	-13.475.580	-	1.410.500	519.610	- 890.890	890.890
PL	-	-	2.045.190	2.045.190	- 2.045.190	-	2.567.900	5.301.890	2.733.990	-2.733.990	2.207.661	426.210	162.990	- 263.220	2.470.881
PT	-	-	146.840	146.840	- 146.840	1.968.523	2.383.430	23.035.000	20.651.570	-18.683.047	-	-	-	-	-

	25.30.11.10*					25.30.11.50*					25.30.11.70*				
	Production	Import	Export	X-M	EU sales (Y+M-X)	Production	Import	Export	X-M	EU sales (Y+M-X)	Production	Import	Export	X-M	EU sales (Y+M-X)
RO	-	2.458.600	1.386.930	- 1.071.670	1.071.670	-	6.026.320	3.582.640	- 2.443.680	2.443.680	-	1.320.030	53.080	- 1.266.950	1.266.950
SK	-	-	-	-	-	-	-	1.573.320	1.573.320	-1.573.320	-	-	-	-	-
SL	-	-	-	-	-	-	1.016.470	876.740	- 139.730	139.730	-	94.260	-	-94.260	94.260
SP	69.658.529	1.535.200	124.736.140	123.200.940	- 53.542.411	24.499.367	14.301.010	11.365.900	-2.935.110	27.434.477	21.763.285	-	2.366.050	2.366.050	19.397.235
SE	-	2.829.140	745.410	-2.083.730	2.083.730	-	1.426.090	4.840.740	3.414.650	-3.414.650	-	3.050.100	1.926.580	- 1.123.520	1.123.520
UK	-	3.131.330	7.709.120	4.577.790	- 4.577.790	38.543.786	8.161.100	10.108.570	1.947.470	36.596.316	-	4.198.830	838.760	- 3.360.070	3.360.070
EU27	1.112.229.307	6.879.280	191.771.270	184.891.990	927.337.317	879.253.735	11.490.770,00	194.519.990	183.029.220	696.224.515	112.990.007	4.290.380	34.729.990	30.439.610	82.550.397

**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: Eurostat

3.5.1 Prodcom 25.30.11.10 – Water tube boilers

EU27 Water tube boilers 2012 sales (Y+M-X) have been **927.337.317 euro** (54% of the total EU).

Amongst the most important national markets in terms of contribution to EU sales it can be highlighted that **Finland** leads the EU sales with a **share of 59%** (545 million euro), followed by **Italy** (153 million euro), representing the **17% of the total EU** sales. Given the confidentiality of data related the production values, it should be noted that negative numbers cannot be taken into account.

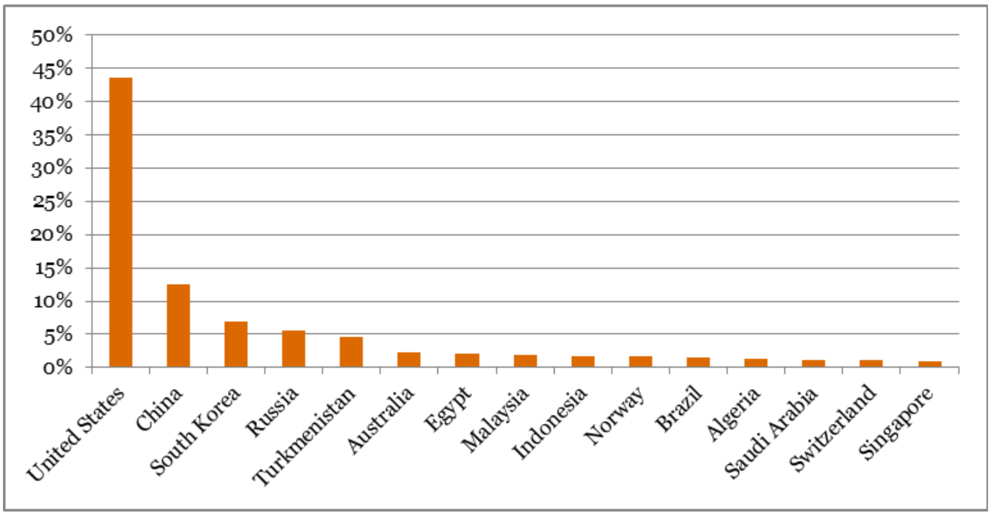
A focus on the Top Five MSs is given below.

MS	% on Production of the Top5	% on Import of the Top5	% on Export of the Top5	% on EU Sale of the Top5
FI	54,48%	10,76%	2,59%	69,85%
IT	19,90%	35,94%	21,16%	19,68%
DE	9,96%	33,54%	18,40%	7,63%
DK	8,77%	0,45%	5,43%	9,70%
SP	6,89%	19,31%	52,41%	-6,86%

Source: Eurostat

As to the Extra E27 trade, in Table 38 it can be observed that on a total Extra EU27 of Water tube boilers trade of **192 million Euro**, the **United States** are the first external trade market with a share of 43,6%, followed by **China** with 12,4%.

Figure 20 - Intra-Extra EU in 2012 Water tube boilers 2012



Source: Eurostat http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do

Table 38 - Export extra EU27 Water tube boilers 2012 data*

PARTNER/REPORTER	HS Codes 840211	HS Codes 840212	% share
United States	83.780.119	431.752	43,639%

PARTNER/REPORTER	HS Codes 840211	HS Codes 840212	% share
China (People's Republic of)	22.383.424	1.663.337	12,461%
Korea, republic of (South Korea)	3.742.060	9.735.448	6,984%
Russian Federation (Russia)	5.841.528	4.938.689	5,586%
Turkmenistan	8.765.587	3.288	4,544%
Australia	114.653	4.198.089	2,235%
Egypt	1.559.344	2.394.508	2,049%
Malaysia	-	3.775.834	1,957%
Indonesia (id+tp from 77,excl. Tp ->2001)	-	3.315.697	1,718%
Norway (incl.sj excl.1995,1996)	478.885	2.804.648	1,702%
Brazil	2.229.149	771.021	1,555%
Algeria	461.606	2.009.108	1,280%
Saudi Arabia	932.043	1.348.564	1,182%
Switzerland (incl. Li->1994)	27.442	2.041.692	1,072%
Singapore	12.718	1.921.341	1,002%
Total	136.586.953	56.388.628	

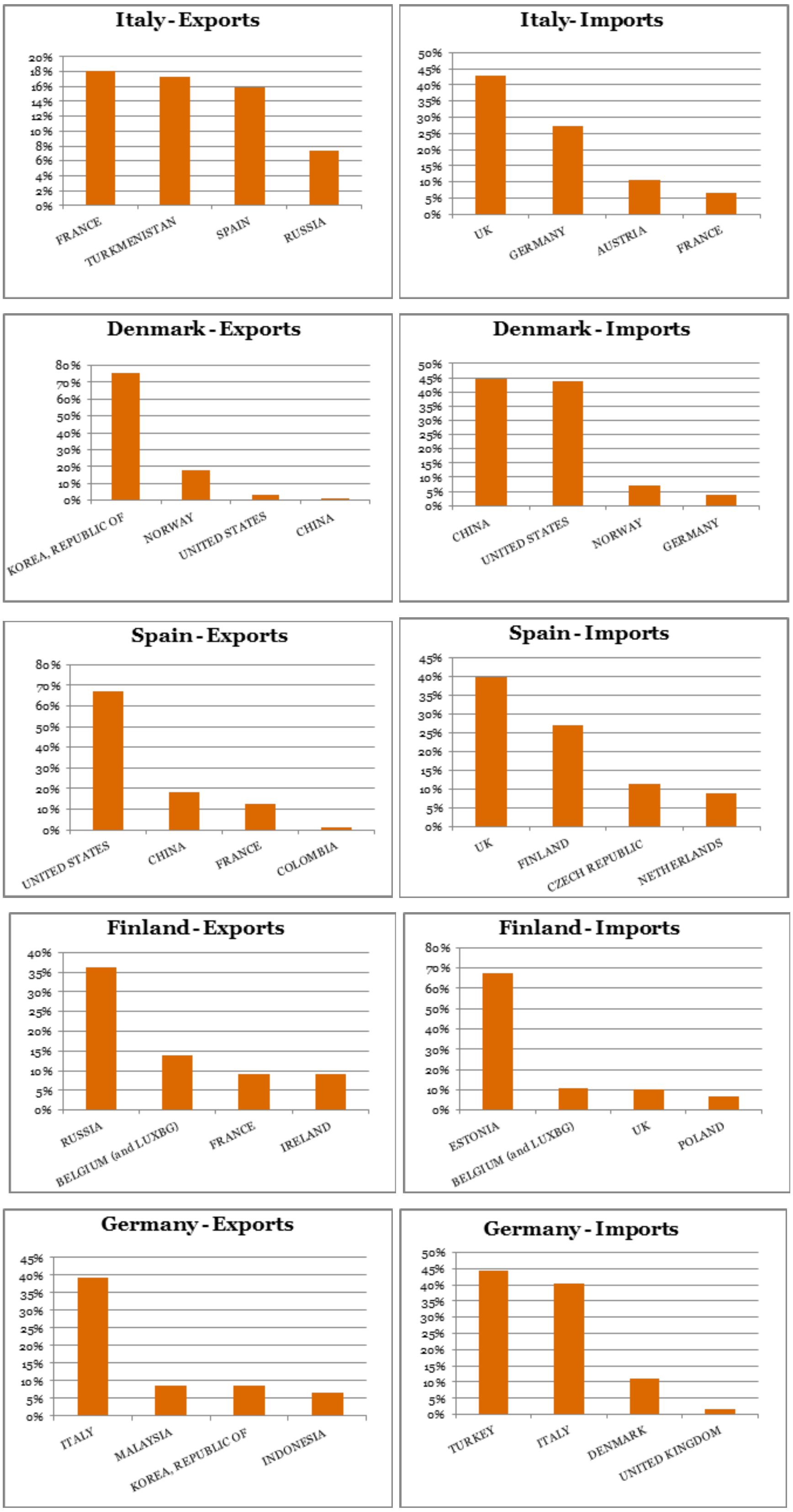
HS Codes 8402 11 Water tube Boilers with a Steam Production Exceeding 45t per Hour

HS Codes 8402 12 Water tube Boilers with a Steam Production Not Exceeding 45t Per Hour

**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

Source: Eurostat http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do

Figure 21 –Exports/Imports in 2012 Water tube boilers Top 5 MSs*



Source: Eurostat http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do

3.5.2 Prodcom 25.30.11.50 – Vapour generating - tube boilers

EU27 Vapour generating 2012 sales (Y+M-X) have been **696.224.515 euro** (41% of the total EU).

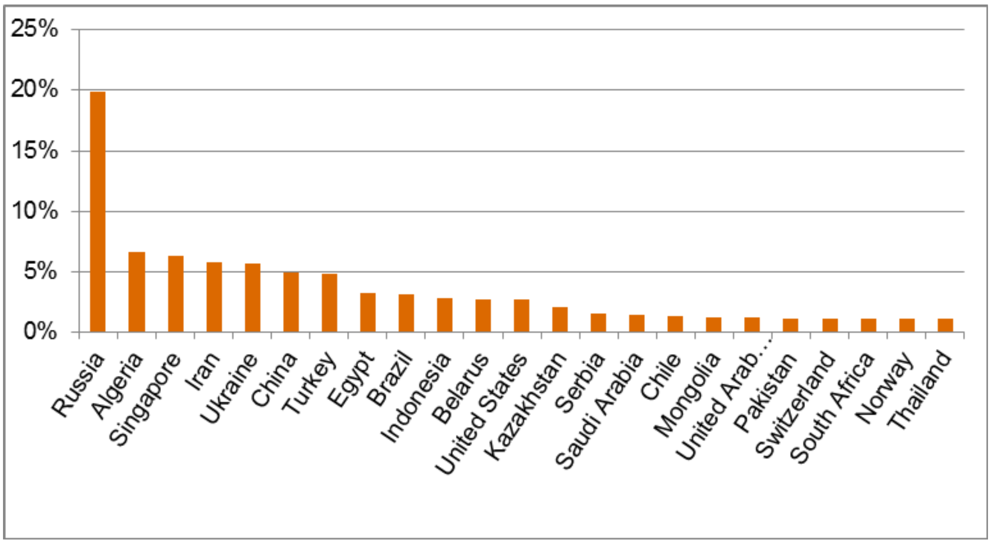
Amongst the most important national markets in terms of contribution to EU sales it can be highlighted that **Italy** leads the EU sales with a **share of 35%** (245 million euro), followed by **Germany** (57 million euro), representing the **8% of the total EU** sales. Given the confidentiality of data related the production values, it should be noted that negative numbers cannot be taken into account.

A focus on the Top Five MSs is given below.

MS	% on Production of the Top5	% on Import of the Top5	% on Export of the Top5	% on EU Sale of the Top5
FI	7,24%	12,23%	6,24%	7,75%
FR	4,32%	42,36%	3,75%	6,67%
DE	22,36%	42,33%	36,03%	14,40%
IT	59,51%	52,66%	49,63%	61,94%
UK	6,57%	35,07%	4,34%	9,23%

As to the Extra E27 trade in Figure 22 it can be observed that on a total Extra EU27 Vapour generating boilers trade of around 194 million Euro, the Russian Federation is the first external trade market with a share of 19,8%, followed by Algeria (6,5%), Singapore (6,2%), Iran (5,7%) and China (4,8%).

Figure 22 - Intra-Extra EU in 2012 Vapour generating boilers 2012



Source: Eurostat http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do

Table 39 - Export extra EU27 Vapour generating boilers - 2012 data*

PARTNER/REPORTER	HS Code 840219	HS Code 84021910	HS Code 84021990	% share
Russian Federation (Russia)	38.452.867	29.021.611	9.431.255	19,848%
Algeria	12.734.078	8.379.308	4.354.770	6,573%
Singapore	12.147.858	800.772	11.347.086	6,270%
Iran, Islamic Republic of	11.092.407	10.808.083	284.324	5,726%
Ukraine	10.862.133	7.878.021	2.984.112	5,607%
China (People's Republic of)	9.433.091	6.378.957	3.054.134	4,869%
Turkey	9.226.938	4.237.000	4.989.938	4,763%
Egypt	6.148.855	1.923.529	4.225.326	3,174%
Brazil	5.964.794	4.233.913	1.730.881	3,079%
Indonesia (id+tp from 77,excl. Tp -> 2001)	5.358.528	4.683.596	674.932	2,766%
Belarus (Belorussia)	5.254.542	4.319.321	935.220	2,712%
United States	5.145.796	4.064.898	1.080.898	2,656%
Kazakhstan	3.960.825	3.546.364	414.461	2,044%
Serbia (EU data from 01/06/05 ex cs)	2.811.055	518.606	2.292.449	1,451%
Saudi Arabia	2.599.748	1.314.281	1.285.467	1,342%
Chile	2.482.192	2.232.845	249.347	1,281%
Mongolia	2.351.695	2.351.695		1,214%
United Arab Emirates	2.268.969	1.161.299	1.107.670	1,171%
Pakistan	2.136.961	800.005	1.336.956	1,103%
Switzerland (incl. Li->1994)	2.097.689	907.226	1.190.463	1,083%
South Africa (incl. Na ->1989)	2.014.311	1.887.284	127.027	1,040%
Norway (incl.sj excl.1995,1996)	2.003.781	907.838	1.095.943	1,034%

PARTNER/REPORTER	HS Code 840219	HS Code 84021910	HS Code 84021990	% share
Thailand	1.977.631	1.412.055	565.576	1,021%
Total	193.734.603	122.972.891	70.761.710	

HS Codes 840219 Other vapour generating boilers including Hybrid boilers

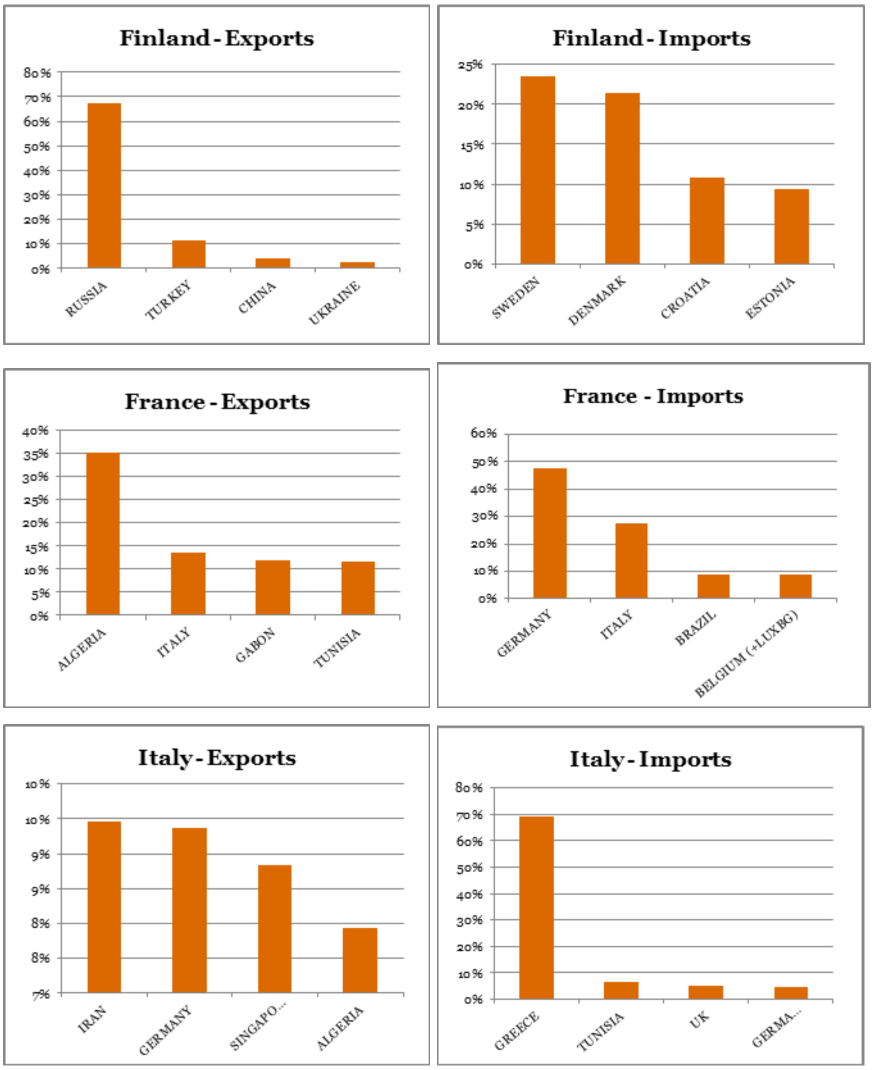
HS Codes 8402 19 10: Fire tube horizontal (lancashire) boilers

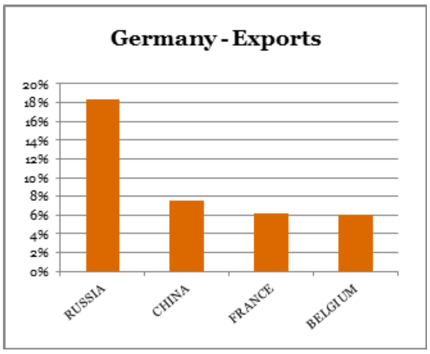
HS Codes 840219 90 Others

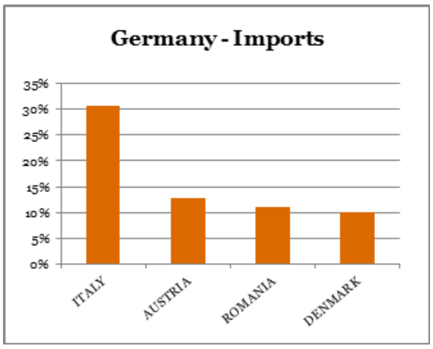
**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

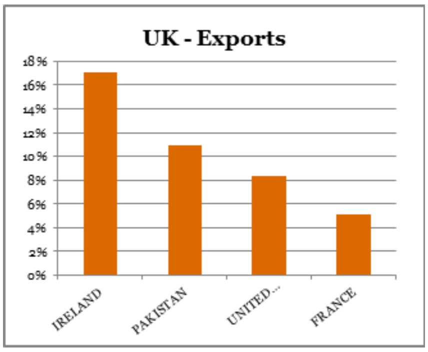
Source: Eurostat http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do

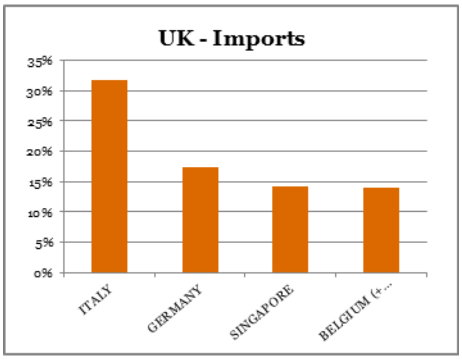
Figure 23 –Exports/Imports in 2012 Vapour generating boilers Top 5 MSs











Source: Eurostat [*http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do*](http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do)

3.5.3 Prodcom 25.30.11.70 – Super-heated boilers

EU27 Super-heated boilers 2012 sales (Y+M-X) have been **82.550.397 euro** (5% of the total EU).

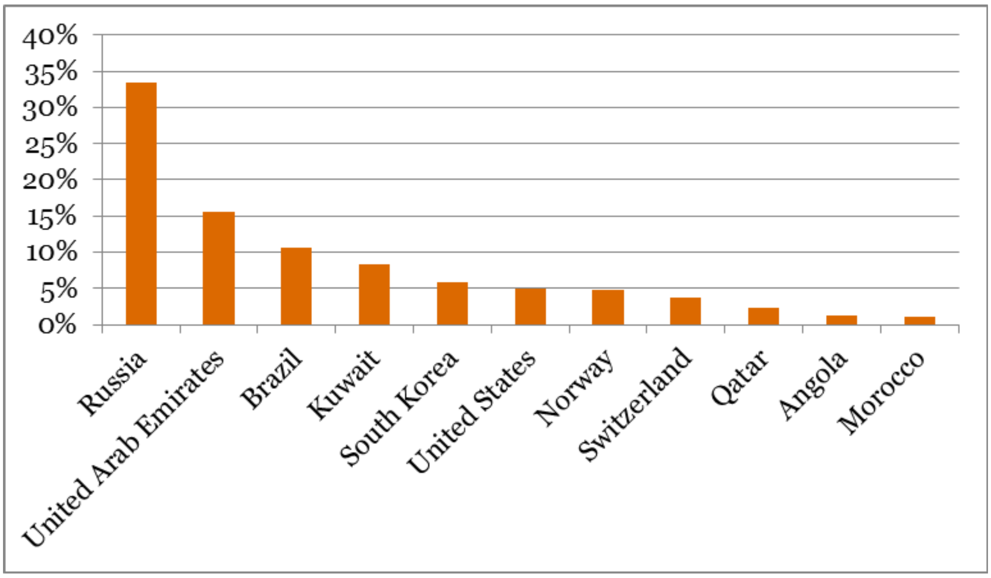
Amongst the most important national markets in terms of contribution to EU sales it can be highlighted that **Finland** leads the EU sales with a **share of 35%** (29 million euro), followed by **France** (19,5 million euro) representing the 23% of the EU sales and **Spain** (19,3 million euro), representing the **23% of the EU sales**. Given the confidentiality of data related the production values, it should be noted that negative numbers cannot be taken into account.

A focus on the Top Five MSs is given below.

MS	**% on Production of the Top5**	**% on Import of the Top5**	**% on Export of the Top5**	**% on EU Sale of the Top5**
FI	49,01%	40,30%	0,00%	78,99%
IT	8,80%	1,66%	44,41%	-14,02%
DE	0,00%	42,85%	44,57%	-24,59%
PL	3,89%	15,19%	0,71%	6,74%
SP	38,31%	0,00%	10,32%	52,88%

As to the Extra E27 trade of Super-heated boilers, in Table 40 it can be observed that on a total Extra EU27 trade of around 34 million Euro, the Russian Federation is the first external trade market with a share of 33,4%, followed by United Arab Emirates (15,5%) and Brazil (10,6%).

Figure 24 - Intra-Extra EU in 2012 Super-heated boilers 2012



Source: Eurostat http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do

Table 40: Export extra EU27 Super-heated water boilers - 2012 data*

PARTNER/REPORTER	HS Codes 840220	% share
Russian Federation (Russia)	11.439.636	33,394%
United Arab Emirates	5.309.397	15,499%
Brazil	3.648.748	10,651%
Kuwait	2.861.851	8,354%
Korea, Republic of (South Korea)	2.026.703	5,916%
United States	1.671.375	4,879%
Norway (incl.sj excl.1995,1996)	1.654.162	4,829%
Switzerland (incl. Li->1994)	1.286.797	3,756%
Qatar	790.105	2,306%
Angola	417.231	1,218%
Morocco	384.771	1,123%
Total	34.256.888	

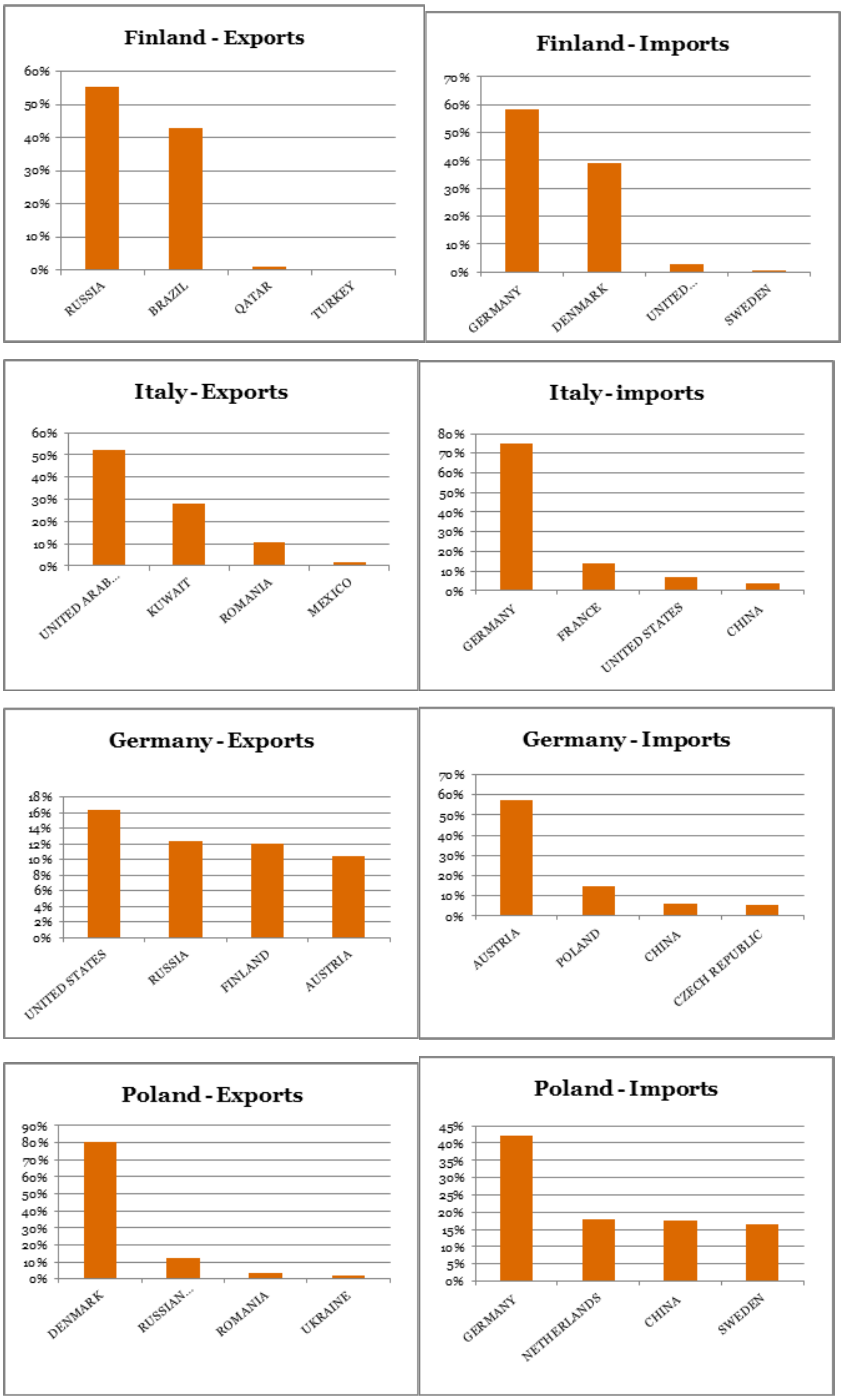
HS Codes 840220 Super-heated Water boilers

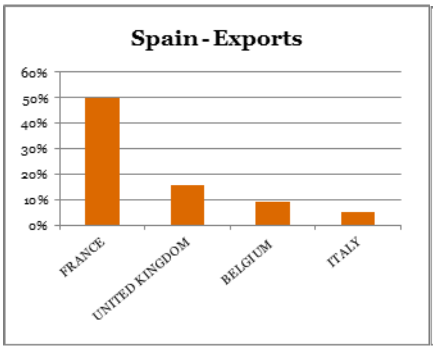
**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

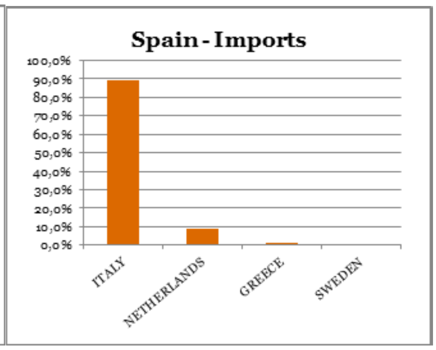
Source: PwC on Eurostat

Source: Eurostat http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do

Figure 25 –Exports/Imports in 2012 Super-heated boilers Top 5 MSs







Source: Eurostat http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do

3.6 Market and stock data

3.6.1 Stock data and penetration rate

Since Eurostat Prodcom does not provide data on imports and exports of units of steam boilers, it has not been possible to calculate the EU sales in units, based on the same calculation used for **apparent consumption in values (Production + Imports – Exports, Y+M-X)**, that according to the key assumptions, correspond to annual installation (new and replaced).

In order to attempt a fair estimation of the existing stock and its possible developments, several European Association and national certification authorities have been consulted. Amongst them, the German Association for Efficiency and Renewable Energies (BDH) has provided inputs with reference to the current unit installed.

On the basis of German data of installed units in 2010 , as benchmarking , **BDH** has calculated the **European steam boilers "park":** "*round about* ***75.000 steam boilers*** *applications under the below mentioned boundaries are installed in Europe. About 50% are currently not state of the art*[23]".

The estimation in Germany has considered the relation between installed units and the Gross Domestic Product (GDP) (*No of Steam boilers installed/GDP)* as a reference factor, for all MSs and at EU aggregated level.

In order to compare BDH's estimations with Eurostat's evidences, that contribution has been reworked excluding countries where no production, import or export activity is reported in the letter, mainly due to irrelevance. In such a review, around **70.000 steam boilers (of all dimensions) are estimated as EU stock**.

Applying BDH's expert opinion on "not-state-of-the-art" machines, around 35.000 steam boilers could be reported as a potential for replacements, absorbing new production.

Table 41 - Estimation of the population of the steam boilers in Europe via GDP on basis of Germany – 2010[24]

Country	GDP	Installed Steam boilers (n)	not state of the art (n)

[23] BDH, December 2013

[24] This is an estimation of the European steam boiler stock from the BDH. Please note that we do not use these figures for Task 7.

Country	GDP	Installed Steam boilers (n)	not state of the art (n)
Germany	2.495.000,00	15.000,00	7.500,00
Austria	285.165,30	1.714,42	857,21
Belgium	355.740,00	2.138,72	1.069,36
Denmark	236.334,10	1.420,85	710,42
Finland	178.724,00	1.074,49	537,25
France	1.936.720,00	11.643,61	5.821,80
Greece	222.151,50	1.335,58	667,79
Ireland	158.096,70	950,48	475,24
Italy	1.551.885,60	9.329,97	4.664,99
Netherlands	586.789,00	3.527,79	1.763,89
Poland	354.616,10	2.131,96	1.065,98
Portugal	172.859,50	1.039,24	519,62
Spain	1.045.620,00	6.286,29	3.143,15
Sweden	349.945,10	2.103,88	1.051,94
United Kingdom	1.731.809,00	10.411,68	5.205,84
TOTAL		**70.108,95**	**35.054,00**

Explanation:15.000 steam boilers are estimated being installed in Germany in the year 2010. Round about 7.500 steam boilers are estimated being not state of the art, as they are installed before the year 2000

Source: PwC on BDH data, December 2013 (here, only EU28 reported and GDP in Euro)

According to Eurostat data, European producers' output in 2012 is around 30.000 and, looking at foreign trade figures, nearly a half is manufactured for extra UE export (see also paragraph 3.7.2 for assumptions on growth forecasts). As import from extra UE countries is limited, we can estimate that **around 15.000 units are available each year in the EU market for industrial clients to replace old equipment or build new plants**.

This data is obviously crucial to estimate the impact of new Ecodesign measures in the sector[25].

More details on stock of steam boilers with a capacity installed between 1 MW and 50 MW are presented in paragraph 2.6.

3.6.2 Market channels and production structure: identification of the major players

The aim is to describe market channels and production structure of the steam boilers sector as characterized in Task 1.

A specific **stakeholders' consultation** has been launched in order to gather useful data and information from the field and to map the major players in Europe. The selection of the main producers has been drawn up focusing on the three Prodcom codes, according to the scope of the study (Task 1).

More than 30 **relevant Producers and Associations** were identified (see tables below), representing a starting point for the product mapping aiming at analysing the main features of the steam boilers market.

Table 42 - Main Industries

AB&Co
Astebo (AT)
ATTSU
Babcock Wanson
BBC
BOSCH
Bono Energia
BWE
BYWORH
Chromalox (UK)
Danstoker & Omnical
Erensan - Clayton Steam Systems
Europea Térmica Eléctrica
Ferroli
ICI CALDAIE
Ivar
Magnabosco

25 To be discussed during the stakeholders' meeting.

MINGAZZINI
Olmar
Panini
PIROBLOC
VKK-Standard - Siat Italia Srl
Unical
Viessmann

Table 43 - Main Associations

AGFW | Der Energieeffizienzverband für Wärme, Kälte und KWK e. V.
Agoria
Anie
Anima
Assotermica
Austrian Association of Gas and District Heat Supply Companies, Austria
Combined Heat and Power Association (CHPA)
CTI2000
Danish District Heating Association
Euroheat & Power, Belgium
European Heating Industry - EHI
FDBR: Fachverband Anlagenbau
Fegeca
Fiper (caldaie biomassa)
FMMI
German Association for Efficiency and Renewable Energies BDH
HHIC, heating and hot water industry council
SBBA, Swedish heating boilers and burners associations
SNCT

Swedish District Heating Association, Sweden
Swiss District Heating Association
UCC
VGB PowerTech

For each single producer an in **depth investigation** has been carried out, mainly looking at the product technical documents (e,g, technical data sheets) available on the Companies websites.

All the selected producers were invited to participate to a Survey aiming at collecting market data and opinions on market trends.

According to selected market operators, the **main EU producers are**: Bosch (ex Loos) - Viessmann -Babcock Wanson - Biworty - Attsu - Ferroli - ICI Caldaie - Mingazzini - Garioni Naval - Macchi - Pensotti (Gruppo Sices) - ~~Standardkessel - Hoval~~[26] – Aalborg, Danstoker. The main extra EU producers are: Thermax (India) - Clyton (USA) - Miura Group - Getabec (German Thai) - Babcock Wilcox (USA) - Fulton (USA) - Stein Energy (France) - Shanghai Huazheng Boiler Manufacturer - Cleverbrooks (USA), Kangrim, Mitsubishi.

According to selected market operators steam boilers are not sold by wholesalers or distributors, except for some export markets/export products.

The **share of SMEs** in Europe is high. Despite that, according to the market operators there will be a concentration of the production, it is possible that some small company will be sold. Thus, the share of SMEs in the steam boilers production will probably decrease.

3.7 Market trends

3.7.1 General market trends

Market trends observation serves as a basis for estimating the impacts of a possible intervention on steam boilers' Ecodesign in years to come. There is a limited number of studies on the matter and the reason is, again, the reluctance of industrial players to reveal their view of the market potential of such products in EU and in other geographies, information which has a significant value in a narrow arena like the steam boilers' one.

Therefore, within the constraints provided by available data, the soundest estimation of the market trends in Europe can be based on the following assumptions:

Steam boilers future production in EU will be driven by:

- internal demand, which is forecasted weak in the medium-long term;
- external demand, from the main commercial partner countries (identified by Foreign trade data).

About this latter, it can be foreseen that foreign growing markets will not be served from EU plants for long, being convenient to establish production premises in the current destination countries. Therefore, the driving effect of external demand should be reconsidered in the longer term, due to globalisation forces. At this stage, we cannot provide a sound estimation of such phenomenon.

[26] Changed due to stakeholder comment as Hoval is not producing any steam boiler.

Since products are designed as per client's specifications, it is assumed that the steam boilers production trend follows the served industries market trend. Steam boilers play a key role in many different industrial process and steam boilers find application in such different industries: pulp and paper, textile, food processing factories, building material industry, chemical industry, pharmaceutical industry, primary metal, Oil&Gas, water treatment, power plant. Other large users of these utilities are in the tertiary sector, in particular in laundries and hospitals.

Industrial boilers have different purposes in different industries and facilities, and even at a single installation, the application of steam from an industrial boiler can change over the course of the year, as well as from day to day and hour to hour, depending on the industrial activities and processes operating underway at a given moment and their demand for steam.

Industry sectors vary in the boilers they use, for example:

Food processing - use some large boilers, but generally a large number of small boilers Steam boiler and steam system play a key role in many food processing factories as they are to process heat for drying, cooking, blanching, steaming and sterilization, etc. Steam boiler is the primary energy consuming equipment in most of food processing factories.

Pulp and Paper industry - generally use large steam boilers in the pulp and paper industry, steam is by far the dominant form of energy use, representing between 84 and 92%[27] of the total energy used. However, manufacturing plants in the pulp and paper industry vary by size, level of integration, process technology, wood type, and final product type and so the total steam energy use.

Chemical Manufacturing - use both small and large boilers. In the chemical industry segments, there are many more products and production processes. Many of these processes are steam-intensive

Primary metals - mainly use large boilers.

According to consulted market operators, China, India and Brazil are the most promising market in terms of production. It is likely that European production will suffer from competition on costs and EU industrial operators take steps to transfer their plants abroad.

On this basis, market trends in production, sales, export, and import can be prudently developed, as represented below.

3.7.2 Forecasts

The following table shows the Production, Import, Export trends up to 2030[28].

27 Steam System Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries

28 Data for production, export and import for 2012 come from EUROSTAT database, data 2013 are estimated.

Table 44 - Trends (Euro.000)*

	2012	2013	2020	2030
Production	2.104.473	2.158.236	2.611.237	3.296.655
Import Extra UE	22.660	23.000	25.527	29.625
Export Extra UE	421.021	435.795	569.571	775.523
- Russia	68.042	73.411	124.928	184.925
-United States	66.016	67.140	75.566	87.518
- China	29.464	32.261	60.874	107.073
- Brazil	12.753	13.794	23.894	38.920
- Korea	12.356	13.067	19.328	44.714
-India	2.230	2.508	5.706	11.474
- Others	230.161	233.613	259.274	300.899
EU sales	1.706.112	1.745.442	2.067.193	2.550.757

Source: PwC estimates on Eurostat data

**Eurostat PRODCOM codes include all the Steam boilers in the scope of work without differentiating by power output.*

The estimations, as commented above, have been driven by the following variables:

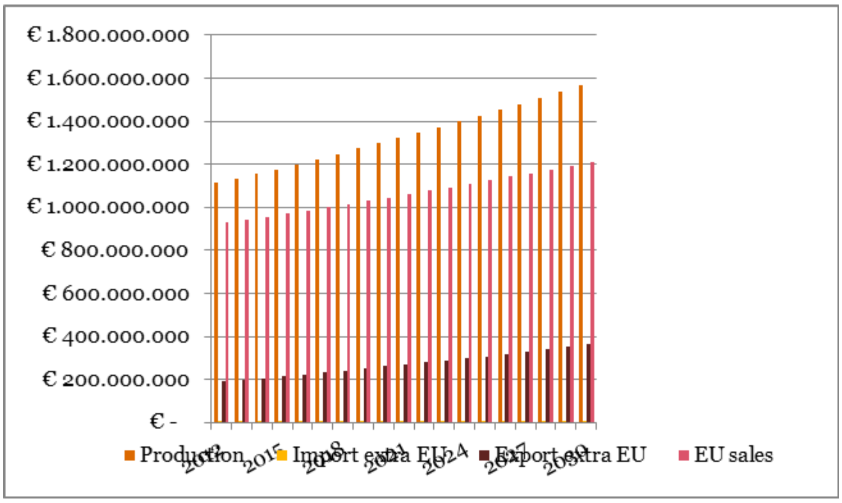
- **Production growth** is linked both to **European GDP and extra EU GDP**[29] growth, as it depends on internal and external demand[30];
- **Import growth** is connected only with **European GDP** growth, which influences EU demand;
- **Export growth** is driven by **extra EU countries GDP growth**, which has been estimated taking into account current commercial relationships between EU and extra EU countries, foreign trade shares of the most important commercial partners in the sector and their specific economic growth rates[31].

29 OECD.

30 External demand share is estimated to be around 53% of the total, according to Italian and German statistics on extra EU vs. intra EU trade.

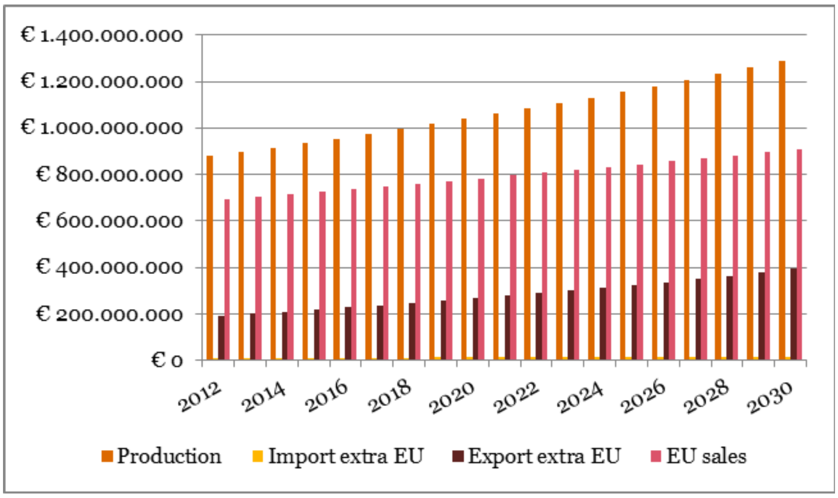
31 We considered a mid-term GDP rate up to 2020, and a long term rate from 2020-2030.

Figure 26 - Estimated Trends Prodcom 25.30.11.10 - € value



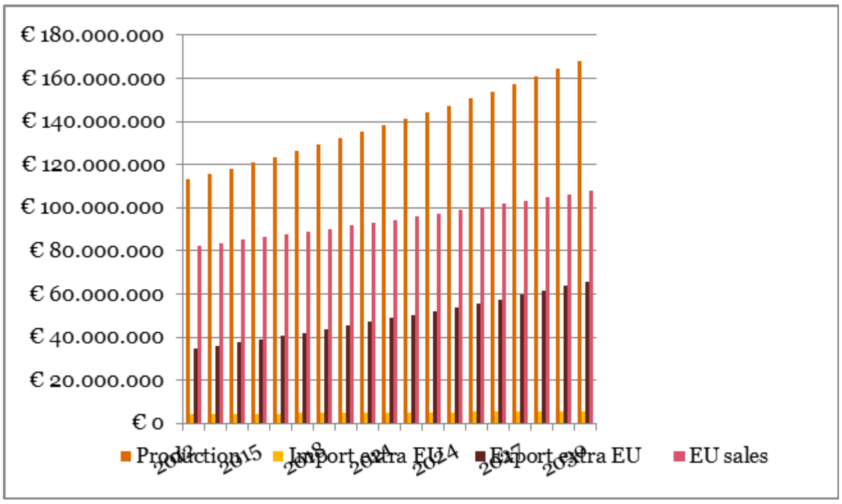
Source: PwC

Figure 27 - Estimated Trends Prodcom 25.30.11.50 - € value



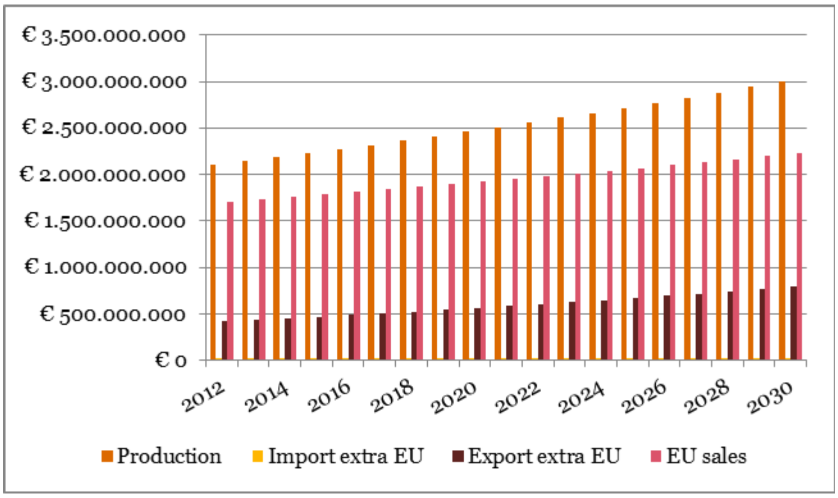
Source: PwC

Figure 28 - Estimated Trends Prodcom 25.30.11.70 - € value



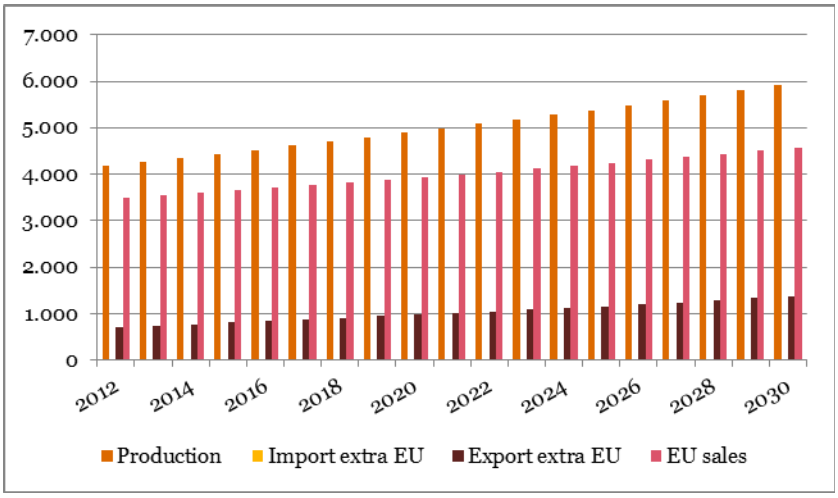
Source: PwC

Figure 29 - Estimated Trends all Prodcom codes - € value



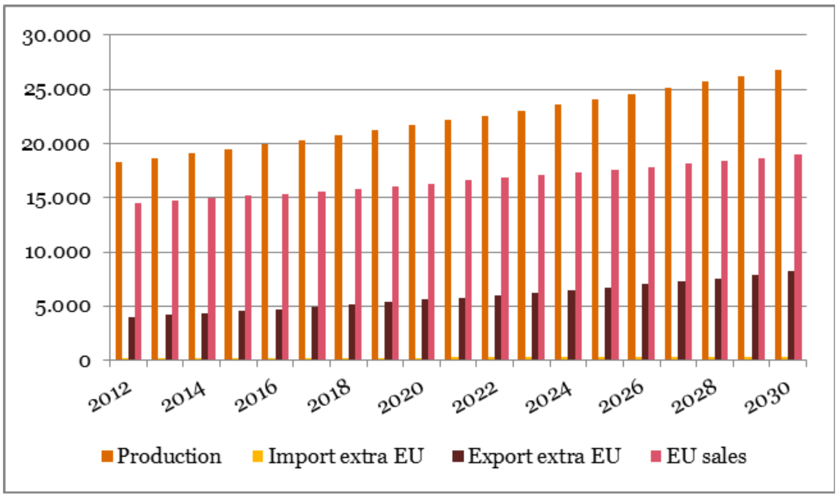
Source: PwC

Figure 30 - Estimated Trends Prodcom 25.30.11.10 - pieces



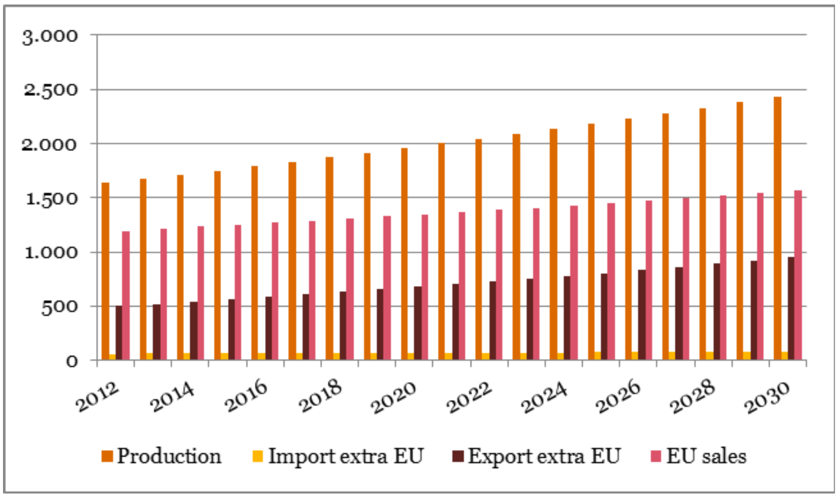
Source: PwC

Figure 31 - Estimated Trends Prodcom 25.30.11.50 - pieces



Source: PwC

Figure 32 - Estimated Trends Prodcom 25.30.11.70 - pieces



Source: PwC

According to Eurostat data (Prodcom database, matched with Europroms), the steam boilers extra EU exports flows are mainly directed to Russia, United States, China, Brazil, Korea and India. Consequently:

- **Production grows** at an average rate of:

  2,73% from 2012 to 2020 and **2,36% from 2021 to 2030** depending on a

  - **1,5% internal** demand growth (considered flat from 2012 to 2030) and a
  - **3,85% average external** demand growth from **2012 to 2020** and **3,13% average external** demand growth from **2021 to 2030**.

  Average external demand growth results from country specific GDP growth ranging from 1,5% for US to 12,46% for India, which have been weighted according to the respective shares as importers from EU countries.

- **Import grows** at an average rate **of 1,5%** along the whole period considered, up to 2030;
- **Export grows** as described for **external demand** in production.

Table 45 - Commercial shares and GDP growth 2012 – 2030

Countries	% as importers from EU	2012-2020 %GDP growth	2021-2030 % GDP growth
Russia	16,16%	7,89%	4,00%
United States	15,68%	1,70%	1,48%
China	7,00%	9,49%	5,81%
Brazil	3,03%	8,16%	5,00%
Korea	2,93%	5,75%	8,75%
India	0,53%	12,46%	7,23%

Countries	% as importers from EU	2012-2020 %GDP growth	2021-2030 % GDP growth
Others	54,67%	1,50%	1,50%

Source: PwC

3.7.3 Trends in product design/ features

According to the market operators, the main trends in product design will focus on **energy efficient technologies**. Moreover, waste heat recovery solutions an increasing, after diesel engines and gas-turbines, up to 50 MW. **Technology improvements for boilers focus on efficiency** and low-cost design while giving increasingly more attention to air pollutant emissions[32].

According to the **Danish Energy Agency**, in Denmark optimisation of all parameters of the whole boiler setup is a topic. There is a focus on **recovery of rest energy** in the flue gas for whatever purpose that can be found (pre-heating of fee water, preheating of combustion air, space heating on site, district heating etc.) Especially for wet fuels, such as some kinds of solid biomass, flues gas condensation is also a trend.

General control and regulation of existing system with fairly small investments can increase the total efficiency of the boiler plant. The **industry** is also trying to **lower the operating pressure as much as possible** to increase the amount of useful energy from the flue gas to the steam. Also, the demand for personal must be minimized, so more and more automation is seen.

Biomass and other type of sustainable energy fuel are gaining ground. Gasification is under development and some installations are up and running. This technology can deal with many types of fuels and is quickly modulating. In the same time, companies can keep their existing gas boilers, install a double fuel burner, and have natural gas as backup. In some industrial applications, steam boilers based on renewable energy (biomass, solar energy) are becoming market competitors for conventional fossil fuels-based boilers[33].

The technology and equipment used for steam boilers is highly dependent on inputs (fuel or electric), fuel type and the quality of the specific fuel . Thus, in terms of energy efficiency, when looking at the product design, energy source should be considered.

Steam temperature, steam saturation pressure, condensate return rate and condensate return temperature should also be taken into account when regulation steam boilers based on fuels.

Thus, key technological drivers of the steam-boiler market are:

- efficiency gains;
- advances in safety;
- lower maintenance costs.

According to the Danish Energy Agency, running costs, such as O&M, will go down. In running costs, fuel and taxes is also included, where biomass is the cheapest solution in some countries (e.g. Denmark). The reason is that some MSs (such as Denmark) are experiencing more and more companies focusing on the total life cost of a new boiler over a period of 10 years, and in this calculation the running

32 EA – ETSAP (International Energy Agency – Energy Technology Systems Analysis Programme) 2010.

33 Industrial Combustion Boilers (IEA ETSAP, 2010).

costs are very important. The complete use of the energy in the flue gas also supports this fact. Moreover the tendency when building new boiler plants is that the installation cost is going up to save money in the long run

3.8 Consumer expenditure base data

A **Fire tube boiler costs 25 to 40% less than a comparatively sized Water tube** boiler[34]. The difference price is mainly due to manufacturing costs which are higher for a Water tube boiler because of the more labour-intensive constructing processes.

According to the document "Industrial Combustion Boilers"[35], the costs of steam generation are usually referred to as a system cost covering the entire boiler life cycle. For a full-load steam system (86%-94% utilization), the fuel cost accounts for 96% of the total life-cycle cost while investment, operating and maintenance costs usually account for 3% and 1%, respectively. The cost structure clearly demonstrates that the energy efficiency is the main cost driver.

According to IEA, a **Gas- or oil–fired packaged fire tube boiler of steam production of 4,7 t/h**, has a **capital cost of $ 60,000** (2008 US$ (3% of the life-time cost). An additional mass flow rate of 1.5 T/h may result in a cost increase of around $ 5.500. This cost does not include components such as water softener, feed water system, chemical treatment equipment, economizer, blow-down equipment, condensate return system and fuel supply equipment. Nor does it include the installation cost. The installation cost may add between 50% and 100% to the investment cost and the O&M cost represents the 1% of the life-time cost. The lifetime is around 25-40 years.

According to BDH, a **Steam Boiler of steam production of 10 t/h** (corresponding to 6,7 MW of thermal capacity) has a **capital cost of < 300.000 Euro** (Boiler body cost estimated < 0,5% of the fuel). The fuel cost is estimated 58.800.000 Euro (assuming *the rice per litre oil (0,7 Euro/ltr) and the fuel necessary to heat up 1 t steam 70 ltr / t/h)*. Manufacturing and disposal costs of the component boilers are assuming a useful life of 20 years while the energy consumption cost is very low (<0.5%) and therefore in the context of LCA irrelevant. The product lifetime is 20 years and the running time per year is 6.000h.

Further inputs on economic data related to Steam boilers have been gathered from informal contacts with selected stakeholders.

As explained in paragraph 3.2, there is no "average steam boiler", as each boiler is custom made or produced in very limited numbers. Steam boilers are designed for and in conjunction with customers to meet very specific requirements.

In order to ensure the proper **coherence and consistency of the assumptions and the users data (Task 3)**, in particular on economic data and market trends, selected market operators have been required to provide to draw up a case study on a "regular" product type including information on technology, power and steam output, product costs, installation costs, O&M costs, main consumables, industry served.

Costs and prices described in the following case studies and table will be the input for the Life Cycle Cost Assessment provided in Tasks 5 and 6.

Case Study 1 - Pharmaceutics

Special high quality steam is used in special applications on hospitals, special

[34] Source: Cleaverbrooks: http://www.cleaver-brooks.com/

[35] IEA – ETSAP (International Energy Agency – Energy Technology Systems Analysis Programme)2010.

institutions, pharmaceutical industry, biochemical industry, food industry, etc In pharmaceutics pure steam is mainly used for sterilizing tanks, filters and piping systems, as well as products in sterilizers. Moreover, it is used for air-moistening in cleanroom systems.

Pharmaceutical boiler types can vary depending on fuel source, unit location, emissions, boiler controls, and heating requirements.

Clean and pure steam applications both require a special design on the feed water provider and the steam generating plant. Obviously the quality of feed water determines the quality of the steam. The general design complies with materials in stainless steel only.

Product description and classification

Type of machinery	Steam generator
Type of execution	Fire Tube
Generators number	2
Power output	4.000 kg/h
Steam pressure	12 bar
Area of application	Industrial plant
Sector of application	Pharmaceutics
Geographic Area	North Italy
Eurostat PRODCOM	25.30.11.50

Technical features

Thermal capacity: 2.800 kW

Steam Production : 4.000 kg

Fuel Type: methane

Main accessories : burner, economizer, power modulating second pump, automatic air vent system security exemption licensed 72H, steam collector.

Costs

Boiler unit cost: Euro 84.700,00
Overall cost of the product: Euro 267.000,00
Main accessories cost : Euro 85.000,00
Installation cost: Euro 85.000,00

Ordinary maintenance cost : (not included in the sale) Euro 2.500
Ordinary maintenance cost on main accessories : (not included in the sale) 2600Euro

Case Study2 - Food industry

Within the food industry steam is used for processing, drying and heating and for general use such as in sanitizing. This type of steam is used for direct injection into the product or to clean or sterilize product contact surface.

The demand of steam varies in different operations. In some plants or parts of the plants steam is used continuously while it is used intermittently in others.

http://www.spiraxsarco.com/us/downloads/features/Spirax-Food-and-Beverage-Best-Practice.pdf

http://osufacts.okstate.edu/docushare/dsweb/Get/Document-3042/FAPC-

142web.pdf

Product description and classification

Type of machinery	Steam generator
Type of execution	Fire tube
Generators number	1
Power output	2.500 kg/h
Steam pressure	10 bar
Area of application	Industrial plant
Sector of application	Food industry: production of pickles
Geographic Area	North Italy
Eurostat PRODCOM	25.30.11.50

Technical features

Thermal capacity: 1.700 kW

Steam Production: 2.500 kg
Fuel type: methane
Main accessories: burner, economizer, power modulating second pump, automatic air vent system security exemption licensed 24H, condensate collection vessel, expansion tank and cooling drains, water softener.

Costs

Boiler unit cost: Euro 29.000,00

Overall cost of the product: Euro 65.000,00

Main accessories cost: Euro 36.000,00
Installation cost: Euro 20.000,00

Ordinary maintenance cost (not included in the sale) Euro 2.300
Ordinary maintenance cost on main accessories : (not included in the sale) 2400 Euro

Case Study 3 - Textile

Textiles (dyeing and printing) are energy intensive industries.

Steam is widely used in textile industry in every process: spinning, weaving, processing and garments. Steam is used for drying, heating and maintaining the temperature of system.

Steam is used for mostly preparation of synthetic fibres. It is used in dry spinning of manmade fibres as when they pass from spinneret they are in liquid form.

Other applications of steam are in Fabric Manufacturing and textile Chemistry.

Product description and classification

Type of machinery	Steam generator
Type of execution	Fire tube
Generators number	2
Power output	16.000 kg/h
Steam pressure	12 bar
Area of application	Industrial plant
Sector of application	Textile

Geographic Area North Italy
Eurostat PRODCOM 25.30.11.50

Technical features

Thermal capacity : 11.600 kW

Steam production: 16.000 kg

Fuel type: methane
Main accessories: burner, economizer, economizer condenser, second pump, automatic air vent system security exemption licensed 72H, fireplace, steam collector.

Costs

Boiler unit cost: Euro 41.700,00

Overall cost of the product: Euro 41.700,00

Main accessories cost: Euro 41.700,00

Installation cost: Euro 41.700,00

Ordinary maintenance cost (not included in the sale) Euro 2.000

Ordinary maintenance cost on main accessories : (not included in the sale) 2.400 Euro

3.9 New data collection

As stated before (see paragraph 3.2), official EU Prodcom statistics on production, import and export of Steam boilers are gathered without differentiating by power output and taking into account confidentiality and market relevance. **Considering such limits, which have a relevant weight in the steam boilers sector, a second round of market operators' consultation has been carried out in order to countercheck statistical data with information directly coming from the field**.

Following the stakeholder meeting held in Brussels, on March 6, 2014, a new survey has been launched in order to better target the reference market on **steam boilers with a power output between 1 and 50 MW**.

The new Survey has been built on a shorter questionnaire with a more specific focus on market data, aiming at having back an expert opinion on the internal composition, by installed power and output capacity, of the three Prodcom codes scoping our study, namely:

- **25.30.11.10 Water tube boilers** (excluding central heating hot water boilers capable of producing low pressure steam);
- **25.30.11.50 Vapour generating boilers** (including hybrid boilers-excluding central heating hot water boilers capable of producing low pressure steam, water tube boilers);
- **25.30.11.70 Super-heated water boilers** (excluding central heating hot water boilers capable of producing low pressure steam).

Among the possible approaches which could be used to overcome the main issues hampering a satisfactory data gathering (market sensitivity and confidentiality, irrelevance of figures in some countries, complete lack of data) **Delphi method** could help pursuing our purposes. Such a technique is widely used and accepted for gathering data from a panel of selected subjects within their domain of expertise.

In this case, **experts** have been mainly selected among the **European producers** and **Associations**.

Questions were not about the market fronted by any producer (therefore confidential information was not asked) but about the whole European market of steam boilers within the relevant scope for the study, as it is perceived by every single expert.

3.9.1 EU 28 production of steam boilers

In particular, the Survey was designed to gather specific values on production, import-export and stock data with reference to steam boilers with a power output between 1MW and 50MW.

Two contributions arrived: one from the **European Heating Association (EHI),** providing figures on production of steam boilers in Europe, the other one by the **Swedish Energy Agency,** related to the Swedish market.

Given the authority of EHI and the European scope of the study, the following section contains a new market analysis based on EHI data.

The following tables show the overall European production per type of steam boiler and size category. The tables provide the number of pieces produced and the related economic value.

As it can be observed in the tables below, as to the water tube boilers, a total of 1000 pieces are produced for an overall value of 500 M€.

Table 46 – Production of Water tube boilers 1-50 MW (25.30.11.10) - EU28

Size of boiler (MW)	Pieces	Value (€)
1-5	400	50.000.000
5-25	300	200.000.000
25-50	300	250.000.000
Total	1000	500.000.000

Source: BDH- EHI

Looking at the vapour generating boilers, it can be observed that the pieces produced, 2500, are 2500 (double than water tube boilers) have an overall value of 220 M€ (around half of water tube boilers production value). Moreover, it can be highlighted that, while as for water tube boilers the production is balanced amongst the different ranges of size of boiler, fire tube boilers are mostly produced in small size (1-5 MW).

Table 47 – Production of Vapour generating boilers 1-50 MW (25.30.11.50) - EU28

Size of boiler (MW)	Pieces	Value (€)
1-5	1.500	66.000.000
5-25	750	110.000.000

25-50	250	44.000.000
Total	2.500	220.000.000

Source: BDH- EHI

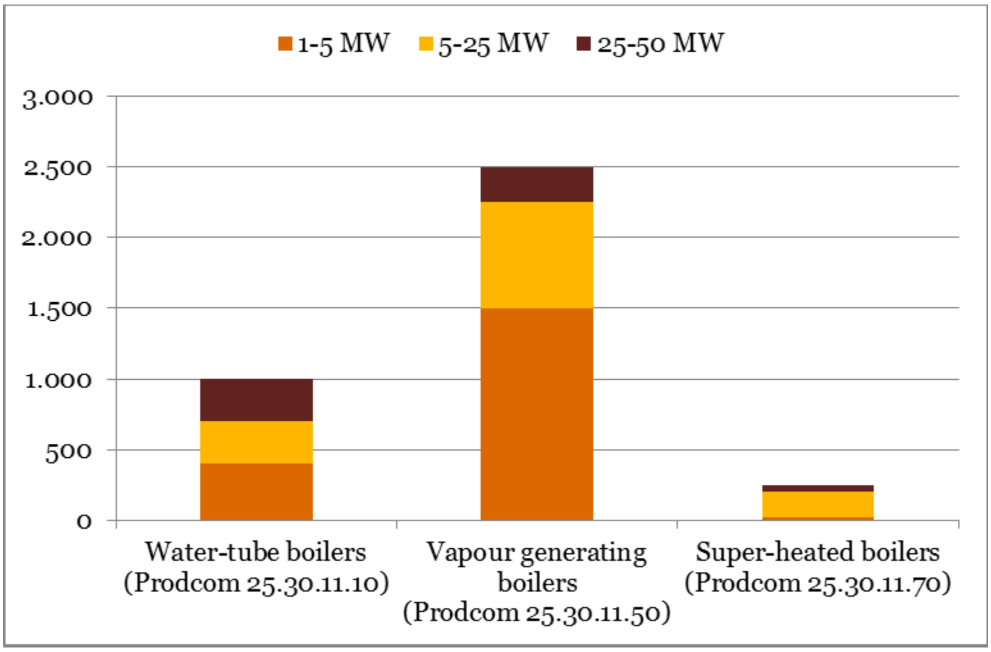
Finally, as to the super-heated boilers, it can be said that, despite the few pieces produced, a total of 250, the amount of production is quite high at 30 M€.

Table 48 – Production of Super-heated boilers 1-50 MW (25.30.11.70) - EU28

Size of boiler (MW)	Pieces	Value (€)
1-5	25	3.000.000
5-25	175	9.000.000
25-50	50	18.000.000
Total	250	30.000.000

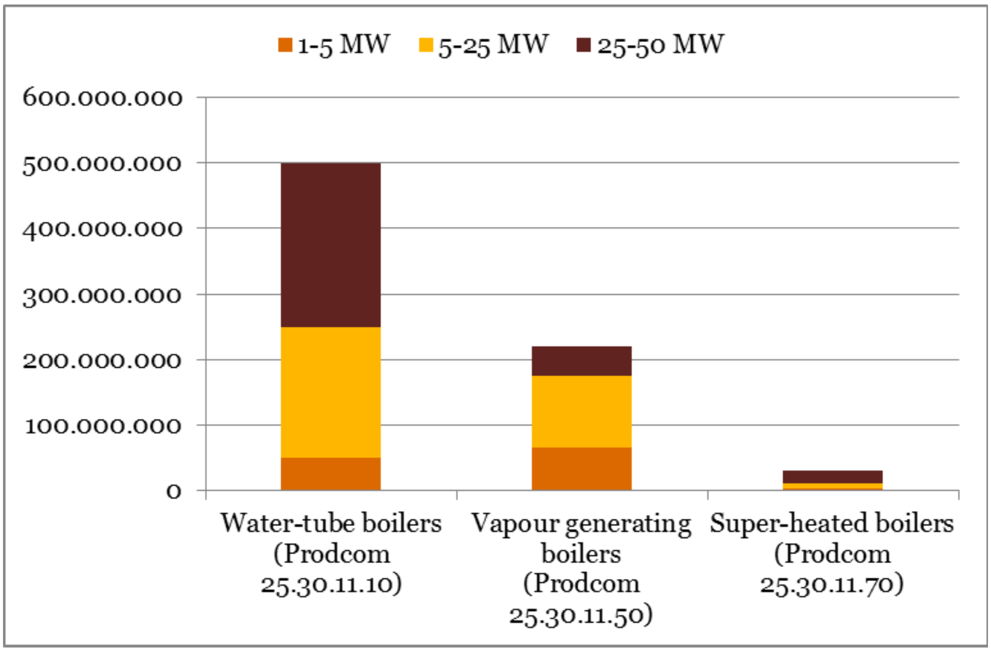
Source: BDH- EHI

Figure 33 - Production of Steam boilers 1-50 MW - EU28 - pieces



Source: BDH

Figure 34 - Production of Steam boilers 1-50 MW - EU28 - value (€)



Source: BDH

3.9.2EU 28 trade

Data on import-export of steam boilers with a power output between 1MW and50MW are not available (for figures related to the overall steam boilers please see Section 3.5).

3.9.3EU 28 sales

As discussed informally with some key market operators, exports can be estimated as 20% of the production, while imports show values not-relevant to our analysis.

Given the assumption that the steam boilers production is equivalent to the sales, overall steam boilers sales in EU can be calculated from Production + Imports – Exports (Y+M-X), representing the apparent consumption.

As to the EU annual sales, it can be observed that a total of 3.040 steam boilers are sold in EU 28, for a total of 600 M€.

Vapour generating boilers lead the market with 1.275 boilers sold.

Table 49 – Annual EU Sales – per type of Steam Boiler

Range size boiler (MW)	**Water tube boilers**		**Vapour-generating boilers**		**Super-heated boilers**	
	Pieces	M€	Pieces	M€	Pieces	Euro
1 to 5	320	40	1.200	52.8	20	2.4
5 to 25	240	160	600	88	140	7.2
25 to 50	240	200	240	35.2	40	14.4

Total	800	400	2.040	176	200	24

Source: PwC on BDH data

3.9.4 Stock data

Finally, as to the stock, the values in table below have been derived from data on stock presented in paragraph 3.6.1. BDH data on stock refer to a total amount of **70.000 steam boilers (of all size) as estimation in EU.**

Given the values on production and the share of small, medium and large steam boilers, it can be assumed that the current EU stock is estimated at 71.044, of which almost 19 thousands are water tube boilers, 47 thousands are fire tube boilers and 4.6 thousands are super-heated.

Table 50 – Stock data of steam boilers – per type of Steam Boiler

Range size boiler (MW)	Water tube boilers	Vapour-generating boilers	Super-heated boilers
1 to 5	7.478	28.604	467
5 to 25	5.609	14.302	3.272
25 to 50	5.609	4.767	935
Total	18.696	47.674	4.674

Such new data have been considered as the reference input for the definition of the base cases presented in Task 5.

3.10 Conclusions and Recommendations

Due to the specific environment of steam boilers market, the analysis dealt with the following issues:

Eurostat data do not differentiate the steam boilers according to their power output. The scope of the Preparatory Study, as defined in Task 1, requires an analysis on steam boilers with a capacity installed between 1 MW and 50 MW. The lack of details in Eurostat data did not allow a pure statistical analysis.

Considering such limits, two market operators' consultations have been carried out in order to countercheck statistical data with information directly coming from the field.

Pursuant to such operators consultations', preliminary results show that:

- There are only a limited number of steam boilers in the European market and only a few manufacturers.
- Even if aggregated at European level, collected data on the thermal capacity of individual steam boilers or the industry utilising them, would inevitably be leading to its manufacturers thus revealing individual companies' market share and other sensitive information.
- There is no "average steam boiler", as each boiler is custom made or at most produced in very limited numbers.
- Steam boilers are designed for and in conjunction with the customer to meet very specific requirements.

- Such complexities cannot be reduced even looking at destination markets.
- In fact, the energy loss of such plants is dominated by the exhaust gas temperature and oxygen content, which is always in direct correlation to the necessary temperature level of the industrial process. Customers would thus be reluctant to disclose information on steam boilers that would shed a light on their industrial processes.

The main recommendation is to build a sound market internal database at European level, for . Such data collection exercise can be coordinated by EC, with the cooperation of the main Associations, such as:

- European Heating Association;
- Conformity Assessment Bodies Forum Pressure CABF PED/SPV;
- National Associations of Boilers;
- National Energy Agencies;
- ...

Such new database would allow European Commission, in case Ecodesign process will go ahead with an Impact Assessment, to gather market information on specific size of steam boilers installed in Europe and in third countries.

The new database, available to European Commission and Associations, can be built in full compliance with confidential and competition rules in place in the different member States.

It will not be consulted or used for commercial purposes.

3.11 Annex to Task 2: Methodological approach for stakeholders' consultation

A not exhaustive list of Steam Boiler/Steam Generators Producers has been drawn up focusing on the three PRODCOM codes according to the scope of the study. Namely the following PRODCOM categories have been taking into account:

- Code: 25.30.11.10 - Description: Water tube boilers (excluding central heating hot water boilers capable of producing low pressure steam)
- Code: 25.30.11.50 Description: Vapour generating boilers (including hybrid boilers) (excluding central heating hot water boilers capable of producing low pressure steam, water tube boilers)
- Code: 25.30.11.70 Description: Super-heated water boilers (excluding central heating hot water boilers capable of producing low pressure steam)

As a preliminary task, an in **depth investigation** for each single Producer was carried out, mainly looking at the product technical documents (e.g., technical data sheets) available on the Companies websites (see list in Annex).

http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do

The period of time considered is **from 1995 to 2012** for all 28 MSs.

The Indicators statuses are listed below:

- Prodval (Production Value): It indicates the value (Euro) of the production and units.
- Prodquant (Production quantities): It expresses the production in units
- Impval (Import Value): stands for the importation in Euro (not available in units).

- Expval (Export value): stands for the exportation in Euro (not available in units).

Official EU statistics on production, import and export of Steam boilers do not provide complete data: for many MSs Data is not available and sometimes, when available, they are not consistent to specific national contributions provided, in particular from German and Italy.

Thus, two specific **Surveys** have been launched in order to gather useful data and information from the field. The selection of the main producers has been drawn up focusing on the three PRODCOM codes according to the scope of the study.

More than 30 **relevant Producers and Associations** were identified, representing a starting point for the product mapping aiming at analysing the main features of the steam boilers market.

For each single producer an in **depth investigation** has been carried out, mainly looking at the product technical documents (e.g., technical data sheets) available on the Companies websites.

All the selected producers were invited to participate to a Survey aiming at collecting market data and opinions on market trends.

The 1st Survey has been developed on a full -scale data collection preceded and based upon a **pilot phase**.

The pilot phase, carried out on some representative companies, was meant to pave the way for an easier and more reliable **full-scale data collection**, through a close analysis of the specific industrial sector and supply chains of the products under consideration.

The pilot phase included both telephone interviews and site visits. In detail, the pilot phase was organised as follows:

1. Set-up of preliminary questionnaire & selection of pilot sites;
2. Pilot data collection and follow up;

Analysis of pilot results and review of the questionnaire.

The companies that were selected as pilots were:

- Bono Energia (located in Milan, Italy);
- Ferroli (located in San Bonifacio, Verona- Italy);
- ICI Caldaie (located in Verona- Italy);

All of them are leaders in the national Italian territory as well as in Europe.

The pilot phase included both telephone interviews with all selected companies and site visits to 2 of them, namely Ferroli and ICI Caldaie.

Site visits were carried out by PwC, respectively, on the 15th of October , 2011, at Ferroli and on the 16h of October , 2011, at ICI Caldaie.

Bono Energia provides design, manufacturing, installation, service and maintenance of industrial boilers for standard and special applications. In particular, R&D department is committed to increase the efficiency of boilers and thermal plants: waste gas heat recovery and optimization of electric energy consumption. Bono Energia is operating since 1958 and it serves several industries, among which Food & Beverage, Textile, Chemical & Pharma, Paper & Cardboard, District Heating, Plastic & Rubber, Oil & Gas and Power Plants

Ferroli Group is a leader company in the heating and cooling and alternative energy sector, with more than 50 years' experience in Italy and around 40 years on the European and world market . Ferroli industrial Heating is the division created by Ferroli Group for the production and marketing of industrial boilers in a range of products and types. Ferroli operates in 14 countries across Europe and Asia with a strong commitment to design innovation.

ICI Caldaie S.p.a is a company with over 50 years of history and experience in energy management and thermal solutions. It was founded in 1958 as a manufacturing company for the production of steel boilers with high water content, a sector in which it currently stands as a global leader, supplying generators aimed at producing high efficiency thermal solutions in the commercial and industrial sector. The company is focused on new technologies and services for energy developed in cooperation with strategic partners.

The 2nd Survey, run between February and March 2014 aimed at focusing the product scope of steam boilers between 1 and 50 MW. The Questionnaire submitted aimed at having back an **expert opinion on the internal composition, by installed power and output capacity, of the three Prodcom codes scoping our study**, namely:

- **25.30.11.10 Water tube boilers** (excluding central heating hot water boilers capable of producing low pressure steam);
- **25.30.11.50 Vapour generating boilers** (including hybrid boilers- excluding central heating hot water boilers capable of producing low pressure steam, water tube boilers);
- **25.30.11.70 Super-heated water boilers** (excluding central heating hot water boilers capable of producing low pressure steam).

By such a survey we aimed at refining the information provided by EUROSTAT data which does not specify the range of power amongst the Prodcoms, while the Preparatory study shall cover only steam boilers within the scope above identified.

Questions were not be about the market fronted by any producer (therefore we are not asking confidential information) but about the whole European market of steam boilers within the relevant scope for the study, as it is perceived by every single expert.

Among the possible approaches which can be used to overcome the main issues hampering a satisfactory data gathering (market sensitivity and confidentiality, irrelevance of figures in some countries, complete lack of data) **Delphi method** can help pursuing our purposes. Such a technique is widely used and accepted for gathering data from a panel of selected subjects within their domain of expertise.

In this case, **experts** have been mainly selected among the **European producers** and **Associations**.

Task 3: Users

4 Task 3: Users

4.1 Objectives

The environmental performance of a product is not only influenced by the technical properties of the product itself but also by the user behaviour. User behaviour in a wider scope includes the direct user behaviour like the control setting of the products. For the specific case of the steam boilers the load profiles are a relevant driver for the environmental performance.

Considering all the different use cases, the performance of the product may substantially differ from the generic product specifications.

4.2 System aspects of the use phase for ErPs with direct impact

Within subtask 3.1 system boundaries of the product have to be defined according MEErP methodology. In order to set a frame for discussing user behaviour systematically we first introduce basic principles of steam generation systems. We then present affected branches with regard to industrial steam boiler within the scope of this study. Finally we define system boundaries according MEErP in the following sub-chapter.

4.3 Steam Generation Systems

Industrial steam boilers have the purpose to generate steam. Steam is formed when water passes from the liquid to the gaseous state. After water is heated beyond its boiling point it vaporizes into steam. Depending on the pressure and temperature it is subjected to different states. There are basically three states of steam:

- Unsaturated (wet) steam: Wet steam is a mixture of molecules in gaseous state and tiny water droplets.
- Saturated (dry) steam: Saturated steam is when all the water molecules are in the gaseous state.
- Superheated steam: When saturated steam is further heated, superheated steam is created. It lies above the saturated steam line.

To discuss steam system components and steam systems operation basically four categories are used in practice: generation, distribution, end use, and recovery. These four categories follow the path of steam as it is described in the following.

Generation: By transferring heat of combustion gases to water, steam is generated in a boiler or a heat recovery steam generator. Water changes its phase from liquid to steam when it absorbs enough heat. In order to increase the energy content of steam some boilers use super heaters. The pressurized steam flows then from the boiler to the distribution system[36].

Distribution: The distribution system carries the steam to the end-users (respectively the end-users equipment). The end-users are connected to the distribution system via several take-off lines. The take-off lines may operate at different pressures.

As a consequence common equipments being used in distribution systems are isolation valves, pressure regulating valves and sometimes backpressure turbines (back-pressure turbines allow to reduce the pressure in the line and extract mechanical energy)[36].

36 USDOE(2012): Improving Steam System Performance: A Sourcebook for Industry, pp2 ff.

End Use: End-users of steam-systems are diverse. Exemplary applications for steam are listed in the following:

- Steam as a heat carrier for industrial processes: Steam is a preferred heat carrier in many industries. The advantage of steam as a heat carrier compared to water in the liquid state is its higher specific energy content. For example for saturated steam at approx. 100°C the energy contained in steam is around six times higher than in water having the same mass and temperature.

- Steam as a carrier of chemical substances (e.g. as a moderator): Steam is also being used as carrier for chemical substances within the chemical industry for a wide range of processes. Examples are distillation or rectification processes.

- Steam for generating mechanical energy: In a turbine, the steam transforms its energy to mechanical work to drive rotating machinery such as pumps, compressors, or electric generators.

Thus common end-users equipment includes heat exchangers, turbines, fractionating towers, strippers, and chemical reaction vessels[36].

Recovery: The recovery system sends the condensate back to the boiler. This is being done by returning the condensate to a collection tank. The condensate is being pumped from the collection tank to the deaerator afterwards where oxygen and non-condensable gases are being extracted. However fresh make up water is necessary due to steam losses in the distribution system and at the end-user (leakages, etc.). Fresh makeup water and additives are being added usually in the collection tank or in the deaerator. Finally the feed water pressure is being increased by the boiler feed pump in order to exceed the minimum boiler pressure so that it can be injected into the boiler.[36] According Swagelok(2011) today's industrial best practice benchmark for condensate return is 90% if the plant is not injecting steam for the process[37].

4.3.1 Branches and Industries

Industrial steam boilers within the scope of this study are being used mostly in energy intensive industries. Affected branches are e.g. the paper, food processing, chemical, metal and petroleum refining industry other branches are shown in Figure 35. The processes where the generated steam is being applied are diverse ranging from applications where only heat is being transferred up to applications where heat- and mass is being transferred such as thermal separation processes.

According to Therkelsen et al. (2013) one third of the industrial energy consumption of the United States is due to steam production[38]. Einstein (2001) analyses the U.S. steam boiler stock according the distribution of boiler sizes within the different industries[39]. The results are listed in paragraph 4.3.3.7. One conclusion is that the food processing industry relies mainly on small boilers whereas the pulp and paper as well as primary metal industry run large boilers. The chemical manufacturing energy needs both. Furthermore a wide range of industrial used steam boilers belong to the range of less than 50 MW thermal output.

Additionally the facility sizes where industrial boilers are being used seem to vary greatly when referring to values from the U.S. market (which is presumed to be comparable to the E.U. market). Thus we have industrial steam boilers being used

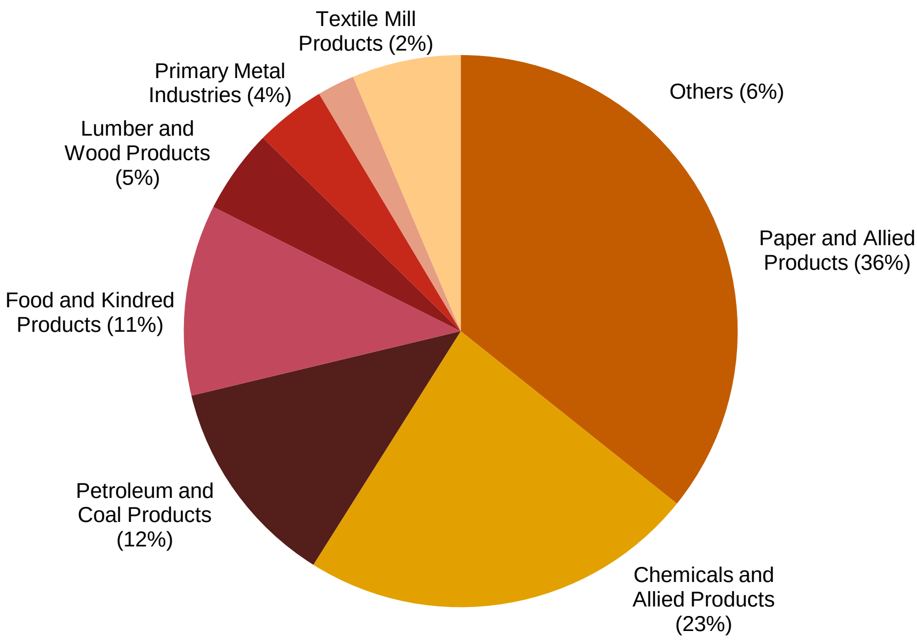
37 Swagelok (2011): Knowing the cost of steam, Document No. 31.

38 Therkelsen et al. (2013): Implementation and rejection of industrial steam system energy efficiency measures , Energy Policy57(2013) 318–328.

39 Einstein et al. (2001): Steam systems in industry: Energy use and energy efficiency improvement potentials, http://escholarship.org/uc/item/3m1781f1.

in very small facilities with up to five employees and in very large facilities with up to 2499 employees[40].

Figure 35 - Share of steam use per sector in the United States of America



Source: Einstein et al. (2001): Steam systems in industry: Energy use and energy efficiency improvement potentials, http://escholarship.org/uc/item/3m1781f1.

Table 51 - Distribution of boilers by size and major industrial sector in U.S. industry

	3-15 MW		15-29 MW		29-73 MW		>73 MW		Total
	MW	%	MW	%	MW	%	MW	%	MW
Chemicals	37.514	25,7	22.923	15,7	41.971	28,8	15.659	29,8	145.846
Food	27.381	35,9	19.130	25,1	19.439	25,5	10.273	13,5	76.225
Paper	10.912	10,1	1.184	10,9	26.915	24,9	58.558	54,1	108.227
Refining	9.651	15,7	8.315	13,5	14.058	22,9	29.474	47,9	61.498
Primary Metals	15.650	28,2	6.829	12,3	12.137	21,9	20.893	37,6	55.509

Source GRI, 1996 in (Einstein et al., 2001, p. 7)

4.3.2Strict product scope

Figure 36 shows an overview of basic components which are usually used to set up a steam system where the focus lies on the generation system. The dashed lines in Figure 36 represent the strict product scope. The system boundary for the strict product scope is based on EN 12952 for water tube boilers and on EN 12953 for

40 EEAInc (2005): Characterization of the U.S. Industrial/Commercial Boiler Population, p.A-12.

shell boilers. The EN 12952-1 and EN 12953-1 define in general those components belonging to the steam boiler assembly. EN 12952-15 and EN 12953-11 deal with acceptance tests. These standards define how to calculate and derive the thermal efficiency by product acceptance test procedures. The components and further devices within this boundary have already been listed in Task 1 defining Steam Boiler within the context of this study. The definition is as follows:

Within the context of this study Steam Boiler:

(a) Means a device -

(i) Most of which is an arrangement of pressure containment parts; and

(ii) The purpose of which is to generate steam at temperatures above 100°C

(A) By the use of a directly applied combustion process; or

(B) By the application of heated gases; and

(b) Includes any of the following:

(i) Boiler piping (within the system boundary from feed water inlet up to steam outlet)

(ii) Combustion equipment

(iii) Combustion management systems

(iv) Controls

(v) Economisers

(vi) Fans

(vii) ~~Feed and~~ circulating pumps

(viii) Pressure fittings

(ix) Reheaters

(c) The Combustion equipment is within the context of this study necessary part of a Steam boiler. The fuel of the Combustion equipment is Natural Gas or Heating Oil. We exclude all solid fuels.

All parts in the graphic marked with an asterisk (*) are optional parts. This means that not all steam boilers are equipped with them. They are often used to increase the efficiency.

The economizer can be designed either belonging to the strict product scope or being a separate part. It is included in this graphic because 80% of all water tube boilers with an output over 2 MW are equipped with one.[41] It is one common design option increasing the efficiency of an industrial steam boiler which will be evaluated in Task 6. The reason why it can be seen nowadays within the strict product scope will be discussed more in detail in Task 4.

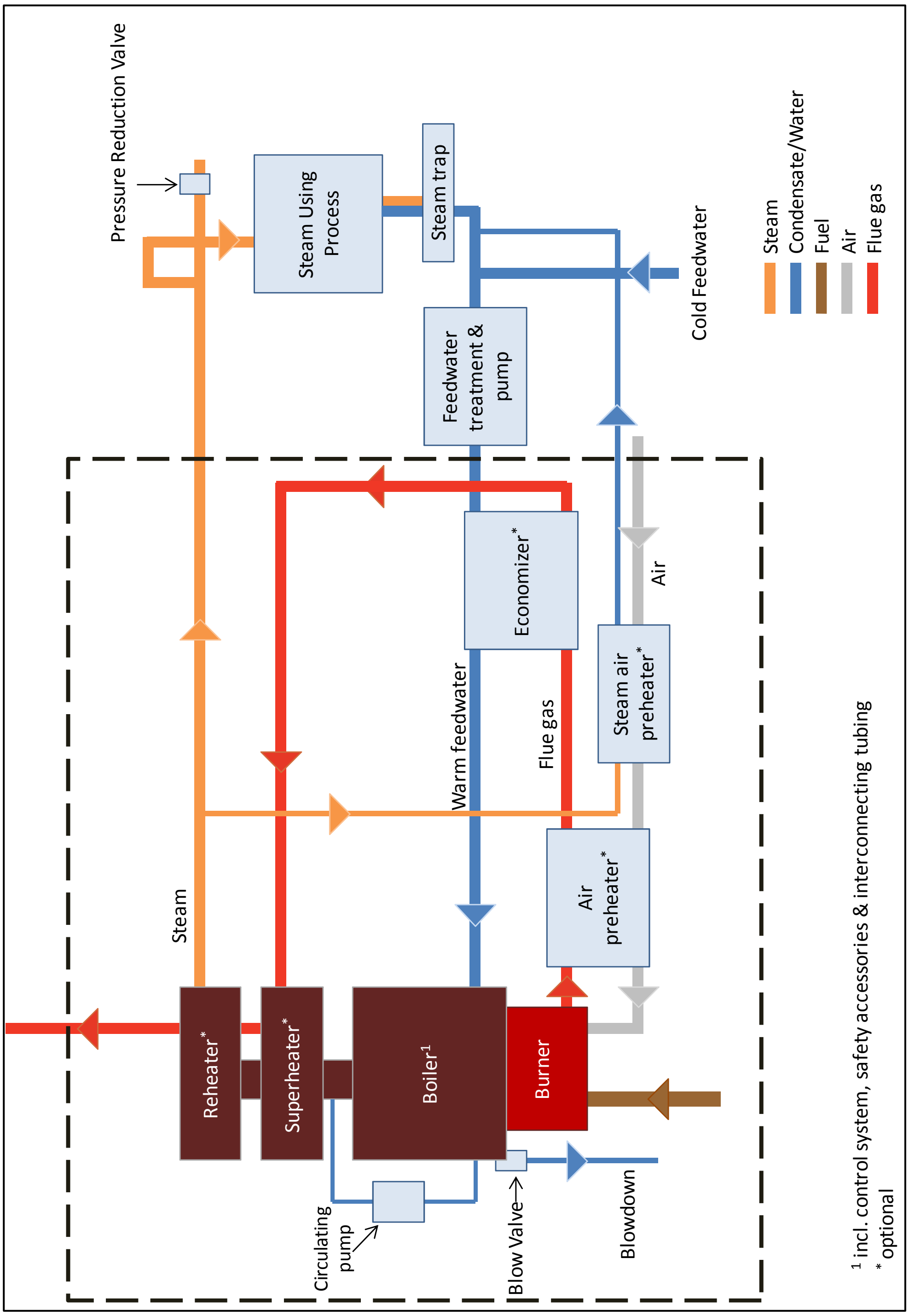
The feed water pump is not part of the strict product/component scope because it is not part of the efficiency calculation. Moreover the pump is regulated in another Ecodesign Preparatory Study. This argument accounts for the circulating pump as well. Nevertheless the efficiency evaluations are based on the European standard which includes the circulating pump.

Nowadays industrial steam boilers achieve comparable high efficiencies. Performing an internet based screening on randomly chosen products, efficiencies for 31 industrial steam boilers (without economizer) could be found, either published public in downloadable data sheets or on websites (Figure 37). Thus 48% of the manufacturers claim to achieve a boiler efficiency of equal or superior

41 European Comission (2009): BREF Reference Document on Best Available Techniques for Energy Efficiency, p.144.

than 90%. Furthermore 39% claim to achieve a boiler efficiency of equal or superior than 85%. For products equipped with an economizer only six efficiency values has been found. The claimed values lie between 94% and 96% boiler efficiency with the exception for one product (Figure 38).

Figure 36 - Basic components within a steam system



However it has to be mentioned that the appropriate load points for the claimed efficiency values has been published very seldom as this is the case only for nine products without economizer and for three with economizer. Thus these values are not sufficient for comparing products and the values are only given to present the range of efficiencies industrial steam boiler can achieve being equipped with and without economizer. The role of part load behaviour will discusses more in detail in the extended product approach and Task 4. Furthermore the BDH (2013) states that the "Efficiency is not a function of the boiler itself but the efficiency is significantly governed by the components and the application. The efficiency of the component steam boiler body is significantly governed by the required operating pressure of the application. Due to the dependence of the saturated vapour temperature of the operating pressure and the physical processes of heat transmission, the exhaust temperature is bounded below."[42] However from our point of view this statement is only valid when not using an economizer.

Figure 37 - Extract of efficiencies of industrial steam boiler without economizer among our sample values, remark: Products are not comparable as the appropriate loads are unknown and/or not the same.

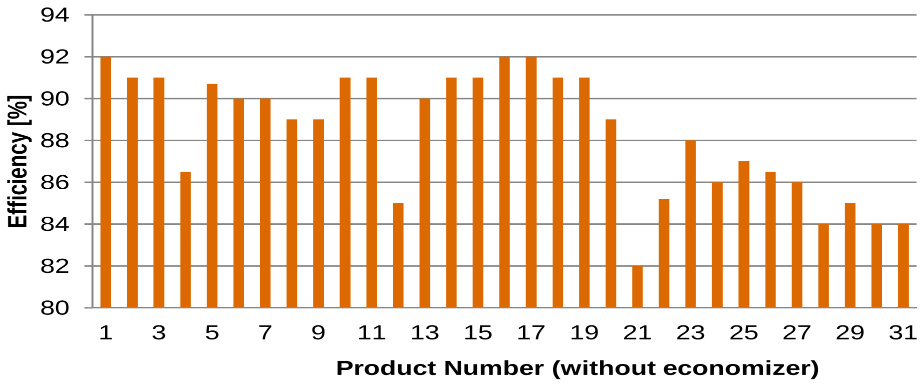
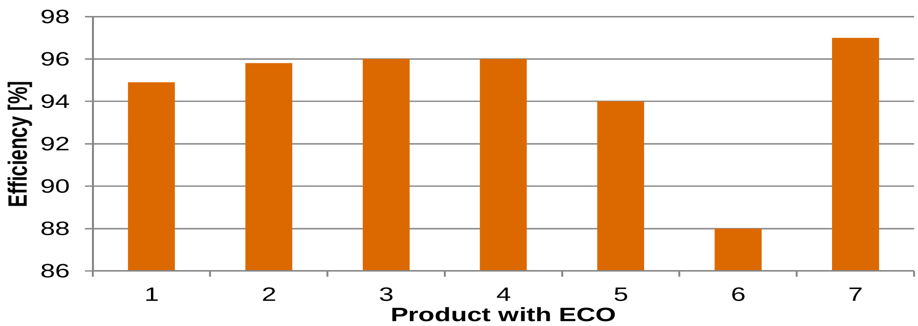


Figure 38 - Extract of efficiencies of industrial steam boiler with economizer among our sample values, remark: Products are not comparable as the appropriate loads are unknown and/or not the same



As a consequence industrial steam boilers are customized products as boundary conditions such as the required pressure of the applications are determining the efficiency and thus the design. In order to set appropriate efficiency assumptions for the LCA further information from the stakeholder is needed. This will be discussed more in detail in the extended product approach.

4.3.3 Extended product approach

The extended product approach includes the same parts as the strict product/component scope. The system boundary does not change. However the focus shifts from the nominal load to varying loads, controllability and auxiliary devices. Thus we first present an extract of processes industrial steam boilers are

42 BDH(2013): Statement from BDH on Steam Boilers Preparatory Study for Ecodesign, submitted to Mr. Davide Polverini on the 11th December of 2013 with reference WL (BDH20413B) via e-mail.

being used for. We then discuss different aspects of steam boiler operation with regard to the user behaviour. Finally we summarize core statements for that discussion.

As already mentioned steam boilers are being used in several heterogeneous industries. Thus the generation is always similar, but the end uses vary greatly in terms of pressure, temperature and steam condition requirements. This can even be the case within one production process consisting of several sub-processes quite significant. One example is the Kraft pulping process in the pulp and paper industry, where the pressure deviates from 1.4 bar up to 9 bar depending on process step (Table 52).

Table 52 - Temperature and pressure-ranges within the Kraft Pulping Process

Process step	Steam temperature [°C]	Steam pressure [bar]
Digesting (Batch Process)	120 - 175	6,89 - 8,96
Digesting (Continuous Process)	165 - 175	6,89 - 8,97
Chemical Recovery	145	3,10
Bleaching	127	1,38
Pulp Drying	127	1,38

Source: USDOE(2002), p. 34

Examples for different processes and the applied steam using equipment can be found in Table 53. It lists the processes and respective industries using them. Especially the chemical and petroleum refining industry rely on steam using processes. Thus steam is majorly being used as carrier for heat, as medium to generate mechanical energy or as a carrier for substances and/or reagents.

Anyhow the influence of different end-user with regard to the impact on the operation of industrial steam boiler cannot be evaluated in detail as there is no quantified database for the European market. Thus further support from the stakeholder is needed to set adequate assumptions for the LCA. It might be that end-users characteristics are negligible assuming that the requirements of end-users (temperature, pressure-level, etc.) are expressed in product requirements. Consequently they are being respected by categorizing product types and setting different base cases within this study.

Table 53 - Examples for steam using processes (based on USDEO 2012)

Steam using processes	Chemical industry	Medical	Petroleum Refining	Pulp and Paper	Steel production	Metal casting	Forest product	Food processing	Agriculture	Medical	Textile	Glass
Fractionation (rectification), Distillation	x	x	x									
Drying	x			x				x			x	
Power generation or drive for other rotating machinery (e.g. pumps, fans, compressors)	x	x	x	x	x	x	x	x	x	x	x	x
Evaporation, concentration	x				x	x		x			x	
Heating process air & water storage tank	x		x		x	x	x					x
Hydrogen generation	x		x									
Agitation/Blending	x		x				x					
Cracking	x		x									
Sterilization		x						x	x			

4.3.3.1 Operation hours

The operation hours of steam boilers are dependent on several boundary conditions. Majorly the following criteria play a role:

- What is the production schedule of the affected plant (e.g. do we have two or three shift operation, etc.)?
- Which are the characteristics of end-user that are being served by the steam boiler? Are the end-users acting volatile?
- Which purpose does the affected steam boilers have (e.g. is it a base load or peak load machine)?

The production schedule of a plant might be dependent on industry and company size. Thus the operation of a steam boiler is influenced indirect by market demands as for example in the food industry where the demand for specific products fluctuates due to consumer behaviour. Examples are the beer production (Figure 39) or the production of cosmetic products[43].

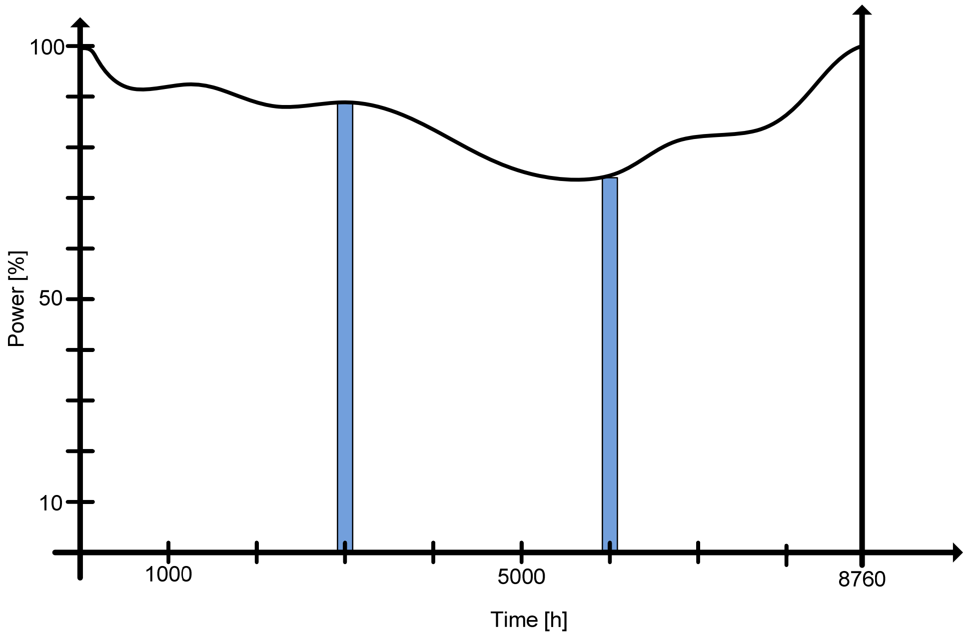
Furthermore the purpose of the machines might be different in a steam system with more than one industrial steam boiler. Within some steam systems a fraction of steam boilers run more or less as base load-machines and another fraction run

43 Derived from an interview with an energy management engineer from a cosmetics production facility.

more or less as peak-load machines resulting in higher operation hours for the first fraction. Thus the operation hours of machines can even deviate within one facility.

However it can hardly be estimated whether a boiler is used as base load machine or as peak demand machine and what characteristics do end-users have on a case basis within the scope of this study. This will be discussed further in the passage on the part load behaviour.

Figure 39 - Example for the steam demand in a brewery



Source: Viessmann(2011), p.17), (power above time)

EAA Inc(2005) estimates fuel consumption and boiler size distribution on a heat input basis for industrial steam boilers in the U.S. market and finally they calculate an average annual capacity factor for each industry. Within the context of this report the capacity factor is an industry specific value representing the real consumption (i.e. the total thermal input) of the estimated industrial steam boiler population within an industry subdivided by the theoretical maximum thermal input (i.e. the consumption which would occur by running all the estimated boilers at full load) within the same industry during a year. Thus we can define it for the purpose of this work as follows:

$$CF_{i,j} = \frac{Q_{i,j}}{C_{i,j} \cdot 8760}$$

With $Q_{i,j}$ as the sum of thermal consumption of estimated boiler population in year j of industry i and $C_{i,j}$ as the sum of capacity of estimated boiler population in this year and industry[44].

Consequently these values represent the average usage rate of industrial steam boilers within an industry. Furthermore these values are the only available, quantified information to gain insights on at least the different operation hours among the industries. They are listed in Table 54.

44 Please not that these values are not being used anymore at a later stage of this study. The explanation is given in Task 5.

Table 54 - Average capacity factors of industrial steam boilers in the U.S.

Industry	Capacity factor [%]	Comment
Food	31	Low capacity factor due to seasonal nature of some production facilities.
Paper	66	Large industry with highest share on overall consumption in the U.S.
Chemicals	50	High number of large and small boilers. Large boiler mainly in large integrated facilities and small boilers mainly in facilities producing niche products. Complex and diverse industry sector.
Refining Industry	25	-
Primary metals industry	47	Higher integrated steel mills are more dominant in steam usage (e.g. for on-site power generation).
Other manufacturing	29	-

Source: EEA Inc(2005), p.2-2 ff

4.3.3.2 Occurrence of load changes

In the foregoing it has been mentioned that the operation hours of industrial steam boilers are dependent on the purpose of the affected machine (e.g. base load or peak-machine) and the characteristics of the end-users. Consequently the frequency of load changes is dependent on the same.

Volatile behaviour of the end-users is affecting steam boilers via distribution systems. Thus distribution systems are not passive as these systems "regulate the delivery of steam and respond to changing temperature and pressure requirements"[45] (USDOE 2012, p.9). In order to respond to these requirements steam systems are often equipped with more than one boiler. In such systems a fraction of the machines is being used more or less as base load machine and another fraction is being used more or less as peak demand machines responding to volatile, increasing steam demand requirements from the steam distribution system[43] (maybe additional source is needed). As a consequence a possible division of industrial steam boiler in industry might be to distinguish between base load-, peak-load and back-up-machines.

However the frequency of load changes can hardly be evaluated as there is no database on this topic available and this would need at least a plant specific review on some facilities. Thus further information from stakeholder is needed.

4.3.3.3 Part load behaviour

The frequency of load changes might be not as crucial for evaluating industrial steam boiler with regard to the scope of this study as the efficiencies of industrial steam boiler are not affected strongly by part load behaviour. The efficiency of modern industrial steam boiler varies about maximum two percent covering an operation range from 40% to 100% load among our sample of data sheets which has been published online by manufacturer. This is the case for industrial steam boiler with and without economizer. Furthermore some of these steam boilers have

45 USDOE (2012): Improving Steam System Performance: A Sourcebook for Industry, p.9.

their maximum efficiency at partial load. The maximum values can be found among the range from 40 to 100% nominal load indicating that customer's requirements are different. Boilers with maximum efficiencies at nominal load are probably being used as base load machines where the share on part load operation is low. Boilers with maximum efficiencies at 45% nominal load are maybe used as peak demand machines (additive to a base load machine) with a high share of part load operation.

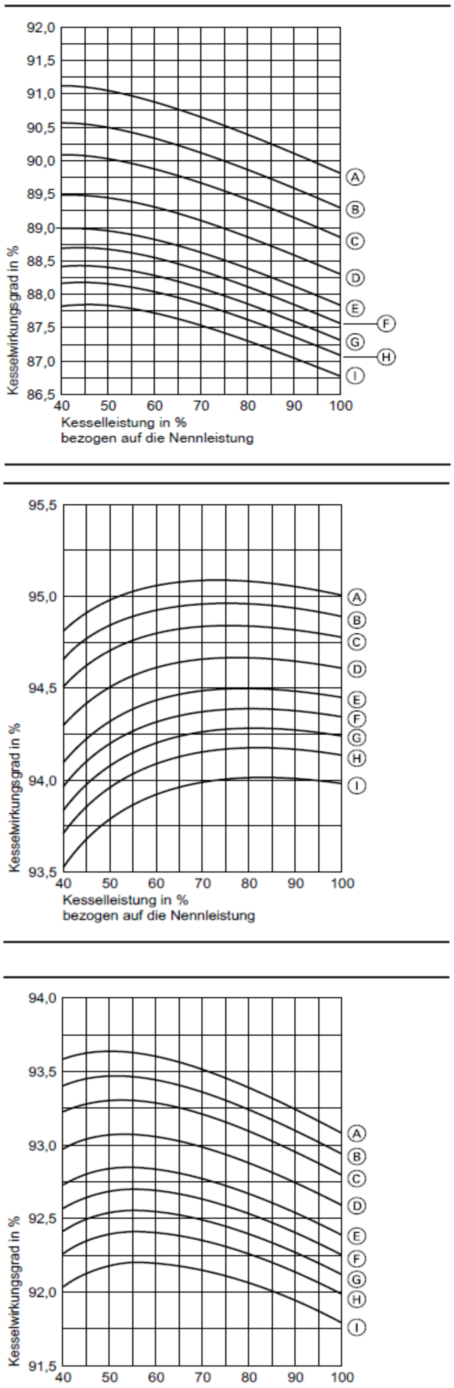
4.3.3.4 Start-up behaviour

The start-up behaviour depends as well as the operation hours on the production schedule and the purpose of the machine. Thus quantification of start up's during a day underlines also uncertainties as peak load machines might start much more often as base load machines which are being started when the production shift starts and shut down when the productions shift ends.

Furthermore it has to be regarded that the start-up of industrial steam boiler should need some time due to technical constraints and safety issues. In gas turbine plants the by-pass chimney has to be aerated with air due to safety reasons before starting the combustion process, preventing flammable mixtures in the chimney. As a rule of thumb the volume throughput to aerate the chimney is around three times higher than then the volume of the combustion chamber. Furthermore gas turbines have a start-up time of around 30 minutes[46]. We assume that this safety requirement is also predominant in industrial steam facilities and the starting time is 30 minutes too. However some solid biomass boilers need more than 30 minutes start up time.

46 Lechner et al. (2010): Stationäre Gasturbinen, p.195

Figure 40 - Three efficiency curves of one data sheet among our sample, the three curves represent different, optional designs, top: without economizer, middle: with "smaller" economizer, bottom: with "larger" economizer



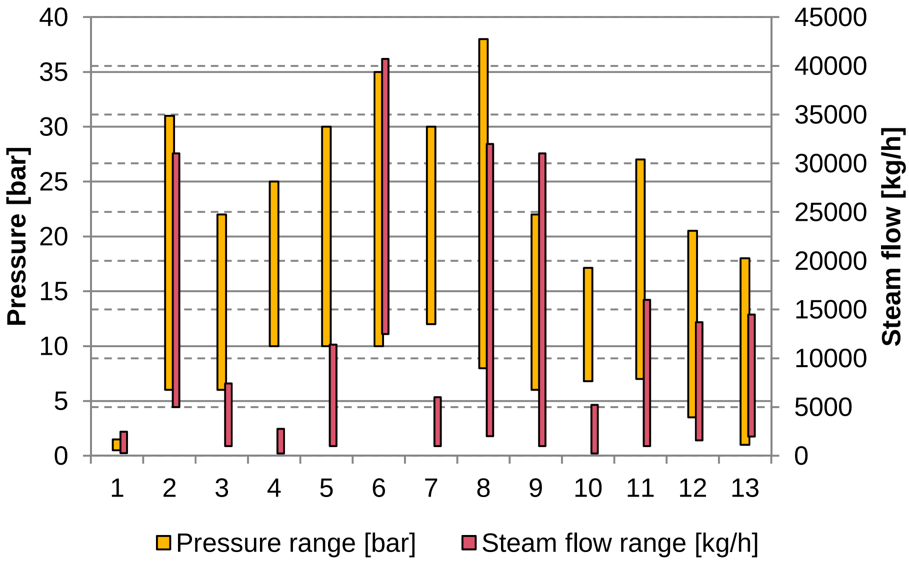
Source: [1] *Viessmann Data sheet for VITOMAX 200-HS, downloaded on the 13th of December 2013 from http://www.viessmann.de/content/dam/internet-global/pdf_documents/datasheets/db-5811487.pdf*

4.3.3.5 Pressure and steam flow ranges

Industrial planning manuals for steam systems list a maximum pressure of circa 30 bar for industrial steam boiler in fire tube design. Furthermore the maximum steam output mass flow is stated to be approximately 30t/h in three-pass design[47,48]. Among our sample of data sheets derived by internet research we find a minimum operation pressure of 0.5 bar and a maximum pressure of 30 bar among the products for fire tube boiler. Furthermore the ranges between minimum and maximum operation pressure deviates between the available data sheets. Thus the maximum difference between minimum and maximum pressure is 22 bar and the minimum is 0.5 bar for the same among the compared products. Additionally we find a minimum steam flow of 125 kg/h and a maximum steam flow of 30 t/h. As a consequence the diverse operating conditions of industrial steam boiler in fire tube design might indicate diverse application of this type of product. An extract of the pressure and mass-flow ranges for the fire tube steam boiler which has been found is visualized in Figure 41.

For water tube boiler a maximum pressure of 200bar is listed in industrial planning manuals. The minimum pressure ranges between one and seven bar and the maximum pressure between 22 and 103 bar for the data derived by internet research. Furthermore the minimum operating steam flow ranges between 150 kg/h and 90 t/h and the maximum flow ranges between 1t/h and 45 t/h. Thus the achievable pressures are by far higher in water tube boiler design than in fire tube design.

Figure 41 - Pressure ranges of 17 fire tube boiler derived from internet research



4.3.3.6 Economizer (feed-water pre-heating)

As already mentioned the economizer is defined to belong to the product system boundary. Around 80% of all water tube boilers with an output over 2 MW are equipped with an economizer within steam systems in European factories. It is one common design option increasing the efficiency of an industrial steam boiler which will be evaluated in Task 6. Reviewing data-sheets of different manufacturer presenting efficiency curves for the same fire tube boiler being equipped with different sized economizer it can be seen that load point for the maximum efficiency is depending on the size of the economizer amongst other factors (e.g. Figure 40). Thus it appears that the size of the economizer is one variable to adapt the design of offered steam boiler to customer requirements as well as possible. Anyhow the size and the usability of an economizer itself might be restricted by

47 SpiraxSarco (2009): Grundlagen der Dampf- und Kondensationstechnologie, p.24.

48 Viessmann (2011): Planungshandbuch für Dampfanlagen, p. 25.

other boundary conditions. One example is when the temperature of the exhaust gas is not allowed to fall under a minimum temperature when passing through the chimney. Based on the condition of the chimney such requirements are not uncommon limiting the usage of an economizer[49].

4.3.3.7 Conclusions on product and user characteristics

Major conclusions of the foregoing passages on product and user characteristics are summarized in the following bullet points:

- Operation hours of industrial steam boilers are deviating among industry and purpose of the machines. However an average utility rate for several industries has been presented based on figures from the EEA Inc. (2005). Further information from stakeholder is needed to set adequate assumptions for the operation hours of the base cases.
- Frequency of load changes deviate among industrial steam boilers. This is based in the fact that a fraction of the machines is used as peak load machines and another fraction as base load machines. Further information is needed in order to evaluate whether the frequency of load changes is relevant with regard to the goal of this study.
- Industrial steam boiler are not affected strongly by part load behaviour in terms of energy efficiency as the efficiency of modern industrial steam boiler varies about maximum two percent covering an operation range from 40% to 100% load among our sample of data sheets.
- Start up behaviour plays a role due to safety reasons. Thus it is assumed that a start-up of a steam boiler takes 30 minutes. Within this time the combustion is not running so that the boiler only causes efforts and no yields during this time (freewheel operation).
- Industrial steam boilers cover a wide range of pressure and steam flow ranges. Fire tube boilers operate with steam rates of up to 55.000 kg/h and pressures of 0.5 and 30 bar. Water tube-boilers achieve pressures up to 260bar.
- To integrate economizer is a common design option to increase energy efficiency of industrial steam boilers. However the usage of an economizer might be limited due to customer requirements. Thus further information from stakeholder is needed in order to evaluate how often this is the case and whether this is crucial for the goal of this study.

As a consequence we are dealing with a customized product where the specific design of a machine is dependent on parameters given by the customer. Thus the following basic parameters are usually requested by manufacturer when applying customer specific product design[49]:

- The required steam flow at the defined delivery point (e.g. connection point to the steam distribution system and/or end-user).
- The required pressure at the defined delivery point (e.g. connection point to the steam distribution system and/or end-user).
- The type of fuel which shall be used.
- Information about the anticipated operation behaviour: e.g. load curves or similar information (frequency of start-ups, average anticipated load, etc.)
- Minimum temperature of the flue gas after the economizer (when using that option).
- Etc. (e.g. wished additional equipment).

[49] Derived from an interview held with a sales-engineer from a steam-boiler manufacturer.

Under these circumstances some manufacturers do not publish product specific efficiency data public as they use sales tools to generate customer specific curves upon request[49].

4.4 Technical system approach

The technical system approach includes the whole system as shown in , especially the steam using system with the steam piping.

As studies indicate that there are significant energy efficiency potentials within steam systems apart from the generation system[50] (respectively the steam boiler itself) we conducted an analysis of energy efficiency potentials within steam systems based on the US Industrial Assessment Centres Database (IAC) (http://iac.rutgers.edu/).

The IAC organizes energy assessments in small and medium sized manufacturing firms and is funded by the U.S. Department of Energy (USDOE). During an assessment a team of students, led by a university professor, collects relevant site specific data and composes a report with recommendations. Afterwards all information is integrated in the database, which can be accessed by the interested public.

The database holds information on the implementation status, possible dollar and resource savings, implementation costs as well as on the assumed payback period, the standard industrial classification (SIC) of each firm and further firm specific details on e.g. sold products, annual sales and production hours. The implementation status can either be implemented, not implemented or pending.

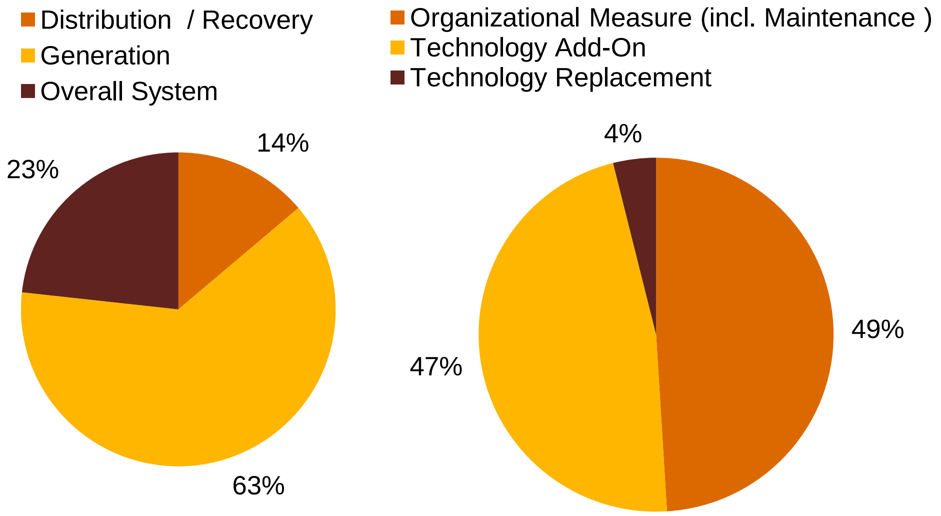
Assessments started in 1981 and up to now over 120,000 recommendations have been made during more than 16,000 assessments (Rutgers CAES, 2012). For our analysis about 9,000 recommendations are relevant, half of them being implemented and the other half not.

We have taken 43 different kinds of recommendation into account, assuming that all measures affecting boilers can be applied on steam boilers. To be able to sort measures according to the different product scopes, they are subdivided into two categories. The first category sorts measures according to the stage of the steam cycle in which they can be applied. The second defines the type of measure in a more detailed way according Fleiter et al. (2012)[51]. The subcategories and the corresponding measures can be found in Table 55. It should be noted that Recovery does not refer to waste heat recovery but to condensate recovery.

50 Therkelsen (2013) and Einstein (2001).

51 Fleiter, T.; Hirzel, S.; Worrell, E. (2012): The characteristics of energy-efficiency measures – a neglected dimension. Energy Policy, 51 (0), pp. 502-513.

Figure 42 - Distribution of recommendations by category (left) and by type for measure (n=9202)



According to Figure 42, 63% of all recommendations can be allocated in the subcategory generation, which is the most important category in matters of the preparatory study as it affects the strict product component scope. Another interesting fact is that 49% of all measures are organizational measures and therefore not relevant for our study as they cannot be changed by an improved product design.

The number of recommendations only for the sub-category "generation" is split as follows: 53% are organizational measures including maintenance, 41% are measures for technology add-on and 6% are measures for technology replacement.

Therefore only around 48% of all 5788 recommendations for the generation system are relevant for the study. This is an interesting fact since the process of steam generation can be optimized by simple measures as regular maintenance although the preparatory study might not be able to make a lot of recommendations for further improved product designs.

Although the results from the analysis are highly interesting the database has certain limits which we have to bear in mind. These limits are either due to the information of the database itself or due to the problems of transferability between US data and the European market.

The information included in the database does not give a holistic overview of possible measures because it focuses only on small and medium sized manufacturing firms that fulfil certain criteria. One important criterion is that the firms do not employ technical staff with the primary duty of energy analysis. Therefore they might be more inefficient than the ones employing technical staff.

We also assume that the measures recommended are in general measures with short payback periods because these measures are more likely to be implemented by companies. Different options, maybe even more efficient ones, might not be listed in the database. However the collected data helped us to gain a general understanding about common measures to increase efficiency.

Table 55 - Categorization of measures

Total (n=9202)	Organizational Measure (incl. Maintenance) (n=4511)	Technology Add-On (n=4333)	Technology replacement (n=358)
Generation (n=5788)	Keep Boiler Tubes Clean Move boiler to more efficient location Operate boilers on high fire setting Reduce excessive boiler blowdown Use minimum steam operating pressure Analyze Flue Gas for proper air/fuel ratio Establish Burner Maintenance Schedule for Boilers Repair Faulty Insulation in Furnaces, Boilers, etc.	Install Turbulator Direct warmest air to combustion intake Minimize boiler blowdown with better feed water treatment Use heat from boiler blowdown to preheat boiler feed water Flue Gas to Preheat Feed water Preheat combustion air with waste heat Waste heat from hot flue gases to preheat combustion air Install waste heat boiler to produce steam Use waste heat from hot flue gases to generate steam Substitute air for steam to atomize oil	Replace obsolete burners with more efficient ones Replace Boiler Install smaller Boiler
Distribution / Recovery (n=1273)	Repair/Replace Steam Trap Turn off steam tracing during mild weather Close off unneeded Steam Lines Use correct size steam traps Shut off steam traps on superheated steam lines not in use Increase amount of condensate returned Lower operating pressure of condenser (steam) Eliminate leaks in high pressure reduction stations	Install Steam Traps Install/Repair insulation on condensate lines Insulate feed water tank Install Deaerator in place of condensate tank Flash condensate to produce lower pressure steam Waste Process Heat to Preheat Makeup Water Use steam condensate for hot water supply (non-potable)	
Overall System (n=2141)	Repair Faulty Insulation Repair leaks in lines and valves Repair and eliminate steam leaks Reduce excess steam bleeding	Insulate Steam/Hot Water Lines Substitute hot process fluids for steam Use heat exchange fluids instead of steam in pipeline tracing systems	

4.5 System aspects of the use phase for ErPs with indirect impact

Indirect impacts occur when another energy system outside the scope of this study is being affected by the product within scope of this study. One popular example of such type of ErP in the building sector is a window. When the insulation of a window is being improved this can lead to a lower energy demand for room heating. Thus when the windows would be in scope (i.e. the ErP) the product in scope would have an indirect impact on the energy demand of the room heating system. We assume that effects of this kind are not relevant for steam boilers. However there is an increasing focus on the use of waste heat from the industry. One of the uses is district heating or other types of space heating. If the efficiency of a steam boiler is raised due to the sales of district heating, it will have an impact or indirect impact on the fuel demand of district heating plants.

4.6 End-of-life behaviour

BDH (2013) states that the medium time of operation is 25 years for industrial steam boiler within scope. Interviews with user of steam boiler indicate that industrial steam boilers are being maintained during regular overhauls at plant facilities. Although this might deviate among facilities we assume a maintenance interval of one year (i.e. the boilers are being maintained one time per year). Furthermore the interviews indicate that all steam boilers are being handed over to waste disposal companies after being discarded. A second hand market for boilers exists but it is really limited and therefore not included in this study.

Furthermore we expect that the major share of materials being fabricated to produce industrial steam boiler is steel. Thus the recycling fraction should be very high (above 90% of the materials being used referred to the overall weight).

4.7 Local infrastructure

Even though the local infrastructure might affect the operation of industrial steam boiler (e.g. the access to gas and water-lines, etc.) we do not think that it affects the actual environmental performance of the product.

4.8 Recommendations

Steam boilers are used in different branches for different applications. As though the product itself might seem comparable to domestic heating boilers, the large differences in application require a different approach for assessment.

As the applications are different, the requirements to the product of the boiler, the steam, vary strongly. The implemented systems therefore are quite heterogeneous in their design. Therefore the system approach leads to a broad variety of different design options.

The boilers themselves have nevertheless reached a rather high level of efficiency if they use an economizer and other design option such as advanced burner control, combustion pre-heater and blowdown heat recovery[52]. The design options will be discussed more in detail in Task 4.

Further improvements may be achieved better, when looking at the whole system instead of the single product. Furthermore, maintenance and sound operation haven been identified as important determinants of the product and system efficiency. Due to the variety in system designs, such an approach may be challenging for Ecodesign implementation. Using a (simpler) product approach helps to improve energy efficiency to a certain extent, but it excludes substantial parts of saving potentials.

Especially larger steam boilers are not an “of the shelf” product in a classical sense. They are always part of a larger system. The shipment of the “boiler” itself may also be quite different. For example, the feedwater pump is not always (but sometimes) delivered together with the boiler.

As steam boilers are normally subject to environmental legislation there might be an overlap with existing legislation. This has to be considered in the Ecodesign

52 USPA (2008): Climate Leaders Greenhouse Gas Inventory Protocol: Project Type: Industrial Boiler Efficiency, p.11.

process, as it may lead to multiple regulation of one technological feature. We will elaborate that point with an example in Task 7.

Task 4: Technologies

5 Task 4: Technologies

5.1 Objectives

Policy makers are often non-technical staff. To support them in their understanding of the processes involved in the functional performance of steam boilers, a brief and simple technological description of the products is prepared within this task. This technological analysis is conducted for technologies that are already on the market and that will become the basis for the Base Cases, but also for Best Available technologies and state-of-the-art Best Not Available Technologies both at product level and at component level and its improvement potential.

For the present study, it was decided that the base cases for the products are presented in Task 5 and not in Task 4, where the energy related product will be described from a technological aspect.

For the further assessment base cases for the EU 27 have to be defined in order to perform the economic and environmental assessment. They should represent the market as best as possible, nevertheless it is clear, that they represent an abstraction of reality.

5.2 Technical product description

The present section will include a technical description of the products under consideration, illustrated with data on performance, price, resources and emissions. It should cover:

- Existing products (working towards definition of Base Cases)
- Products with standard improvement (design) options
- Best available Technology BAT (best of products on the market)

"Best" shall mean most effective in achieving a high level of environmental performance of the product. "Available technology shall mean any technology developed on a scale, which allows implementation for the relevant product, under economically and technically viable conditions, taking into consideration the costs and benefits, whether or not the technology is used or produced inside the Member States in question or the EU-27, as long as they are reasonably accessible to the product manufacturer. Barriers for take-up of BAT should be assessed, such as cost factors or availability outside Europe.

Best Not yet Available Technology BNAT (best of products in field tests, labs, etc). "Not yet available technology shall mean that not developed yet on a scale which allows implementation for the relevant product but that is subject to research and development. Barriers for BNAT should be assessed, such as cost factors or research and development outside Europe.

Best available Technology (BAT) entails a technical analysis not of the current products on the market but on currently available technology, expected to be introduced at product level in the shorter term. Best Not yet Available Technologies (BNAT) summarise the state-of-the-art in research and development for a product, indicating market possibilities in the longer term. The analysis of the BAT and the BNAT provide an input for the identification of the improvement potential (task 6).

Since the determination of the BAT and BNAT products is very complex and needs substantial analysis, it will not be included in the present Task 4, but will be conducted later on. This is because it is impossible to determine in a simplistic and straightforward way the most efficient products by only considering the design options of the steam boilers. The market of steam boilers generally exhibits not sufficient standardisation for any conclusions and generalizations to be made about the categories of BAT and BNAT products. Most existing steam boilers are tailor-made and adapted to very specific requirements of the end use industry. This is one of the reasons that it is not possible to determine "base case" boilers corresponding to "average" or "typical" existing products. Furthermore, specific technical data are scarce and difficult to obtain mainly because of the confidentiality of steam boiler manufacturers.

The effects of the various efficiency improvement measures on the cost savings and environmental behaviour need to be properly quantified before any results can be drawn. This process will be undertaken in later tasks.

5.3 Basic Parts of an Industrial Steam Boiler

5.3.1 Steam generation system

Steam is generated in a boiler or a heat recovery steam generator by transferring the heat of combustion gases to water. When water absorbs enough heat, it changes phase from liquid to steam. In some boilers, a superheater further increases the energy content of the steam. Under pressure, the steam then flows from the boiler or steam generator and into the distribution system. The strict product scope of this Ecodesign study encompasses the steam generation system and more specifically the following components:

- Burners, boilers, superheaters, reheaters, air preheaters, steam air preheaters economizers
- Pressure parts
- Safety accessories
- Fuel preparation
- Expansion vessels/tanks

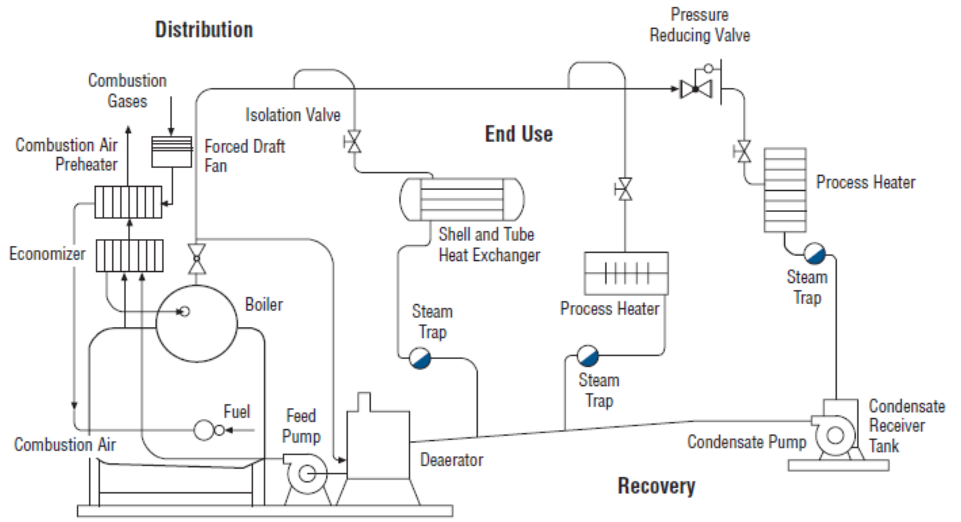
5.3.1.1 Steam distribution system

The distribution system carries steam from the boiler or generator to the points of end use. Many distribution systems have several take-off lines that operate at different pressures. These distribution lines are separated by various types of isolation valves, pressure regulating valves, and, sometimes, backpressure turbines. A properly performing distribution system delivers sufficient quantities of high quality steam at the right pressures and temperatures to the end uses. Effective distribution system performance requires proper steam pressure balance, good condensate drainage, adequate insulation, and effective pressure regulation.

5.3.1.2 Steam end use system

There are many different end uses of steam. Examples of steam's diverse uses include process heating, mechanical drive, moderation of chemical reactions, and fractionation of hydrocarbon components. Common steam system end-use equipment includes heat exchangers, turbines, fractionating towers, strippers, and chemical reaction vessels. In a heat exchanger, the steam transfers its latent heat to a process fluid. The steam is held in the heat exchanger by a steam trap until it condenses, at which point the trap passes the condensate into the condensate return system. In fractionating towers, steam facilitates the separation of various components of a process fluid. In stripping applications, the steam pulls contaminants out of a process fluid. Steam is also used as a source of water for certain chemical reactions. In steam methane reforming, steam is a source of hydrogen.

Figure 43 - Steam System Schematic



Source: "U.S. Department of Energy", Steam System Performance, a sourcebook for industry (2012)

5.3.1.3 Recovery system

The condensate return system sends the condensate back to the boiler. The condensate is returned to a collection tank. Sometimes the makeup water and chemicals are added here while other times this is done in the deaerator. From the collection tank the condensate is pumped to the deaerator, which strips oxygen and non-condensable gases. The boiler feed pumps increase the feedwater pressure to above boiler pressure and inject it into the boiler to complete the cycle.

Figure 43 provides a general schematic description of the four principal areas of a steam system.

5.3.2Steam Generation system

The generation part of a steam system uses a boiler to add energy to a feedwater supply to generate steam. The energy is released from the combustion of fossil fuels, process waste heat, or other sources of energy such as biomass, electricity etc.. The boiler provides a heat transfer surface (generally a set of tubes) between the combustion products and the water. The most important parts of the generating system include the boiler, the fuel supply, combustion air system, feedwater system, and exhaust gases venting system. These systems are related, since problems or changes in one generally affect the performance of the others.

5.3.2.1 Boilers

There are two basic types of boilers: fire tube (sometimes called "shell" boilers) and water tube boilers. The fundamental difference between these boiler types is which side of the boiler tubes contains the combustion gases or the boiler water/steam.

5.3.2.1.1 Firetube Boilers

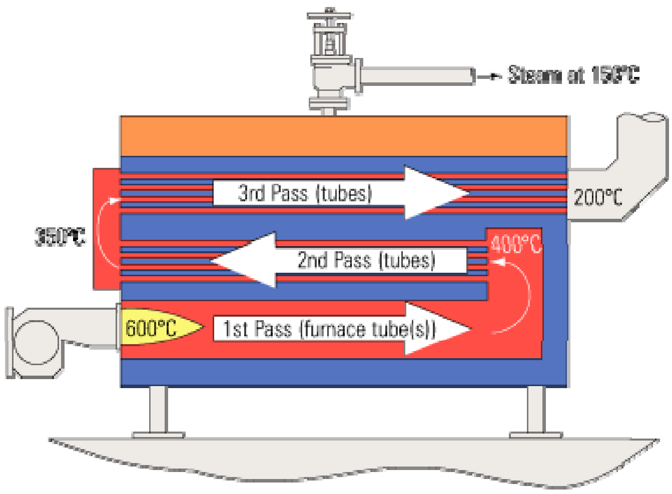
In fire tube boilers, the combustion gases pass inside boiler tubes, and heat is transferred to water on the shell side. A representative fire tube boiler is shown in Figure 44. Scotch marine boilers are the most common type of industrial fire tube boiler. The Scotch marine boiler is an industry workhorse due to low initial cost, and advantages in efficiency and durability. Scotch marine boilers are typically cylindrical shells with horizontal tubes configured such that the exhaust gases pass through these tubes, transferring energy to boiler water on the shell side. Scotch marine boilers contain relatively large amounts of water, which enables them to respond to load changes with relatively little change in pressure. However, since the boiler typically holds a large water mass, it requires more time to initiate steaming and more time to accommodate changes in steam pressure. Also, Scotch marine boilers generate steam on the shell side, which has a large surface area, limiting the amount of pressure they can generate. In general, Scotch marine boilers are not used where pressures above 300 psig are required.

Fire tube boilers are often characterized by their number of passes, referring to the number of times the combustion (or flue) gases flow the length of the pressure vessel as they transfer heat to the water. Each pass sends the flue gases through the tubes in the opposite direction. To make another pass, the gases turn 180 degrees and pass back through the shell. The turnaround zones can be either dryback or water-back. In dryback designs, the turnaround area is refractory-lined. In water-back designs, this turnaround zone is water-cooled, eliminating the need for the refractory lining.

Figure 44 - Firetube boiler

Source: U.S. Department of Energy, Steam System Performance, a sourcebook for industry (2012)

Figure 45 - Three-pass Firetube boiler schematic

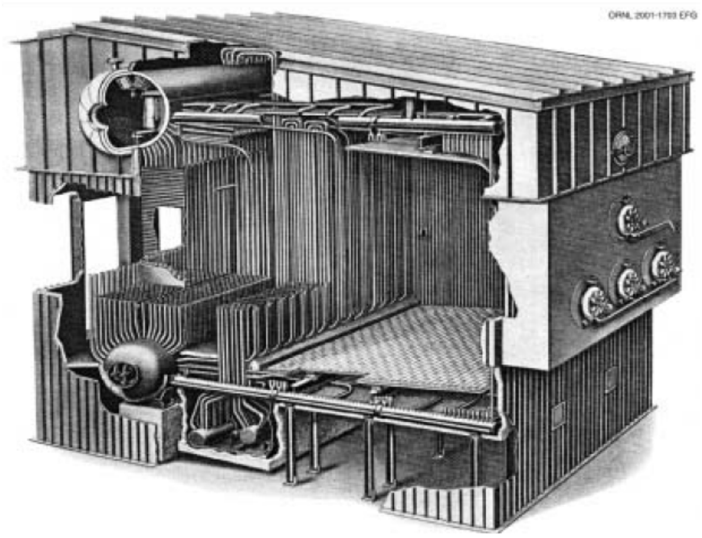


Source: [*http://www.spiraxsarco.com*](http://www.spiraxsarco.com)

5.3.2.1.2 Watertube Boilers

In watertube boilers, boiler water passes through the tubes while the exhaust gases remain in the shell side, passing over the tube surfaces. A representative watertube boiler is shown in Figure 46. Since tubes can typically withstand higher internal pressure than the large chamber shell in a fire tube, watertube boilers are used where high steam pressures (3,000 psi, sometimes higher) are required. Watertube boilers are also capable of high efficiencies and can generate saturated or superheated steam. In fact, the ability of watertube boilers to generate superheated steam makes these boilers particularly attractive in applications that require dry, high-pressure, high-energy steam, including steam turbine power generation. The performance characteristics of watertube boilers make them frequently used in process industries, including chemical manufacturing, pulp and paper manufacturing, and refining. Although fire tube boilers account for the majority of boiler sales in terms of units, watertube boilers account for the majority of boiler capacity.

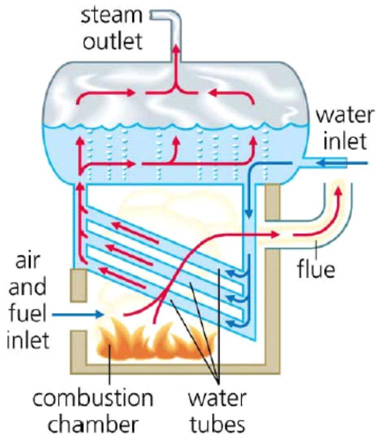
Figure 46 - Water tube boiler



Source: U.S. Department of Energy, Steam System Performance, a sourcebook for industry (2012)

Watertube boilers (Figure 46 and Figure 48) are divided in two categories, depending on the way that the circulation of the water-steam is achieved in the system. In natural circulation boilers, the pressure difference required for the movement of the medium is due to only the density (and weight) difference between water and steam. These boilers have usually lower capacities. In forced circulation boilers, extra pumps are installed that help increase the circulation rate and provide additional pressure difference. Forced circulation boilers are often encountered in cases where there is demand for high pressure steam.

Figure 47 - Water tube boiler schematic



Source: Thermal Energy Equipment: Boilers & Thermic Fluid Heaters",RETScreen

5.3.2.1.3 Packaged Boilers

It is common for industrial-use boilers to be manufactured, traded and sold as a complete package, rather than being constructed on demand from scratch. Once delivered to a site, a packaged boiler (Figure 48) requires the steam, water pipe, fuel supply and electrical connections to be made to become operational. These boilers are generally of a shell type with a fire tube design in order to achieve high heat transfer rates by both radiation and convection. Their main features are:

- Small combustion space and high heat release rate resulting in faster evaporation rates
- Large number of small diameter tubes leading to good convective heat transfer conditions
- Forced or induced draft systems resulting in good combustion efficiency
- A high number of flue gas passes (2 or more) resulting in ameliorated overall heat transfer efficiency

Figure 48 - Packaged steam boiler by BOSCHTM

Source: www.bosch-industrial.com

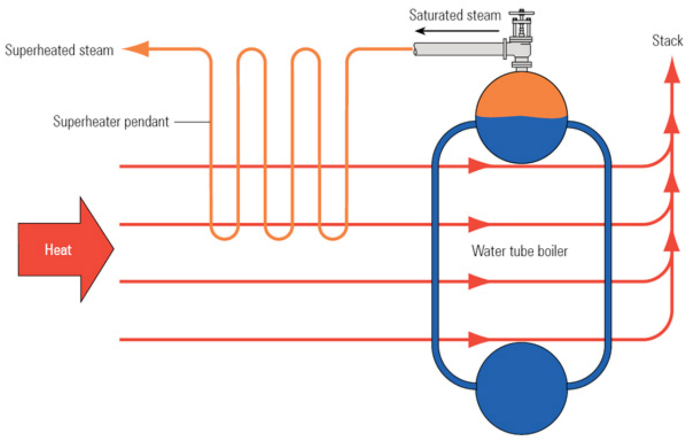
Owing to the above characteristics, packaged boilers usually exhibit high thermal efficiency levels that can exceed 90%. The most common boiler of this class is a three-pass unit with two sets of fire tubes and with the exhaust gases exiting through the rear of the boiler.

5.3.2.2 Superheaters

Superheaters (Figure 47) add additional energy to steam, resulting in a steam temperature that exceeds the saturation temperature at a specific pressure, under which the saturated steam exits the boiler. Because steam that is formed above the water surface in a shell boiler is always saturated it cannot become superheated as it is constantly in contact with the water surface. For this reason, superheaters must provide a separate, distinct heat exchange area from that of the steam boiler.

Superheaters can be convective or radiant, depending on the heat transfer method that they make use of. Radiative superheaters rely on the energy transferred directly from the combustion flame to increase the energy level of the steam while convective superheaters rely on the transfer of additional energy from the flue gases to the steam.

Figure 49 - Schematic of boiler with superheater



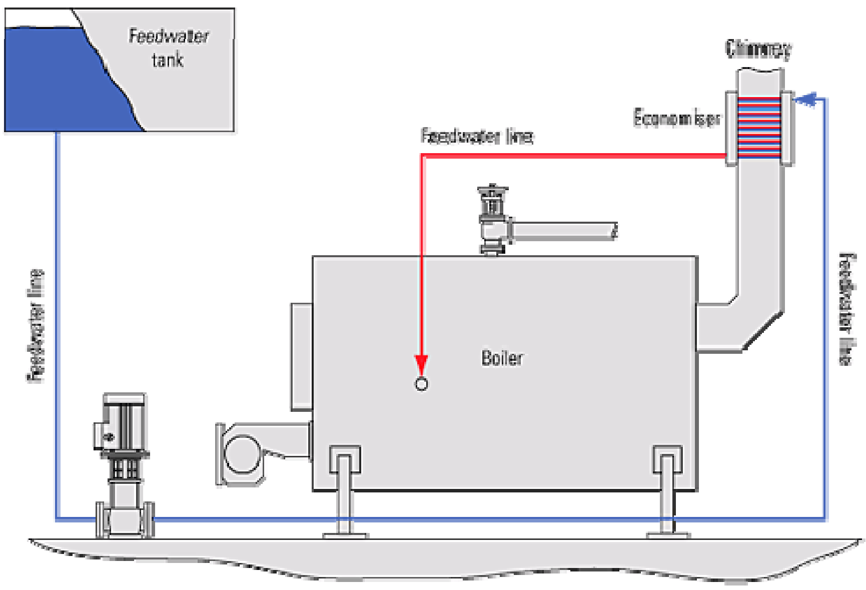
Source: http://www.spiraxsarco.com

5.3.2.3 Economizers

In many boilers, the flue gases still have useful amounts of energy even after they have passed through the boiler since their temperature is typically in the range of 200 to 300 °C. In many of these applications, economizers (Figure 50) provide effective methods of increasing boiler efficiency by transferring the heat of the flue gases to incoming feedwater. There are two principal types of economizers: non-condensing and condensing. Non-condensing economizers are usually air-to-water heat exchangers. Since these economizers are not designed to handle flue gas condensation, non-condensing economizers must be operated at temperatures that are reasonably above the dew points of the flue gas components. The dew point of the flue gases depends largely on the amount of water in the gas, which, in turn, is related to the amount of hydrogen in the fuel. For example, to avoid condensation in the exhaust gases produced by combusting natural gas, the exhaust gas temperature should typically be kept above 50-60°C. However, in sulphur-containing fuels in order to prevent sulphur oxide condensation in the flue gases, their temperature is kept at a minimum of 200°C. Condensing economizers are designed to allow condensation of the exhaust gas components. Due to latent heat recovery, these economizers typically extract more energy than do non-condensing economizers. Often, special materials are required.

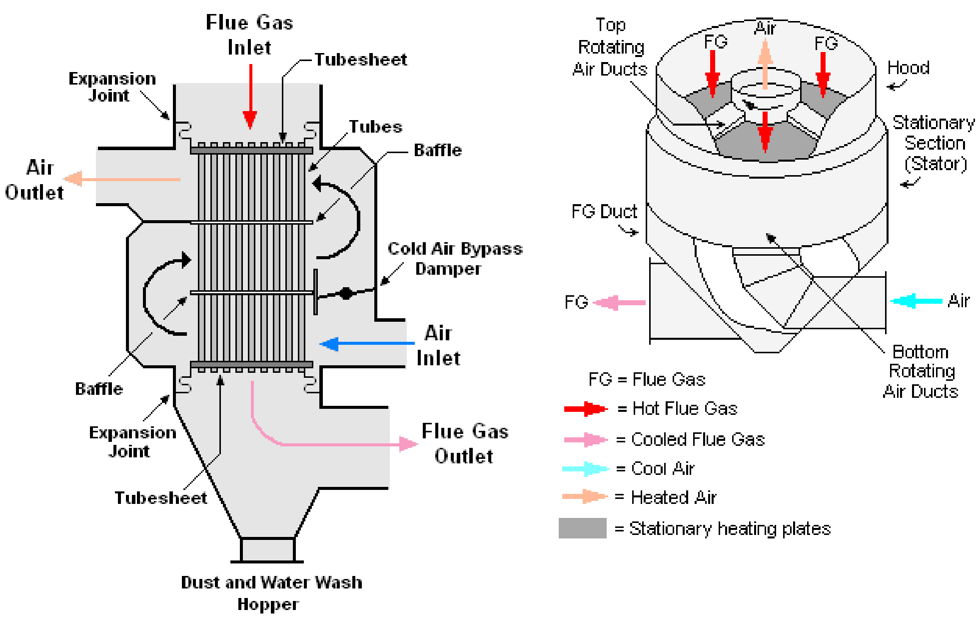
The potential of energy savings by the installation of an economizer depends on the type of the boiler and the fuel used. For a typical old shell boiler with a flue gas exit temperature of 260°C, an economizer could be used to reduce it to 200°C, increasing the feed water It is estimated that for a modern 3-pass shell boiler firing natural gas with a flue gas exit temperature of 140°C, a condensing economizer would reduce the exit temperature to 65°C, thus increasing the thermal efficiency by 5%.

Figure 50 - Boiler system with economizer to utilize the energy content of the flue gases



Source: http://www.spiraxsarco.com

Figure 51 - Tubular and regenerative air preheaters



Source: *http://en.citizendium.org*

5.3.2.4 Combustion Air Preheaters

Combustion air preheaters (Figure 51) are similar to economizers in that they transfer energy from the flue gases back into the system. In these devices, however, the energy is transferred to the incoming combustion air. The efficiency benefit is roughly 1 percent for every 22°C decrease in the flue gas temperature.

5.3.2.5 Boiler Insulation

The walls and combustion regions of boilers are typically lined with insulating materials to reduce energy loss and to prevent leakage. There are several types of boiler insulating materials, including brick, refractory, insulation and lagging. The selection and design of boiler insulating materials depend largely on the age and design of the boiler. Since the insulating lining is exposed to high temperatures and is subject to degradation, it should be periodically inspected and repaired when necessary.

The insulation of the steam boiler is distinguished in two categories: the internal (inside the furnace) which is refractory and the external. The purpose of the external insulation is to reduce the heat losses and at the same time offer protection against burns for the people working near the steam boiler.

5.3.2.6 Boiler Control System

Boiler control systems are designed to protect the boiler and to ensure proper boiler operation. These systems include the combustion control system, flame safeguard, water level control, and fuel control.

5.3.2.6.1 Combustion Control System

The combustion control system regulates the fuel air mixture to achieve safe and efficient combustion and maintains steam system pressure. Control systems have varying levels of sophistication. Simple systems use a fixed linkage between the fuel-regulating valve and the combustion air damper. This is called single point positioning. A change in steam pressure makes a proportional change in the combustion air and fuel. Advanced systems rely on signals from transmitters to determine independent fuel valve and air damper positions. This is called a full monitoring system.

5.3.2.6.2 Burner Flame Safeguard System

A flame safeguard system is an arrangement of flame detection systems, interlocks, and relays which will sense the presence of a proper flame in a furnace and cause fuel to be shut off if a hazardous condition develops. Modern combustion systems are closely interlocked with flame safeguard systems and also pressure-limit switches, low-water level cutoffs, and other safety controls that will stop the energy input to a boiler when an unsafe condition develops. The flame safeguard system senses the presence of a good flame or proper combustion and programs the operation of a burner system so that motors, blowers, ignition, and fuel valves are energized only when they are needed and then in proper sequence.

5.3.2.6.3 Safety Shutoff Valve

Safety shutoff valves isolate the fuel supply to the boiler in response to certain conditions such as low or high gas pressure or satisfied load demand. The type of safety shutoff valves and the settings are often determined by code or insurance requirements.

5.3.2.6.4 Water Level Control

The boiler water level control system ensures a safe water level in the boiler. Typically, the control system provides a signal to the feedwater control valve to regulate the feed rate. Simple water level control systems that only sense water level are single element systems. More complex systems incorporate additional data such as steam flow rate (dual element system) and feedwater flow (triple element system) and will provide better water level control during abrupt load changes.

5.3.2.6.5 Safety Valve

The safety valve is the most important valve on the boiler and keeps the boiler from exceeding its maximum allowable working pressure (MAWP).

5.3.2.6.6 Steam Pressure Control

Steam pressure controls (Figure 52) regulate the combustion equipment to maintain a constant pressure in the steam header. As the pressure rises above or falls below the pressure setting, the control adjusts the burner firing rate to bring the pressure back to the setpoint.

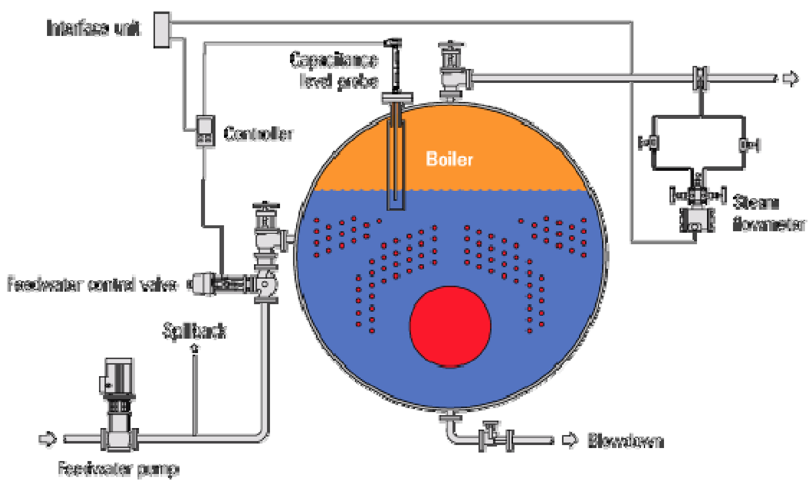
5.3.2.6.7 Nonreturn Valve

The non-return valve is a combination shutoff and check valve that allows steam out of the boiler, but prevents backflow from the steam header in the event the boiler pressure drops below that of the header. The valve is opened only when the pressure inside the boiler rises slightly above the steam header pressure.

5.3.2.6.8 Steam Flow Meter

Steam flow meters are helpful in evaluating the performance of the system and can provide useful data in assessing boiler performance, calculating boiler efficiency, and tracking the amount of steam required by the system. In some systems, steam flow meters provide a measurement signal for the boiler control system. Additionally, steam flow meters can be useful in benchmarking efforts. There are three basic types of steam flowmeters: differential pressure (DP), vortex, and Coriolis. Differential pressure flowmeters rely on the change in pressure as steam flows by an element such as a nozzle, orifice, or venturi. This pressure difference provides an indication of flow velocity, which, in turn, can be used to determine the flow rate. Vortex flowmeters rely on the principal that flow past an element creates vortices that have frequencies that correspond to the flow velocity. Coriolis flowmeters rely on tubes placed in the steam flow path that twist according to the velocity of the flow.

Figure 52 - Schematic overview of steam boiler control systems



Source: http://www.spiraxsarco.com

Boiler Feedwater System

The boiler feedwater system supplies water to the boiler. Its main purpose is to regulate the water flowrate to the boiler in order to meet the steam demand. Furthermore, it involves a series of components that are used for pretreating the water to make sure that its properties are suitable for the safe, efficient and unproblematic operation of the boiler system. Sources of feedwater include returning condensate and makeup water. Feedwater is typically stored in a collecting tank to ensure that a steady supply of heated water is available to the boiler.

5.3.2.6.9 Feedwater Flow Control Valve

A modulating feedwater flow control valve moves up or down in response to the water level transmitter(s). On smaller fire tube boilers, it is not uncommon for the feedwater valve to operate in a closed or open position, depending on the water level transmitter signal.

5.3.2.6.10 Softener

Softeners remove hardness minerals, such as calcium, magnesium, and iron, from a water supply. The presence of hardness in boiler water leads to many problems, including scale buildup and foaming, which reduce boiler efficiency and can cause tube failure. Softeners reduce this problem through an ion exchange process. As the hard water passes through a chamber filled with resin, an exchange occurs that removes hardness minerals from the water. The sodium that replaces the hardness minerals has a higher solubility in water and generally will not form scale.

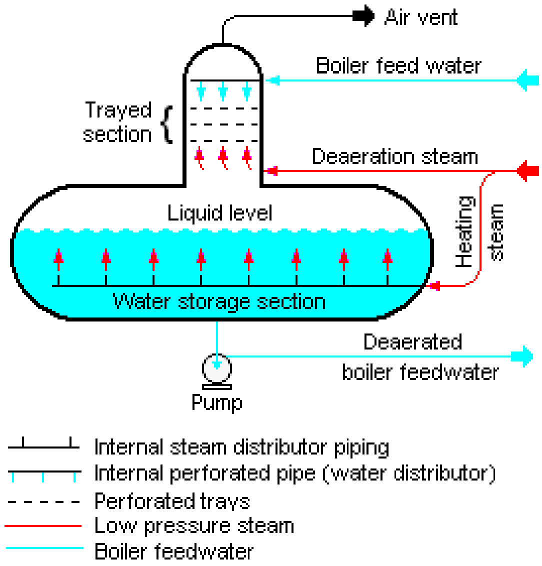
5.3.2.6.11 Pre-treatment Equipment

Pre-treatment equipment improves the quality of the incoming water so that it may be used in the boiler without excessive scaling or foaming, which can reduce boiler efficiency and cause tube failure. Pre-treatment equipment includes, but is not limited to, clarifiers, filters, softeners, dealkalizers, decarbonators, reverse osmosis (RO) units, and demineralizers.

5.3.2.6.12 Deaerator, Deaerating Heater, and Atmospheric Deaerator

The presence of oxygen in the boiler system can be a significant problem due to its corrosivity at high temperatures. Deaerators (Figure 53) and deaerating heaters use heat, typically steam, to reduce the oxygen content in water. Deaerators and deaerating heaters are typically pressurized tanks that raise the water temperature to the point of saturation. They also break the incoming water into either fine droplets or thin sheets to facilitate the removal of oxygen and other noncondensible gases. Depending on the design, the feedwater oxygen content can be reduced to levels ranging from 7 to 40 parts per billion (ppb). Atmospheric deaerators are typically found in smaller, lower-pressure boiler systems. They operate at atmospheric pressure, so the maximum operating temperature is 100°C. Most will operate at temperatures lower than this. Atmospheric deaerators cannot achieve the same level of oxygen removal as deaerators and deaerating heaters, typically providing water with oxygen levels of 0.5 to 1 parts per million (ppm). In applications that require lower oxygen levels than achievable with a deaerator, deaerating heater, or open feedwater heater, a chemical agent, known as an oxygen scavenger, can be used to remove more oxygen. In most systems, an oxygen scavenger is part of the system's water treatment program.

Figure 53 - Boiler feedwater deaerator



Source: www.wikipedia.org

5.3.2.6.13 Feedwater Pump

Feedwater pumps transfer water from the deaerator to the boiler. Feedwater pumps are driven by electric motors or by steam turbines. In a modulating feedwater system, the feedwater pumps run constantly as opposed to an on-off operation in relatively small boilers.

5.3.2.6.14 Collecting/Storage Tank

The return of condensate is often erratic due to changing steam requirements by the end uses. The condensate is usually returned to a condensate receiver or directly to the deaerator if the system does not have a receiver. Pre-treated water may also be stored in a tank prior to use. This provides the boiler system with additional water capacity in case the pre-treatment equipment malfunctions. The condensate and pre-treated water, or makeup, are transferred from the storage tanks to the deaerator prior to being sent to the boiler.

5.3.2.7 Boiler Combustion Air System

The combustion air system supplies the oxygen necessary for the combustion reaction. To provide enough air for the amount of fuel used in industrial boilers, fans are typically required. Dampers, inlet valves, or variable speed drives typically control the amount of air allowed into the boiler.

5.3.2.7.1 Forced Draft Fan

A forced draft fan is located at the inlet of a boiler and pushes ambient air into the burner region, ensuring that adequate air is delivered to the combustion process. These fans either pull air directly from the boiler room or connect to a duct system that allows outside air to be drawn into the boiler.

5.3.2.7.2 Induced Draft Fan

Induced draft fans (Figure 54) are located on the outlet gas side of the boiler and pull flue gases out. The induced draft fan creates a slightly negative furnace pressure that is controlled by outlet dampers on the boiler. In some systems where a bag house, mechanical collector, or precipitator is involved, special considerations should be given in sizing and selection of this fan.

Figure 54 - Picture of a draft fan used in industrial steam boilers

Source: www.alibaba.com

5.3.2.7.3 Damper

Dampers control the amount of air allowed into and out of a combustion chamber. Dampers, in combination with fuel regulating devices, are positioned by the combustion control system to achieve certain fuel/air ratios. Dampers on the boiler outlet are used to regulate the negative furnace draft

5.3.2.8 Boiler Fuel System

The fuel system includes all equipment used to provide fuel to generate the necessary heat. The equipment required in the fuel system depends on the type of fuel used in the system. There are many different types of fuels used in boilers, requiring several different types of fuel handling systems. Fossil fuels such as coal, oil, and gas are most commonly used. Others fuels are used in many industries, particularly the forest products, petroleum refining, and chemical manufacturing industries where there is an available supply of by-products such as bark, wood chips, black liquor, and refinery gas.

5.3.2.8.1 Fuel Regulating Valve

In gaseous and liquid fuels, regulating valves control the fuel delivered to the boiler. In many systems these valves can be quickly shut in response to an operating problem.

5.3.2.8.2 Fuel

The fuel types that are commonly used in boilers include natural gas, coal, propane, fuel oils, and waste fuels (for example, black liquor, bark, and refinery gas). Fuel type significantly affects boiler operation, including efficiency, emissions, and operating cost. Natural gas accounts for about 36 percent of the total U.S. industry boiler capacity. Coal accounts for about 14 percent of the boiler capacity. Fuel oils account for about 21 percent. Other fuels, which include waste fuels, account for about 29 percent of the boiler capacity.

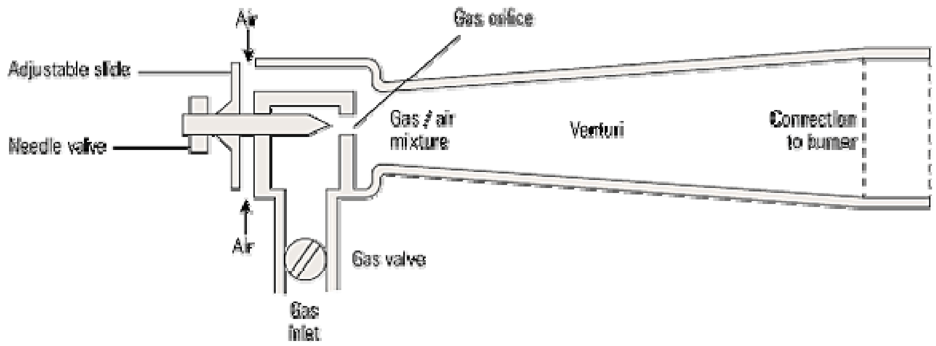
5.3.2.8.3 Fuel Flow Meter

Fuel meters measure the amount of fuel delivered to a boiler. Fuel meters provide essential data in determining boiler efficiency. Since fuel flow meters measure volume or mass of fuel, it is important to know the energy content of the fuel when determining boiler efficiency.

5.3.2.8.4 Burner

Burners combine the fuel and air to initiate combustion. There are many different types of burners due to the many different types of fuels. Additionally, burners have different performance characteristics and control requirements. Some burners are on/off while others allow precise setting of the fuel/air mixture over a range of conditions. Some burners can fire different types of fuel, allowing boiler operation to continue despite the loss of one fuel supply.

Figure 55 - Depiction of a gas burner used in steam boilers



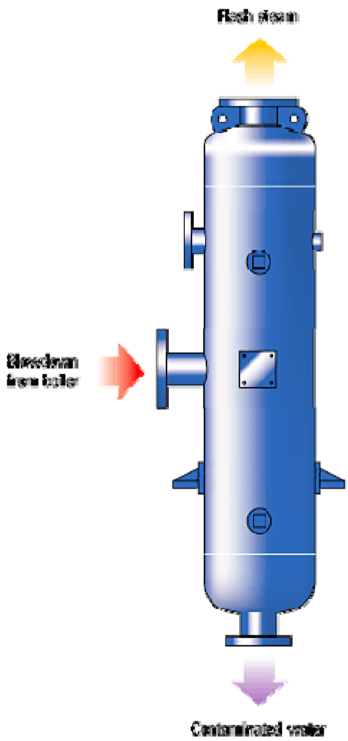
Source: www.spiraxsarco.com

5.3.2.9 Boiler Blowdown System

The boiler blowdown system includes the valves and the controls for the continuous blowdown and bottom blowdown services. Continuous blowdown removes a specific amount of boiler water (often measured in terms of percentage of feedwater flow) in order to maintain a desired level of total dissolved solids in the boiler. Setting the flow for the continuous blowdown is typically done in conjunction with the water treatment program. Some continuous blowdown systems rely on the input of sensors that detect the level of dissolved solids in the boiler water. The bottom blowdown is performed to remove particulates and sludge from the bottom of the boiler. Bottom blow downs are periodic and are typically performed a certain number of times per shift or according to a set schedule. In some systems, bottom blow downs are controlled by an automatic timer.

The continuous blowdown water has the same temperature and pressure as the boiler water. Before this high energy water is discharged into the environment, it is often sent to a heat exchanger and flash tank. Flash tanks permit the recovery of low-pressure flash steam, which can be used in Deaerating or process heating. They also permit the use of a smaller heat exchanger than would be required without the flash tank. Blowdown heat exchangers are most often used to preheat boiler makeup water.

Figure 56 - Flash vessel used to separate the blowdown stream of the steam boiler



Source: www.spiraxsarco.com

5.3.3 Distribution system

The distribution system transports steam from the boiler to the various end uses. Although distribution systems may appear to be passive, in reality, these systems regulate the delivery of steam and respond to changing temperature and pressure requirements. Consequently, proper performance of the distribution system requires careful design practices and effective maintenance. The piping should be properly sized, supported, insulated, and configured with adequate flexibility. Pressure regulating devices such as pressure reducing valves and backpressure turbines should be configured to provide proper steam balance among the different steam headers. Additionally, the distribution system should be configured to allow adequate condensate drainage, which requires adequate drip leg capacity and proper steam trap selection. Steam distribution systems can be broken down into three different categories: buried pipe, above-ground, and building sections, and selection of distribution components (piping, insulation, etc.) can vary depending on the category.

5.3.3.1 Piping

Steam piping transports steam from the boiler to the end-use services. Important characteristics of well-designed steam system piping are that it is adequately sized, configured, and supported. Installation of larger pipe diameters may be more expensive, but can create less pressure drop for a given flow rate. Additionally, larger pipe diameters help to reduce the noise associated with steam flow. As such, consideration should be given to the type of environment in which the steam piping will be located when selecting the pipe diameter.

Important configuration issues are flexibility and drainage. With respect to flexibility, piping, especially at equipment connections, needs to accommodate thermal reactions during system start-ups and shutdowns. Additionally, piping should be equipped with a sufficient number of appropriately sized drip legs to promote effective condensate drainage. Additionally, the piping should be pitched properly to promote the drainage of condensate to these drip lines. Typically these drainage points experience two very different operating conditions: normal operation and start up; both load conditions should be considered in the initial design.

5.3.3.2 Insulation

Thermal insulation provides important safety, energy savings, and performance benefits. In terms of safety, insulation reduces the outer surface temperature of the steam piping, which lessens the risk of burns. A well-insulated system also reduces heat loss to ambient workspaces, which can make the work environment more comfortable. Consequently, the energy saving benefits include reduced energy losses from the steam system and reduced burden on the cooling systems that remove heat from workspaces. In addition to its safety and energy benefits, insulation increases the amount of steam energy available for end uses by decreasing the amount of heat lost from the distribution system. Important insulation properties include thermal conductivity, strength, abrasion resistance, workability, and resistance to water absorption. Thermal conductivity is the measure of heat transfer per unit thickness. Thermal conductivity of insulation varies with temperature; consequently, it is important to know the right temperature range when selecting insulation. Strength is the measure of the insulation's ability to maintain its integrity under mechanical loads. Abrasion resistance is the ability to withstand shearing forces. Workability is a measure of the ease with which the insulation is installed. Water absorption refers to the tendency of the insulation to hold moisture. Insulation blankets (fiberglass and fabric) are commonly used on steam distribution components (valves, expansion joints, turbines, etc.) to enable easy removal and replacement for maintenance tasks. Some common insulating materials used in steam systems include calcium silicate, mineral fiber, fiberglass, perlite, and cellular glass.

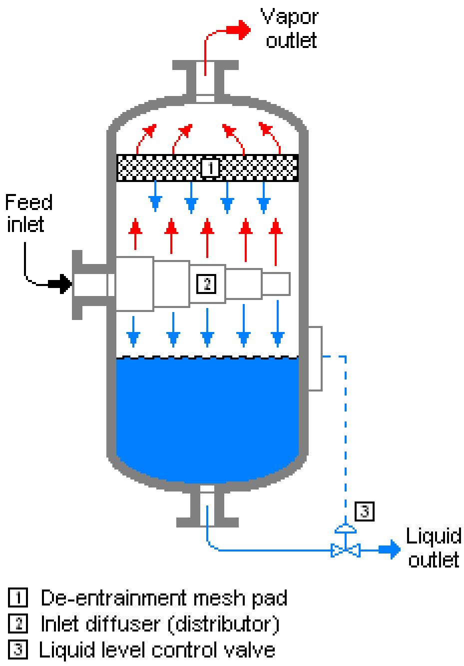
5.3.3.3 Valves

In steam systems, the principal functions of valves are to isolate equipment or system branches, to regulate steam flow, and to prevent overpressurization. The principal types of valves used in steam systems include gate, globe, swing check, pressure reducing, and pressure relief valves. Gate, globe, and swing check valves typically isolate steam from a system branch or a component. Pressure reducing valves (PRV) typically maintain certain downstream steam pressure conditions by controlling the amount of steam that is passed. These reducing valves are often controlled by transmitters that monitor downstream conditions. Pressure relief valves release steam to prevent overpressurization of a system header or equipment.

5.3.3.4 Steam Separators

In some steam systems, wet steam is generated. This wet steam contains water droplets that can reduce the effectiveness of the steam system. Water droplets erode turbine blades and passages reducing efficiency and life. Water droplets also tend to erode pressure reducing valves. Furthermore, liquid water can significantly reduce heat transfer rates in heat exchange components as well as result in water hammer. Removing water droplets before they reach end-use equipment is necessary. Steam separators (Figure 57) remove water droplets, generally relying on controlled centrifugal flow. This action forces the entrained moisture to the outer wall where it is removed from the separator. The means of moisture removal could be a steam trap or a drain. Some manufacturers include the trap as an integral part of the unit. Additional accessories include water gage connections, thermometer connections, and vent connections. Steam separators can be installed in either a horizontal or vertical line. They are capable of removing 99% of particulate entrainment 10 microns and larger over a wide range of flows.

Figure 57 - Schematic of steam separator

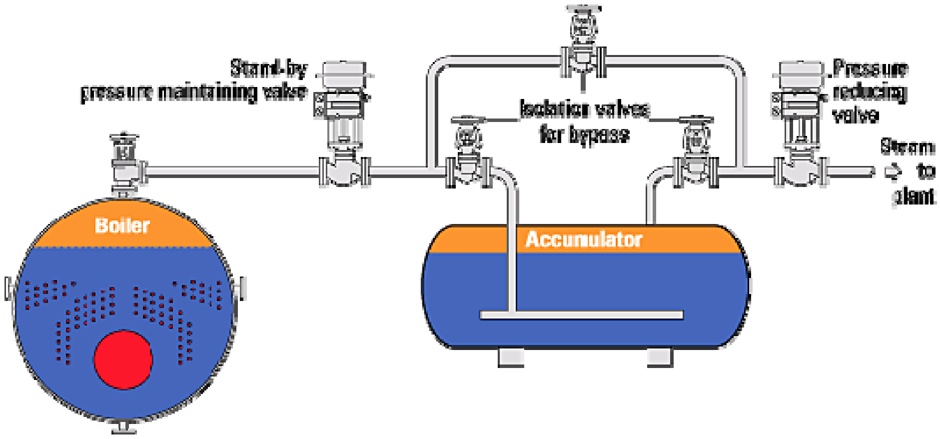


Source: www.wikipedia.org

5.3.3.5 Steam Accumulators

A steam accumulator (Figure 58) is a large insulated pressure vessel, partially filled with hot water (saturated liquid). When steam supply exceeds demand, the excess high-pressure steam is charged into the accumulator through special charging nozzles. The steam is condensed, giving up its latent heat, to raise the pressure, temperature, and heat content of the water body. When the steam demand exceeds the supply, the pressure in the accumulator drops and the additional required steam flashes from the water, taking back the heat previously stored. A simple system of control valves and check valves regulates the charging and discharging. The excess steam is charged quietly and smoothly, and when steam is needed, it is available with the speed of a control valve operation. There is also an accumulator design that stores hot water for use as boiler feedwater.

Figure 58 - Schematic of steam accumulator



Source: www.wikipedia.org

5.3.3.6 Steam Traps

Steam traps are essential for proper distribution system performance. During system startups, traps allow air and large quantities of condensate to escape. During system operation, the traps allow collected condensate to pass into the condensate return system, while minimizing the accompanying loss of steam. There are three primary types of traps: thermostatic, mechanical, and thermodynamic.

5.3.3.7 Steam Meters

The use of flowmeters within the distribution system can provide important data for monitoring the efficiency of a process or an end use. Tracking the amount of steam required can be particularly useful in benchmarking efforts.

5.3.4 Steam end use system

Steam system end-use equipment transfers steam energy into other forms of useful energy. Common end-use equipment includes heat exchange devices to transfer thermal energy and turbines to recover mechanical energy. In manufacturing industries, steam end uses often directly support production, making their performance and reliability essential to plant productivity. Improvements in end-use efficiency and effectiveness also tend to result in better performance and increased reliability. There is a wide range of end-use equipment, largely due to the advantages of steam. Steam end-use equipment is grouped into three basic categories:

- Industries of the Future (IOF) key end-use equipment;
- Conditioning and control equipment; and
- Additional equipment.

The key IOF equipment category includes the largest uses of steam in those industries. Although IOF facilities use steam for other services as well, the key end uses account for the largest amount of steam use. The conditioning equipment category includes equipment that facilitates the effective use of steam. The additional equipment category includes equipment that is used in other industries and, though significant, does not account for most of the steam use in IOF industries.

In the three IOF industries of forest products, petroleum refining, and chemicals, steam accounts for the largest amount of end-use energy. In another IOF industry, steel production, steam represents a significant amount of end-use energy and is used to generate most of that industry's on-site electric power.

5.3.4.1 Condensers

In steam applications, condensers are associated with condensing steam turbines and with multiple stage ejector systems. In steam turbine applications, condensers typically operate under a vacuum.

They remove energy from the exhaust steam allowing it to be recovered as condensate. In steam ejector applications, condensers increase the effectiveness of the ejectors by condensing both the motive steam and condensables pulled from the process, reducing the amount of motive steam required. Condensers can be surface type or barometric. Surface condensers are supplied with cooling water that circulates through condenser tubes providing a cool surface area that causes steam condensation. The condensate is typically collected in a condensate well, and pumped into the condensate return system. Barometric condensers rely on direct contact between the cooling water and the steam. In petroleum refining and chemical manufacturing applications, condensers are also used to condense components from gaseous mixtures. In these applications, the condensers use a cooling medium to extract energy from the gases and collect the condensed components.

5.3.4.2 Distillation Towers

The petroleum refining and chemical manufacturing industries use large amounts of steam to facilitate the separation of crude oil or chemical feedstocks into various components. This separation process relies on differences in the boiling points of these hydrocarbon components. Fractionating towers use a furnace to heat crude oil above 700°F. As the volatile components boil off and rise up the tower, they cool and condense on trays. Steam is injected into the bottom of these towers to reduce the partial pressures of the hydrocarbons, which facilitates their separation, and to reduce coke formation on tray and tower surfaces.

5.3.4.3 Dryers

Dryers reduce the water content of a solid. Dryers account for the largest end use of steam in the pulp and paper industry12. The chemical manufacturing, textiles, and food processing industries also use large amounts of steam for drying. Dryers can be indirect or direct. Indirect dryers remove moisture thermally as energy is transferred from condensing steam, flue gases, or high temperature process fluid to the product being dried. Common indirect dryer types are coil and rotating drum. Direct dryers use hot gases that have been heated with steam or flue gases to directly contact and dry a product. Dryers, like evaporators, can be arranged in multiple stage configurations. Multiple-stage steam dryers use a cascading set of steam pressures, allowing steam released from an upstream stage to supply steam to the next stage. In many multiple-stage dryers, thermocompressors are used to increase the steam pressure of downstream-effect stages.

5.3.4.4 Evaporators

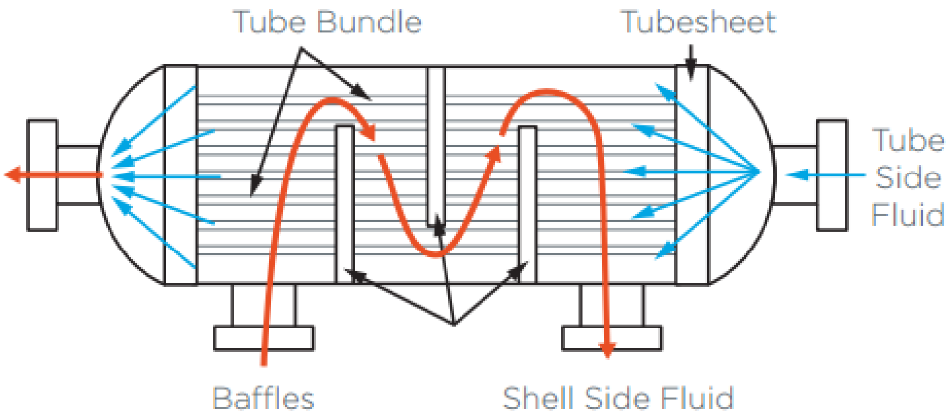
Evaporators reduce the water content of a liquid, generally by heating it with steam in order to concentrate the product. Evaporators are used extensively in industries such as food processing, chemical manufacturing, steel, forest products, and textiles. In most cases, evaporators are shell and tube heat exchangers with the steam on the shell side and the product being concentrated in the tubes. Evaporators can be single effect or multiple effect. A single effect evaporator uses steam at one set of pressure and temperature conditions to boil off the vapor from a product. Multiple-effect evaporators take the vapor produced from one evaporator and use it to heat the product in a lower-pressure evaporator. Multiple-effect evaporators are generally more efficient at concentrating a fluid than single-effect evaporators.

5.3.4.5 Heat Exchangers

Heat exchangers transfer thermal energy from one fluid to another. In manufacturing facilities, steam is a common source of heat for many reasons, some of which are discussed in the Introduction. There is a wide range of heat exchanger designs that use steam, largely due to the wide range of products that are heated with steam. Many process and product considerations must be incorporated into the selection of a heat exchanger. Some basic heat exchanger types are discussed below, including:

- Tubular;
- Plate and frame;
- Jacketed; and
- Coil.

Figure 59 - Shell and Tube Heat Exchanger



Source: U.S. Department of Energy, Steam System Perfomance, a sourcebook for industry (2012)

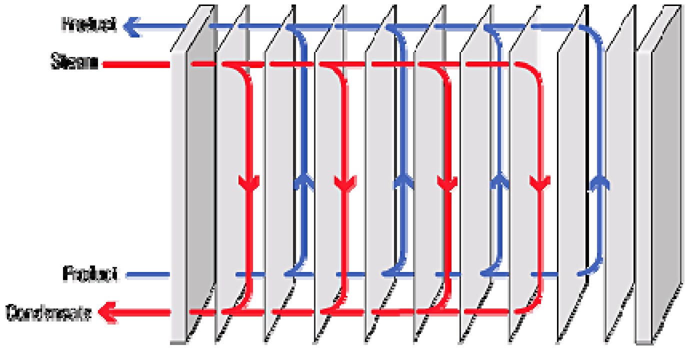
5.3.4.5.1 Tubular Heat Exchanger

Tubular heat exchangers are tube bundles that are surrounded by the heated or heating medium. This type of heat exchanger includes finned tube and shell and tube designs as shown in Figure 59. Finned tube heat exchangers are often used to heat air for drying and space heating applications. Shell and tube heat exchangers are often used for liquid heating and evaporation. Since the tube side of shell and tube heat exchangers can be designed to withstand high pressures, sometimes exceeding 1,500 psig, heat exchangers of this type are often used in high temperature and high-pressure applications.

5.3.4.5.2 Plate and Frame Heat Exchanger

In plate and frame heat exchangers, the two heat exchange fluids are separated by plates. The plates are corrugated, or ridged, as shown in Figure 60, to increase the surface area available for heat transfer. Plate and frame heat exchangers are often used in low viscosity applications, where the risk of clogging is less severe. The plate ends are typically sealed by casketed covers that can be removed to allow disassembly and cleaning. This heat exchanger type is used when temperatures and pressures are moderately low, typically below 150°C and 370 psi. Plate and frame heat exchangers also have a common design variation that has the plates welded or brazed together. This allows higher temperature service but eliminates the possibility of mechanical cleaning.

Figure 60 - Plate and frame heat exchanger



Source: www. spiraxsarco.com

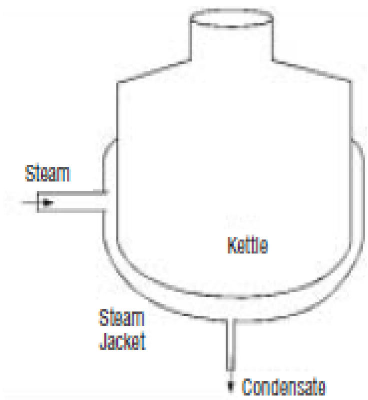
5.3.4.5.3 Jacketed Heat Exchangers

Jacketed heat exchangers use an enclosure to surround the vessel that contains the heated product. A common example of a jacketed heat exchanger is the jacketed kettle. A representation of a jacketed heat exchanger is shown in Figure 61. Jacketed heat exchangers are practical for batch processes and for product types that tend to foul or clog tube bundles or coils.

5.3.4.5.4 Coil Heat Exchangers

Coil heat exchangers characteristically use a set of coils immersed in the medium that is being heated. Coil heat exchangers are generally compact, offering a large heat transfer area for the size of the heat exchanger.

Figure 61 - Configuration of a Jacketed Kettle Heat Exchanger

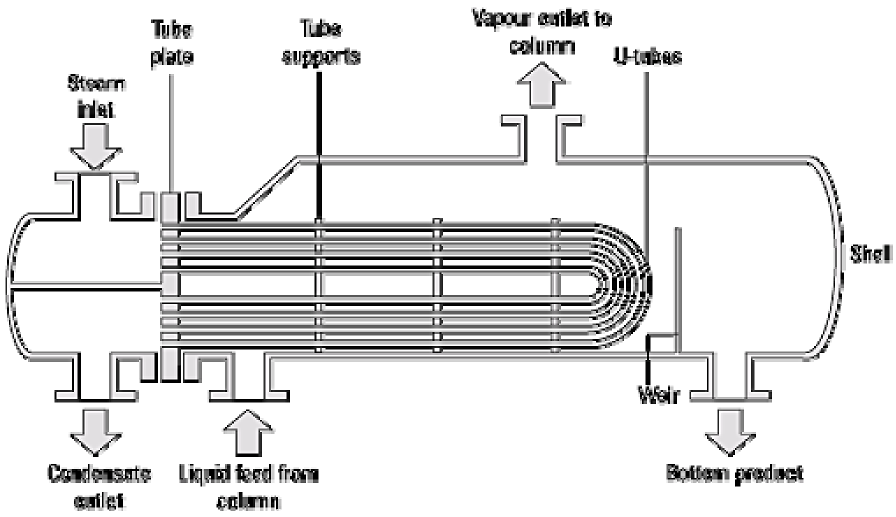


Source: U.S. Department of Energy, Steam System Performance, a sourcebook for industry (2012)

5.3.4.6 Reboilers

Reboilers (Figure 62) are typically used in distilling processes to increase component separation. Reboilers use heat, often provided by steam, to evaporate the volatile components of a product that has been drawn from a fractionating tower. These volatile components are sent downstream for further processing. The residual components are sent back into the fractionating tower or sent on to a vacuum distillation process. There are several types of reboilers, including jacketed kettle, kettle, internal reboiler, and thermosyphon reboiler. These designs differ from one another in the way the product is heated with steam.

Figure 62 - A kettle reboiler



Source: *www.spiraxsarco.com*

5.3.4.7 Reformers

Steam reformers are used to generate hydrogen, typically from a hydrocarbon feedstock such as methane (the largest component of natural gas). In turn, hydrogen is used in many petroleum refining and chemical manufacturing processes. Reformers use steam for both energy and as a source of hydrogen. Steam is injected with the hydrocarbon feedstock to initiate the following reaction:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

Methane Steam Carbon monoxide Hydrogen

Reformers often have secondary stages that are used to convert the carbon monoxide to carbon dioxide and additional hydrogen. Although large amounts of steam are used throughout the reforming processes, steam is also generated by the reformers and is sometimes exported for other uses.

5.3.4.8 Steam Ejectors

Steam ejectors use steam flow through a nozzle to create a vacuum (similar in operation to thermocompressors). They are used in several different types of system applications and process equipment. Low-pressure conditions promote the evaporation of liquids at reduced temperatures. Consequently, many chemical manufacturing processes use steam ejectors to increase the concentration of a product. In petroleum refining, steam ejectors are commonly used in the vacuum distillation of heavy hydrocarbon products. Steam ejectors are also used to initiate and maintain vacuum conditions in the condensers of condensing turbines.

5.3.4.9 Steam Injectors

Steam injectors are used to inject steam directly into a tank or a pipe containing a process fluid, generally for heating purposes. Many injector types use a nozzle and a diffuser to pull process fluid into the steam before the mixture is injected into the process fluid to promote an even distribution of heat. Important performance characteristics of injectors include accurate control of the amount of steam injected and effective mixing of the steam and process.

5.3.4.10 Strippers

Steam strippers are used to remove contaminants from a solution. Strippers are commonly found in petroleum refining and chemical manufacturing applications, where process solutions contain components that have different boiling points and removal of one or more of the components is necessary. Injecting steam into the process solution lowers the partial pressure of volatile components, allowing some of them to vaporize and get transported away with the steam. Steam can also raise the temperature of the mixture, lowering the solubility of the objectionable material and causing it to strip off with the steam. Often, the steam and the contaminants are condensed and separated, allowing recovery of the condensate and disposal or further processing of the contaminant.

5.3.4.11 Conditioning and Control Equipment

Conditioning equipment is generally used to improve the performance of, or to protect the end-use equipment. For example, desuperheaters are often used to control the energy of a steam supply to end-use equipment to reduce the risk of damage to the equipment or to effectively improve temperature control of the process.

5.3.4.11.1 Desuperheaters

The purpose of a desuperheater is to remove the superheat from steam. The majority of heating and process equipment performs more efficiently using saturated rather than superheated steam. Desuperheaters inject a very fine mist of high-purity water, such as condensate, into the steam flow. The superheated vapor gives up heat to the water mist, and by doing so, reduces its temperature.

5.3.4.11.2Vacuum Breakers

Vacuum conditions can develop in a steam system when steam flow into a component or a branch is throttled or shut off. If the rate of downstream steam use exceeds the steam supply, the pressure decreases and vacuum conditions can form. Vacuum conditions also result when the load on the heat exchanger is significantly less than the heat exchanger capacity. If the pressure in the heat exchanger drops too far, the condensate will not drain from the trap due to a higher pressure on the trap's downstream side. If uncorrected, the condensate level will rise in the heat exchanger, reducing the available heat transfer area and increasing the risk of corrosion by condensate. Vacuum breakers are pressure-controlled devices that essentially vent a heat exchanger or system branch in which a vacuum has formed. By allowing in air when they open, vacuum breakers restore pressure and allow the condensate to drain.

5.3.4.11.3Air Vents

Before start up, the steam system contains air that must be removed. The presence of air in a steam system reduces heat transfer effectiveness and promotes condensate corrosion. Air vents remove this air. Air vents are often thermostatic devices, similar to thermostatic steam traps that rely on the temperature difference between air and steam. When exposed to the lower temperature air in the system side, the vent opens. As the higher temperature steam reaches the vent, it closes, preventing the escape of steam.

5.3.4.11.4Traps

Steam traps are important to the performance of end-use equipment. Traps provide for condensate removal with little or no steam loss. If the traps do not function properly, excess steam will flow through the end-use device or the condensate will back up into it. Excess steam loss will lead to costly operation while condensate backup will promote poor performance and may lead to water hammer. Traps can also remove noncondensible gases that reduce heat exchanger effectiveness.

5.3.4.11.5Insulation

End-use equipment, such as heat exchangers and turbines, should generally be insulated due to the significant heat loss that the surface areas of this equipment can provide.

5.3.4.12 Additional Equipment

The additional equipment category refers to end uses throughout industry, which, though still significant users of steam, generally account for less steam energy than the key IOF end uses.

5.3.4.12.1Absorption Chillers

Absorption chillers provide cooling using an interesting variation of the vapor compression cycle. Instead of a compressor, which is generally used in chillers, absorption chillers exploit the ability of one substance to absorb a refrigerant at one temperature and then release it at another. In ammonia-based systems, water is the absorbent and ammonia is the refrigerant. In lithium bromide based systems, lithium bromide is the absorbent, while water is the refrigerant. An absorption chiller uses a pump instead of a compressor to increase refrigerant pressure. Once it is at the higher pressure, the absorbent/refrigerant solution is heated, often with steam, which releases the refrigerant. Although absorption chillers generally have lower coefficients of performance (COP) (indicating lower thermodynamic efficiency) than traditional chillers, they use less electric power per ton of cooling and are well suited for use with steam systems.

5.3.4.12.2 Humidifiers

Humidifiers inject steam into an air or other gas source to increase its water vapor content. In humidification, steam is used as a source of both water and energy. Humidification applications are found in the chemical manufacturing industry where control of ambient temperature and moisture content are critical for product quality.

5.3.4.12.3 Preheat/Reheat Air Handling Coils

Steam is often used in space heating applications to preheat and reheat air. In many HVAC systems, the conditioned air must have both its temperature and humidity adjusted. In preheat applications, steam is used to heat an air supply, which is typically a mixture of return air and outside air. The air is then conditioned to achieve a certain humidity and temperature. In reheat applications, the air is cooled to a particular dew point to remove water and achieve a desired humidity. As a result, before the air is delivered back to the workspaces, steam coils must reheat the process air stream up to the proper temperature. In both reheat and preheat applications, finned tube heat exchangers are generally used.

5.3.4.12.4 Tracing

In tracing applications, steam is used to maintain the temperature of a fluid in a pipe. A common application of tracing lines is to prevent the freezing of a process fluid in piping that runs outside of a temperature controlled area. Since tracing lines are exposed to freezing conditions, proper insulation, steam flow, and condensate drainage are essential to prevent freezing of the tracing lines as well as the process piping.

5.3.4.12.5 Meters

Steam meters are used to measure steam flow, and are important for tracking the steam use of a particular part of a steam system or a particular end use.

5.3.5 Recovery

The recovery components of a steam system collect and return condensate back to the generation part of the system. Condensate recovery provides thermal and water treatment benefits. Condensate that is not returned must be compensated for by the addition of makeup water, which is generally much cooler than condensate. Condensate temperature often exceeds 93°C while makeup water temperature is typically between 10°C and 27°C. As a result, the enthalpy difference between condensate and makeup water is generally over 280 KJ/Kg, an amount of energy that is often more than 10 percent of the energy in the boiler generated steam. Additionally, makeup water is generally treated with chemicals that remove minerals and establish certain pH levels in the boiler water and in the system. Reducing the amount of makeup water added to the system reduces chemical use. Additionally, some of the treatment chemicals that are contained in condensate are problematic to a plant's wastewater treatment facility. Industrial steam plants often extend across large areas. Recovering condensate from steam systems requires piping, collecting tanks, pumping equipment, and, in many cases, flash steam separators, meters, and filtration/clean-up equipment. However, the cost savings available from avoiding the purchase, treatment, and heating of makeup water often make investments in condensate recovery systems highly feasible.

5.3.5.1 Condensate Return Piping

Condensate return piping transports condensate as it drains from distribution and end-use equipment piping back to the boiler. Condensate piping should be adequately sized and insulated. Although the installation of larger pipe diameters is more expensive, larger pipes create less pressure drop for a given flow rate; this reduces the load on the condensate pumps. Larger pipe diameters also reduce the noise associated with condensate flow and are more suitable for carrying flash steam. Insulating the condensate piping helps to retain the thermal energy that provides much of the benefits of a condensate recovery system.

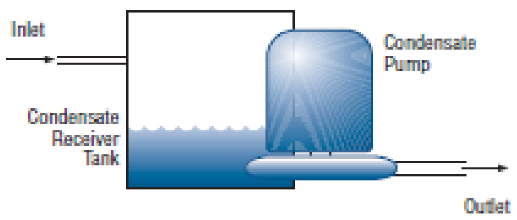
5.3.5.2 Insulation

Insulation provides energy savings and safety benefits. In terms of energy savings, insulation reduces heat loss from the condensate piping and recovery equipment surfaces, which can make the surrounding work environment more comfortable. Reducing this heat loss can also reduce the burden on the cooling systems that support surrounding workspaces. In terms of safety, insulation reduces the outer surface temperature of the piping, which lessens the risk of burns.

5.3.5.3 Condensate Receiver Tanks

Condensate receiver tanks collect and store condensate. These tanks are usually located remotely around the condensate system and are configured in conjunction with condensate pumps, as shown in Figure 63. Condensate flows can be highly variable due to changes in steam demand, especially during system startups. Receiver tanks minimize the effects of this flow variability on condensate pumps by providing storage, which maintains a minimum water level that prevents downstream condensate pumps from running dry. Since many condensate pumps are centrifugal types, it is important to keep a certain suction pressure to prevent cavitation damage. By maintaining a minimum condensate level, receiver tanks provide enough static pressure to avoid cavitation. Most systems also contain a large condensate receiver tank that collects all the condensate returned from the system. This tank may also be used to store pre-treated water.

Figure 63 - Condensate Receiver Tank and Pump Combination



Source: U.S. Department of Energy, Steam System Performance, a sourcebook for industry (2012)

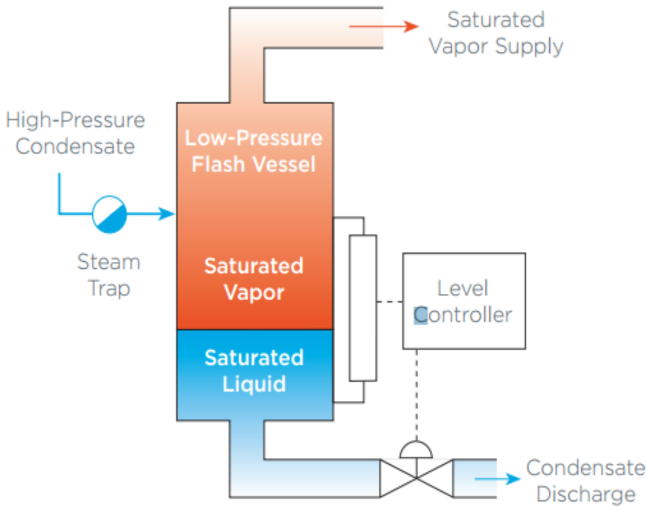
5.3.5.4 Condensate Pumps

Condensate pumps move condensate from receiver tanks back to the boiler room. Condensate pumps can be driven by electric motors, steam, or compressed air, depending on the availability of these sources. Motor-driven condensate pumps are usually centrifugal type pumps. In many cases, receiver tanks and motor driven pumps are packaged together and equipped with a control system that de-energizes the pump under low water level conditions. Steam or compressed air powered condensate pumps are used where electrical pumps would not be suitable, and are generally pressure powered pumps. Condensate pumps also can be important to the performance of end-use equipment. Effective use of condensate pumps can eliminate condensate back up into end-use equipment, improving process control and reducing potential equipment problems from condensate acidification and water hammer.

5.3.5.5 Flash Steam Vessels

Flash steam vessels allow the recovery of steam from condensate lines as illustrated in Figure 64. By removing steam from the condensate system, flash steam vessels provide an efficient source of steam to low-pressure end uses. For example, 120°C condensate has a saturation pressure of about 15 psig. Consequently, steam that is separated by flash steam vessels can be used in low-pressure steam applications such as space heating and preheating.

Figure 64 - Flash Steam Recovery Vessel



Source: U.S. Department of Energy, Steam System Performance, a sourcebook for industry (2012)

5.3.5.6 Condensate Meters

Condensate meters measure the flow rate of condensate in the return system. Knowing the condensate flow rate can be helpful in monitoring the condensate system and the condition of steam traps. Condensate meters are often inline rotary types, relying on turbine or scroll rotation to measure flow rate.

5.3.5.7 Filtration/Clean-up Equipment

In many systems, the flow of steam and condensate picks up rust, scale, and trace contaminants that are either carried over from the boiler or that form in carbon steel piping and on copper alloy heat exchange surfaces. Although strainers and filters are used to catch the particulate matter, some contaminants are dissolved in the condensate and can cause problems if returned to the boiler. In systems that require a high level of cleanliness, condensate polishers are used. Condensate polishers use ion exchange to remove these contaminants, preventing the re-deposition.

5.3.6 Energy balance-heat balance and energy performance in steam boilers

Steam production is basically an energy conversion process in which fuel energy is converted into energy resident in steam. Boilers are the most energy-intensive components of a steam system. This implies energy management should have a focal point on the boilers. Several factors are key ingredients in boiler performance.

Typically the most significant loss associated with boiler operation is the energy exiting the boiler with the flue gas. This loss is directly impacted by the temperature of the flue gas and the amount of excess air supplied to the combustion process. Other combustion factors also impact this portion of the energy conversion process.

Additional factors that impact boiler performance must also be considered. Boiler blowdown is generally important for the continued operation of any steam boiler. Boiler blowdown is also a loss to the boiler operation. To a large extent, this loss can be managed and reduced. Heat transfer losses from the boiler shell are also an area of potential loss management.

Energy takes many forms, such as heat, kinetic energy, chemical energy, potential energy but because of interconversions it is not always easy to isolate separate constituents of energy balances. However, under some circumstances certain aspects predominate. In many heat balances in which other forms of energy are insignificant; in some chemical situations mechanical energy is insignificant and in some mechanical energy situations, as in the flow of fluids in pipes, the frictional losses appear as heat but the details of the heating need not be considered. We are seldom concerned with internal energies.

Therefore practical applications of energy balances tend to focus on particular dominant aspects and so a heat balance, for example, can be a useful description of important cost and quality aspects of process situation. When unfamiliar with the relative magnitudes of the various forms of energy entering into a particular processing situation, it is wise to put them all down. Then after some preliminary calculations, the important ones emerge and other minor ones can be lumped together or even ignored without introducing substantial errors. With experience, the obviously minor ones can perhaps be left out completely though this always raises the possibility of error.

Energy balances can be calculated on the basis of external energy used per kilogram of product that comes out from the system, or raw material processed, or some key component.

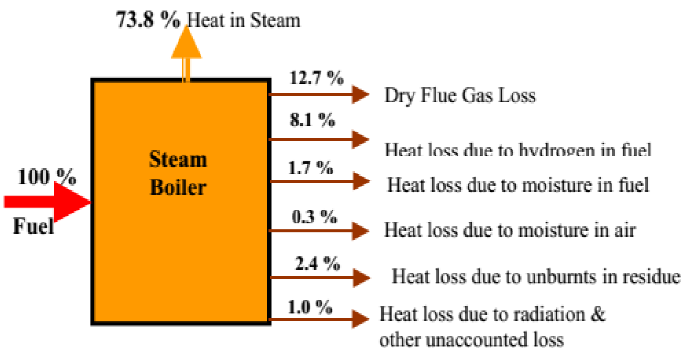
5.3.6.1 Heat balance in steam boilers and steam boiler efficiency

Performance of the boiler, like efficiency and evaporation ratio reduces with time, due to poor combustion efficiency (an increased amount of the fuel’s mass escapes the combustion chamber without being ignited), heat transfer fouling and poor operation and maintenance. Deterioration of fuel quality and water quality also leads to poor performance (low thermal efficiency) of boiler. Efficiency testing helps us to find out how far the boiler efficiency drifts away from the desired/designed or reported (by the manufacturer) efficiency. The boiler efficiency is mainly determined by the flue gas temperature, i.e. the amount of excess air as measured by the oxygen content in the flue gas and unburnt. A more efficient method for supervising the operation is therefore to directly monitoring these measured parameters. Any observed abnormal deviations could therefore be investigated to pinpoint the problem area for necessary corrective action. Hence it is necessary to find out the current level of efficiency for performance evaluation, which is a pre requisite for energy conservation action in industry.

The most common important energy form is heat energy and the conservation of this can be illustrated by considering operations such as heating and drying. In these, enthalpy (total heat) is conserved and as with the mass balances so enthalpy balances can be written round the various items of equipment, or process stages, or round the whole plant.

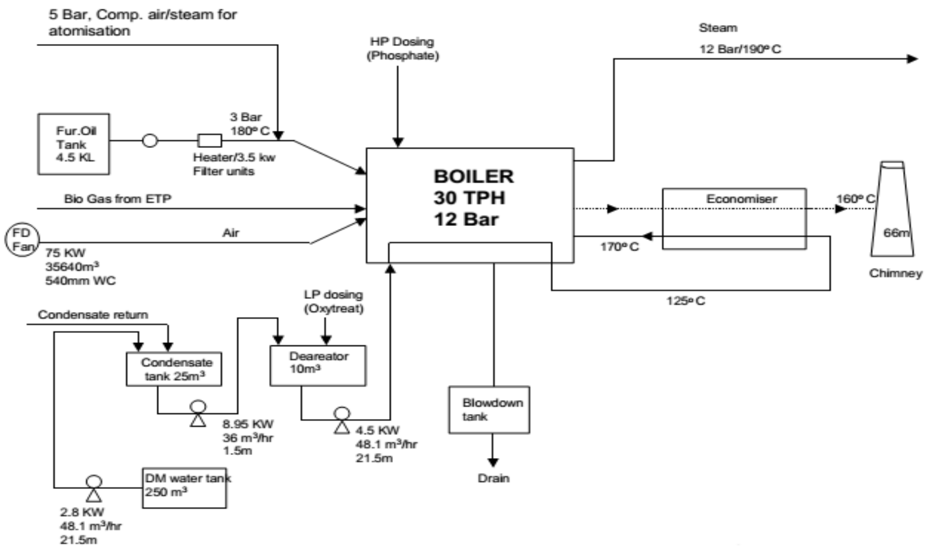
Enthalpy is always referred to some reference level or datum, so that the quantities are relative to this datum. Working out energy balances is then just a matter of considering the various quantities of materials involved, their specific heats, and their changes in temperature or state (as quite frequently latent heats arising from phase changes are encountered).

Figure 65 - Schematic of indicative heat balance in a coal-fired steam boiler



Source: http://www.em-ea.org/

Figure 66 - Typical energy flow diagram in a steam boiler system



Source: http://www.em-ea.org/

5.3.6.2 Steam boiler efficiency

In steam boilers, the utilization of the provided thermal input and its conversion to useful heat output is not complete, since a part of it is lost and rejected to the environment in the form of various thermal losses. Consequently, the useful heat output gained is always lower than the original heat input and the efficiency of the steam boiler is smaller than one. This is not true in the case of condensing steam boilers, which also make use of the latent heat of the flue gas that is produced during its condensation. Since the steam boiler efficiency is defined based on the lower heating value of the fuel, in this case the efficiency can be higher than one. The thermal efficiency of the steam boiler is consequently given by the expression:

$$\eta = \frac{\dot{Q}_{useful}}{\dot{Q}_{in}}$$

The amount of the useful heat output, Q_{useful} is the heat that is delivered to the feedwater during its conversion to saturated (or superheated) vapour. Therefore, if h_w is the enthalpy of the feedwater and h_u the enthalpy of the output saturated or superheated steam the useful heat output is expressed by the equation:

$$\dot{Q}_{useful} = \dot{m}_D (h_u - h_w)$$

where m_D is the steam mass flowrate

Determination of boiler efficiency originated from useful heat output power as presented in the equation above is called direct efficiency. The advantages of the direct efficiency estimation method are mainly its speed of applying, its requirement of fewer parameters for computation, fewer instruments for monitoring and the ease which is inherent in comparing evaporation ratios with benchmark figures. On the other hand, it does not give clues to the operator as to why efficiency of one system is lower than another, since the losses which are accountable for various efficiency levels are not calculated.

Some steam boiler installations are equipped with additional devices for reheating streams of water/steam that return to the boiler. In that case, the total useful heat output is given by the equation:

$$\dot{Q}_{useful} = \dot{m}_D (h_u - h_w) + \dot{Q}_{reheat}$$

The heat input to the steam boiler, Q_{in}, is considered the energy that is provided in the burning chamber that is derived from a heat source that is outside the steam boiler. There are three main cases of the origin of the heat input:

1) Heat input in chemical bonds of the fuel :

$$\dot{Q}_{B,ch} = \dot{m}_B \, H_u$$

where m_{fuel} is the fuel consumption rate and H_u is the lower heating value of the fuel used.

2) Heat input derived from the temperature difference of the fuel stream:

$$\dot{Q}_{B,physical} = \dot{m}_B \, \Delta h_B$$

where Δh_B is the drop of the specific enthalpy of the fuel stream as it enters the combustion chamber

3) Heat input derived from the temperature difference of the combustion air:

$$\dot{Q}_{air} = \dot{m}_{air} \, \Delta h_{air}$$

where Δh_{air} is the drop of the specific enthalpy of the fuel stream as it enters the combustion chamber and m_{air} is the mass flowrate of the combustion air.

Considering the above, the total of the heat input to the steam boiler can be expressed in the equation:

$$\dot{Q}_{in} = \dot{Q}_{B,ch} + \dot{Q}_{B,ph} + \dot{Q}_{air}$$

However, generally the second and third term of the right hand part of the above equation are omitted and the heat input is considered solely as the energy released by the combustion of the fuel:

$$\dot{Q}_{in} = \dot{Q}_{B,ch}$$

As stated previously, some part of the input heat is converted to useful heat output and some remaining part become losses:

$$\dot{Q}_{in} = \dot{Q}_{useful} + \dot{Q}_{loss}$$

Given the above equation, a second expression of the boiler efficiency can be derived:

$$\eta = \frac{\dot{Q}_{useful}}{\dot{Q}_{in}} = \frac{\dot{Q}_{in} - \dot{Q}_{loss}}{\dot{Q}_{in}} = 1 - \frac{\dot{Q}_{loss}}{\dot{Q}_{in}}$$

The indirect method of calculating the boiler efficiency that is based on the calculation of the heat losses provides a complete mass and energy balance for each individual stream, making it easier to identify options for performance improvements. However, when contrasted with the direct method, it is more time consuming and requires dedicated lab facilities for analysis.

The heat losses that occur in the operation of a steam boiler can be attributed to a variety of reasons. There reasons are :

- Losses due to the fuel that escapes the combustion chamber without reacting
- Losses due to high temperature ash contents of the fuel that escape in the stream of the flue gases
- Losses due to the high temperature of the flue gases that exit the steam boiler
- Losses due to radiative and convective heat transfer from the shell of the steam boiler to the atmosphere

Some of the dominant categories of heat losses are analyzed in the following section.

It is reminded that according to the European standard EN 12925-15, the efficiency of a steam boiler is given by the equations:

$$\eta_{th,\mathrm{EN}} = \frac{\dot{Q}_N}{\dot{Q}_{(N)Ztot}}$$

where

$$\dot{Q}_N = \dot{m}_{ST}(h_{ST} - h_{FW}) + \dot{m}_{SS}(h_{FW} - h_{SS}) + \dot{m}_{RHI1}(h_{RHI2} - h_{RHI1}) + \dot{m}_{SRI}(h_{RHI2} - h_{SRI})$$
$$+ \dot{m}_{RHII1}(h_{RHII2} - h_{RHII1}) + \dot{m}_{SRII}(h_{RHII2} - h_{SRII}) + \dot{m}_{BD}(h_{BD} - h_{FW}) + \dot{m}_{SA}(h_{SA} - h)$$

and

$$\dot{Q}_Z = P_M + P_{UG} + P_U + P + \dot{Q}_{SAE} + \dot{m}_{AS} h_{AS}$$

The above equations are explained in Section 1.2.3.2.

5.3.6.3 Type of losses in a steam boiler and their definition

5.3.6.3.1 Stack Losses

Boiler stack loss is typically the major loss component associated with the boiler operation. Many factors are incorporated in the stack loss category, but the major contributors are the flue gas temperature and excess air amount. Rarely do these losses combine to be less than 8% of the total fuel energy input to the boiler, and generally they result in more than a 15% loss.

Stack loss is usually determined through a combustion analysis. The analysis can be completed in many different ways with the most common being conducted with tabular data, graphical data, or electronic data. The analysis is based on combustion principles with the main input or measured data being flue gas exit temperature, ambient temperature, and flue gas oxygen content. The result of this analysis is the stack loss associated with the boiler operation. This is a representation of the amount of energy exiting the boiler with the flue gas in comparison to the total energy entering the boiler with the fuel. Commonly, stack loss is converted into an expression of efficiency termed "combustion efficiency (" $\eta_{combustion}$") and is determined by the equation that follows.

$$\eta_{combustion} = 100\% - \eta_{stack}$$

In fact, combustion efficiency represents the major components of indirect efficiency with shell losses, blowdown losses, and miscellaneous losses omitted. Stack loss, η_{stack}, is the only loss considered in combustion efficiency and is expressed as a percentage of total fuel input energy.

Because stack losses can be massive and are generally the largest loss in magnitude, they require close management. The investigation of stack losses will be segregated into the two main categories: a)temperature effect and b)excess air effect. These investigations follow.

5.3.6.3.1.1 Flue gas oxygen content

Steam generation efficiency centers around the energy transfer process in the boilers. The main factors affecting the efficiency of this energy transfer process are the temperature of the exiting flue gas and the flue gas oxygen content. These issues are related in many areas. Flue gas oxygen content can represent a significant loss to the steam system if the content is not maintained within the proper limits.

In the combustion process, fuel must come in contact with oxygen to allow the release of the chemical energy resident in the fuel. If the fuel does not react, it leaves the combustion area and the boiler. This is a loss to the system because the fuel energy, which was purchased, was not released. This also presents a safety and environmental hazard because combustion can result in boiler areas not designed for combustion. Also, the partial combustion of the fuel will form carbon monoxide, which is a toxic low-grade fuel. An additional factor accompanying reduced oxygen content is the potential to produce smoke or opacity. This is a result of poor combustion and is the formation of particles from partial combustion of the fuel.

These conditions must be avoided; therefore, excess oxygen is supplied to the combustion zone to ensure that all of the fuel is combusted. However, this excess oxygen enters the boiler at ambient temperature, 20°C for example, and exits the boiler with the flue gas at an elevated temperature, 230°C for example. Therefore, the extra air brought into the boiler was heated from ambient temperature to flue gas temperature by the fuel. Further compounding the problem is the fact that the oxygen source is ambient air, which contains much more nitrogen than it does oxygen. The nitrogen does nothing for the combustion process except to extract energy and increase the loss. Management of this flue gas loss requires the excess oxygen to be maintained within a range. The appropriate range depends on the fuel type and the method of monitoring and control.

Table 56 - Flue gas oxygen control parameters

Fuel	Automatic control flue gas O_2 content		Positioning control flue gas O_2 content		Automatic control excess air		Positioning control excess air	
	Minimum (%)	Maximum (%)	Minimum (%)	Maximum (%)	Minimum (%)	Maximum (%)	Minimum (%)	Maximum (%)
Natural gas	1.5	3.0	3.0	7.0	8.5	18.0	18.0	55.0
No. 2 fuel oil	2.0	3.0	3.0	7.0	11.0	18.0	18.0	55.0
No. 6 fuel oil	2.5	3.5	3.5	8.0	14.0	21.0	21.0	65.0
Pulverized coal	2.5	4.0	4.0	7.0	14.0	25.0	25.0	50.0
Stoker coal	3.5	5.0	5.0	8.0	20.0	32.0	32.0	65.0

Source: Thermal Energy Equipment: Boilers & Thermic Fluid Heaters", RETScreen

Table 56 provides some general information of the typical control limits for steam boilers. The table represents the amount of oxygen (O2) in the flue gas as it exits the combustion chamber. This is also expressed as excess air. Excess air is the amount of air introduced to the combustion zone in comparison to the theoretical, stoichiometric amount, required for complete combustion with no excess air. The excess air values in the table correspond to the flue gas oxygen content values.

The two main designations in Table 56 are automatic control and positioning control. Positioning control is generally accomplished as part of an overall boiler control system without flue gas oxygen measurement. Typically, a pressure controller observing steam pressure is the main system controller. As the steam pressure decreases, the controller will increase fuel flow to increase boiler steam output. Combustion air flow will be increased in a preset manner in response to the fuel flow setting. Combustion air is not adjusted based on flue gas oxygen content. Periodically the relationship between the combustion air setting and the fuel flow is verified and adjusted through flue gas oxygen content evaluation.

Non-automatic control is also accomplished through monitoring of the flue gas oxygen content and manually adjusting the quantity of combustion air. This type of operation is usually found on boilers with constant load.

Automatic control refers to any type of boiler control that continually monitors flue gas oxygen content and adjusts the combustion air flow to maintain required limits. Any type of control will result in a range of flue gas oxygen content. Most boilers operate with less excess oxygen requirement at higher loads than at lower loads primarily because of the improved mixing and combustion parameters at higher loads.

The example boiler (Table 57) has a flue gas exit temperature of 293°C and a combustion air inlet temperature of 38°C. This produces a flue gas temperature of 255°C (293°F - 38°C). The flue gas oxygen content was measured to be 11.0%. Table 4 identifies the loss associated with the energy exiting the boiler with the flue gas, 25.18%.

If this loss can be reduced, by recovering energy to the steam, the operating cost of the boiler will decrease. The example boiler initially has no automatic combustion controls or flue gas monitoring. Even without flue gas monitoring and control, this boiler should be capable of operating with a flue gas oxygen content ranging between 3.0% and 7.0%. If the oxygen content is reduced to an average of 5.0% and the flue gas exhaust temperature remains constant, the combustion loss will reduce to 18.18%. In other words, the boiler efficiency will improve 7.0 percentage points (25.18% to 18.18%). The initial boiler efficiency was determined to be 72.2%. After tuning the boiler, the efficiency would increase to 79.2%. This assumes that blowdown losses, shell losses, and other miscellaneous losses remain constant (approximately 2.6% of fuel energy input). An oxygen content of 5.0% was chosen because the boiler would be operating within the control range of flue gas oxygen content (3.0% to 7.0%).

The example boiler could be equipped with an automatic oxygen trim system to further reduce the stack loss. The oxygen trim system could control the flue gas oxygen content to 2.5%. In this case the combustion loss would decrease to 16.6% if the flue gas temperature remains constant. In other words, the boiler efficiency would increase to 80.8%.

Table 57 -Boiler stack losses as a function of flue gas temperature and oxygen content

Flue gas O_2 content (%)	Flue gas temperature—combustion air temperature (°F)														
	230	250	270	290	310	330	350	370	390	410	430	450	470	490	510
1.00	10.33	10.74	11.16	11.58	12.00	12.43	12.85	13.28	13.70	14.13	14.56	14.99	15.42	15.85	16.28
2.00	10.55	10.99	11.43	11.87	12.31	12.75	13.20	13.64	14.09	14.54	14.99	15.44	15.89	16.34	16.79
3.00	10.79	11.25	11.72	12.18	12.65	13.11	13.58	14.05	14.52	14.99	15.46	15.94	16.41	16.89	17.36
4.00	11.07	11.56	12.04	12.53	13.02	13.52	14.01	14.50	15.00	15.50	15.99	16.49	17.00	17.50	18.00
5.00	11.38	11.89	12.41	12.93	13.45	13.97	14.49	15.01	15.54	16.07	16.59	17.12	17.65	18.18	18.72
6.00	11.73	12.28	12.83	13.38	13.93	14.48	15.04	15.59	16.15	16.71	17.27	17.83	18.40	18.96	19.53
7.00	12.13	12.72	13.30	13.89	14.48	15.07	15.66	16.26	16.85	17.45	18.05	18.65	19.25	19.85	20.45
8.00	12.60	13.22	13.85	14.48	15.11	15.75	16.38	17.02	17.66	18.30	18.94	19.58	20.23	20.88	21.52
9.00	13.14	13.81	14.49	15.17	15.85	16.54	17.22	17.91	18.60	19.29	19.98	20.68	21.38	22.07	22.77
10.00	13.77	14.51	15.25	15.99	16.73	17.47	18.22	18.96	19.71	20.46	21.22	21.97	22.73	23.49	24.25
11.00	14.54	15.35	16.15	16.96	17.78	18.59	19.41	20.23	21.05	21.87	22.70	23.52	24.36	25.18	26.02
12.00	15.48	16.37	17.26	18.16	19.06	19.96	20.87	21.77	22.68	23.59	24.51	25.42	26.34	27.26	28.18

Care should be given to the oxygen measurement location. This is true especially for boilers that operate with a negative pressure in the combustion zone and downstream of the combustion zone. Boilers operating with a negative pressure will have some air leaking into the flue gas stream. This air has not passed through the combustion zone and as a result did not contribute to the combustion process. This can provide false oxygen reading that results in poor combustion performance if the input air flow is reduced based on this erroneous measurement. Therefore, the oxygen content should be measured as close to the combustion zone as possible. However, the combustion zone environment is extremely harsh, and a compromise must be reached. The idea is to install the oxygen sensor as close to the combustion zone as practical to achieve an acceptable sensor life and accurate measurement.

In the example analysis, flue gas temperature was assumed to remain constant when excess air was reduced. Typically, flue gas temperature will not remain constant as the amount of excess air is adjusted. In general, flue gas temperature will decrease as excess air is decreased. However, this is not universal and should be investigated on a case-by-case basis.

Flue gas combustibles

A secondary measurement, which is extremely helpful in determining combustion performance, is a measurement of the concentration of combustible material remaining in the flue gas after the combustion zone. Poor or incomplete combustion can result even if the appropriate amount of oxygen is introduced to the combustion chamber. Three main factors affect combustion: (1) reaction time, (2) reaction temperature, and (3) reactants mixture.

For the combustion reaction to proceed to completion, fuel and oxygen must have enough time, they must be at the proper temperature, and they must be appropriately mixed. If any component is missing, the reaction will not proceed to completion. Babcock and Wilcox describe this as "the three T's of combustion": "Time, Temperature, and Turbulence". The main chemical component arising from incomplete combustion is carbon monoxide (CO). Periodic carbon monoxide (or combustibles) measurement can provide insight into the performance of the combustion zone.

A generally accepted limit is to have no more than 200 parts per million (ppm) combustibles in the flue gas. However, this limit is general, and each boiler should be investigated to determine the base combustibles level. After the base level has been established, periodic monitoring will allow changes in combustibles concentration to be observed as a problem in the combustion process. As an example, a natural-gas-fired boiler may have 15 ppm combustibles in the flue gas under normal operating conditions. An indication of a combustion problem would be if the combustibles concentration increased to 50 ppm (well below the generally

Flammability limits

Not only must fuel and air be in the appropriate concentrations to obtain efficient combustion, but they must be within proper limits to establish a flame at all. For example, methane (natural gas essentially) must be mixed with at least 85% air (by volume) and no more than 95% air to burn. This indicates that the air fuel mixture will not burn if there is more than 100% excess air (10% oxygen in the combustion products). However, many boilers are found operating with more excess air than this. The explanation is that the full amount of extra air is not passing through the flame zone. Air is either entering as "tramp air" through a shell leak, or it is entering through the combustion air system but is not affecting the flame zone. Even though this air is not passing through the flame zone, it is still affecting the boiler efficiency by absorbing energy from the fuel.

The point of this discussion arises from the method of attack to reduce stack loss. Typically excess air loss is reduced by more precise control of the combustion air entering the flame zone. However, if a significant portion of the air passing through the boiler does not pass through the flame zone, then reducing flue gas oxygen content may result in a substoichiometric condition (oxygen starved) in the flame zone. This can result in an explosion and other detriments of an economic nature. When correcting boilers with gross errors in flue gas oxygen content, care must be exercised to ensure that combustion is not compromised. In fact, care must be exercised for all boilers. This is accomplished by periodically measuring flue gas combustibles concentrations.

Flue gas temperature

An obvious loss associated with boiler operation occurs when the exhaust flue gas exits the boiler with an elevated temperature. A diagnostic measurement essential to boiler efficiency evaluation is the exhaust flue gas temperature. This measurement should be recorded at least daily and should be recorded with respect to boiler steam load and ambient conditions. Furthermore, the location of the sensing point is critical. The sensing location should be as close to the flue gas exit of the last point of heat exchange for the flue gas. In other words, if the boiler is equipped with a feedwater economizer, the temperature sensor should be located at the flue gas exit from the economizer. The idea is to obtain the true energy content of the flue gas stream in relation to the energy exchange processes within the boiler. An annual comparison should be made between the current boiler flue gas temperature and previous temperatures with the boiler operating under similar conditions of steam loading and ambient conditions. Flue gas exit temperature is affected by many factors, such as:

- boiler load,
- boiler design,
- combustion-side heat transfer surface fouling,
- water-side heat transfer surface fouling,
- flue gas bypassing heat transfer surfaces because of failed boiler components, and excess air (possibly).

5.3.6.3.2 Blowdown losses

When water is boiled and steam is generated, any dissolved solids contained in the water remain in the boiler. If more solids are put in with the feed water, they will concentrate and may eventually reach a level where their solubility in the water is exceeded and they deposit from the solution. Above a certain level of concentration, these solids encourage foaming and cause carryover of water into the steam. The deposits also lead to scale formation inside the boiler, resulting in localized overheating and finally causing boiler tube failure.

It is therefore necessary to control the level of concentration of the solids in suspension and dissolved in the boiled water. This is achieved by the process of 'blowing down', where a certain volume of water is blown off and is automatically replaced by feed water – thus maintaining the optimum level of total dissolved solids (TDS) in the boiler water and removing those solids that have fallen out of solution and which tend to settle on the internal surfaces of the boiler. Blow down is necessary to protect the surfaces of the heat exchanger in the boiler. However, blow down can be a significant source of heat loss, if improperly carried out.

Since it is tedious and time consuming to measure TDS in a boiler water system, conductivity measurement is used for monitoring the overall TDS present in the boiler. A rise in conductivity indicates a rise in the "contamination" of the boiler water.

There are two main conventional methods for blowing down the boiler, intermittent and continuous blowdown.

Intermittent blow down

The intermittent blown down is given by manually operating a valve fitted to a discharge pipe at the lowest point of the boiler shell to reduce parameters (TDS or conductivity, pH, Silica and Phosphates concentration) within prescribed limits so that steam quality is not likely to be affected. This type of blow down is also an effective method to remove solids that have fallen out of solution and have settled upon the fire tubes and the internal surface of the boiler shell. In intermittent blow down, a large diameter line is opened for a short period of time, the time being based on a general rule such as “once in a shift for 2 minutes”.

Intermittent blow down requires *large* short-term increases in the amount of feed water put into the boiler, and hence may necessitate larger feed water pumps than if continuous blow down is used. Also, TDS level will vary, thereby causing fluctuations of the water level in the boiler due to changes in steam bubble size and distribution which accompany changes in concentration of solids. Also, a substantial amount of heat energy is lost with intermittent blow down.

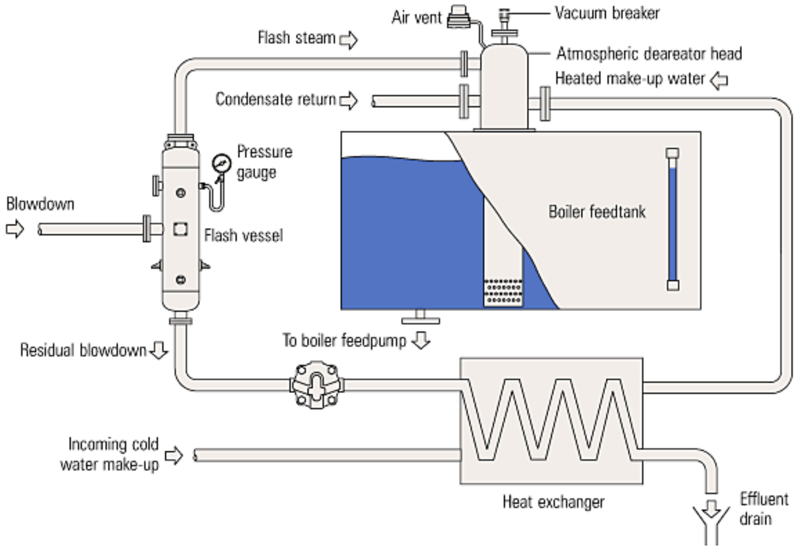
Continuous blow down

There is a steady and constant dispatch of a small stream of concentrated boiler water, and replacement by steady and constant inflow of feed water. This ensures constant TDS and steam purity at a given steam load. Once a blow down valve is set for a given conditions, there is no need for regular operator intervention.

Even though large quantities of heat are removed from the boiler, opportunities exist for recovering this heat by blowing into a flash tank and generating flash steam. This flash steam can be used for pre-heating boiler feed water. This type of blow down is common in high pressure boilers.

The residual blowdown which leaves the flash vessel still contains a good deal of heat energy and a significant proportion of this can also be recovered by introducing a heat exchanger to heat up cold make-up water. Complete blowdown heat recovery systems which extract the flash steam and the energy content of the residual blowdown, can recover up to 80% of the energy contained in the blowdown. They can be applied to any size of steam boiler and an investment in such a system is often recovered in a matter of months.

Figure 67 - Schematic of recovery of heat from boiler blowdown



Source: Thermal Energy Equipment: Boilers & Thermic Fluid Heaters", RETScreen

Reducing the loss associated with boiler blowdown is achieved through two avenues. First, blowdown rates are reduced through improved feedwater quality with the main focus on make-up water treatment and recycled condensate quality. Along with this is proper chemical treatment in the boiler. The second avenue centers on recovering the resident energy in the blowdown.

The impurities found in boiler water depend on the untreated feed water quality, the treatment process used and the boiler operating procedures. As a general rule, the higher the boiler's operating pressure, the greater will be the sensitivity to impurities. In Table 58 the recommended boiler water limits for certain substances is given:

Table 58 - Recommended boiler water limits

Factor	Up to 20 kg/cm^2	21-39 kg/cm^2	40-59 kg/cm^2
TDS, ppm	3000-3500	1500-2500	500-1500
Total iron dissolved solids ppm	500	200	150
Specific electrical conductivity at 25°C	1000	400	300
Phosphate residual ppm	20-40	20-40	15-25
pH at 25°C	10-10.5	10-10.5	9.8-10.2
Silica (max) ppm	25	15	10

Source: Thermal Energy Equipment: Boilers & Thermic Fluid Heaters", RETScreen

Boiler blowdown amount is typically controlled through the use of chemical analysis of the boiler water. Probably the most common control mechanism utilizes the measurement of boiler water conductivity, which is a gross indication of boiler water chemical concentrations. This measurement is repeatable and reliable, which makes it an excellent control measurement. Often a conductivity value is maintained in the boiler water by continuously modulating the amount of blowdown water removed from the boiler. Conductivity measurements should be supported by periodic boiler water chemical analysis.

Boiler water conductivity control is excellent to control blowdown rate; however, the actual flow of blowdown water is not known from the control scheme. To determine the magnitude of the loss associated with blowdown, the mass flow rate of blowdown must be known. Blowdown flow is typically not measured directly because of flowmeter difficulties. However, accurate estimates of blowdown amount can be obtained through chemical analysis of chloride, silica, or other chemical components when continuous blowdown is employed. Blowdown is typically expressed as a percentage of total feedwater flow.

Care must be given to evaluation of boilers using only intermittent blowdown. Intermittent blowdown can be very effective (and preferred) for the control and management of boiler water chemistry of relatively small-capacity, low-pressure boilers. Intermittent blowdown is accomplished one to three times each day and consists of releasing boiler water for only several seconds. This type of blowdown control allows the chemical constituents in the boiler water to concentrate until the blowdown event occurs. The blowdown event significantly reduces the chemical concentrations in the boiler water and allows continued operation. This control method will release more blowdown water than continuous control; therefore, in larger capacity boilers, continuous blowdown will generally be more economically attractive.

Blowdown amounts are generally less than 10% of total feedwater flow. However, 5% would be extraordinarily high for a system with high-quality water treatment systems. The correct blowdown amount for a given boiler is a function of steam pressure, feedwater purity, and chemical treatment program. The main factors to be controlled by blowdown are the chemical concentrations in the boiler.

The next area of discussion centers on recovery of the energy resident in blowdown. Blow-down is necessary for the continued operation of any typical steam boiler; therefore, it is beneficial to understand the mechanisms available to recover a portion of the energy in the blowdown. Two primary methods will be discussed here.

First, flash steam recovery is a potential efficiency improvement opportunity. As the blow- down exits the steam drum and decreases in pressure, a portion of the liquid blowdown flashes to steam. This steam is free from the impurities resident in the blowdown and can be used. The amount of flash steam increases as the pressure difference between the boiler pressure and the flash pressure increase. Generally, the blowdown stream is reduced in pressure and passed through a pressure vessel (flash tank). The flash tank serves as a separator to allow the remaining liquid blowdown to separate from the flash steam. The flash steam is piped into the low-pressure steam system or many times into the deaerator.

Second, a heat exchanger can be employed to transfer the energy in the blowdown to makeup water. Caution should be exercised in the choice of heat exchanger because the blow-down stream has a significant fouling potential. The heat exchanger must be capable of being cleaned.

The flash tank and heat exchanger can be used in combination to provide low-pressure steam and preheat makeup water. In the combined arrangement, blowdown water exiting the flash tank is passed through the heat exchanger. A steam system specialist should be contacted to analyse the opportunity associated with these projects. It is often difficult to implement this type of energy recovery system in systems employing intermittent blowdown.

5.3.6.3.3 Shell Loss

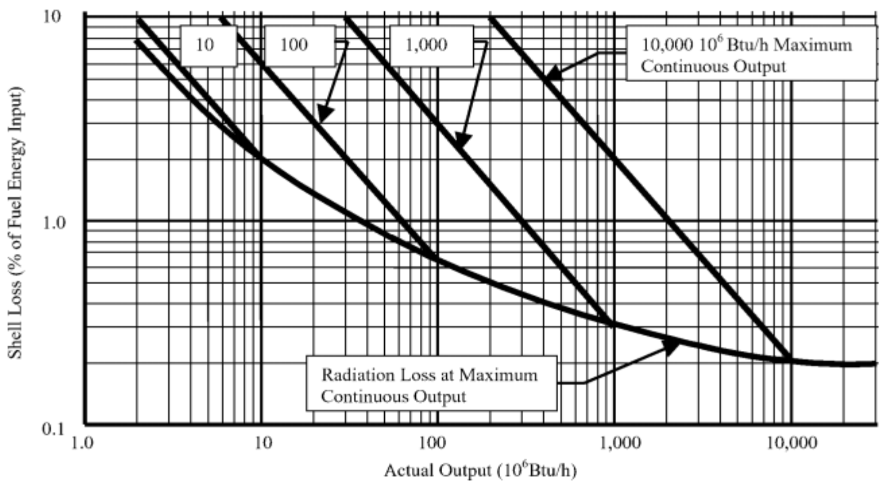
Shell losses are categorized as the heat transfer (radiation and convection) losses from the boiler's external surface. Most watertube boilers should have less than a

1.0% shell loss as related to total fuel input if the boiler is operating close to full load. This is the expected loss if there are no problems with the refractory or boiler cladding. The magnitude (KW) of the shell loss does not change appreciably with respect to boiler load. As a result, if the loss is considered as a percentage of fuel input energy, the loss percentage increases as boiler load decreases.

Fire tube boilers typically (but not always) tend to have shell loss percentages much less than watertube boilers of comparable capacity. In general this is because the external shell of a fire tube boiler is usually in thermal contact with boiling water (at relatively low temperature) rather than combustion gases at elevated temperatures. As a result, the temperature gradient between the environment and the core of the steam boiler has a more gradual distribution in the case of fire tube boilers. Moreover, since the temperature difference between the environment and the boiling water in the shell of a fire tube boiler is lower than the respective temperature difference between the environment and the flue gases in the shell of a watertube boiler, the heat losses due to convection and radiation in the first case tend to be lower.

A general boiler shell analysis should be conducted to determine if there are areas where the refractory or insulation is in poor condition. This analysis can be completed with sophisticated thermal scanning equipment, infrared thermometers, or an excellent initial investigation can be completed by a visual and "gross thermal" inspection of the boiler surface. During this inspection, the main targets are "hot spots;" these areas usually indicate a problem associated with the internal refractory. The example boiler would be expected to experience a shell loss of approximately 0.8% of total fuel input energy. This was determined from Figure 68.

Figure 68 - Typical values of shell loss percentage as a function of heat output



5.3.6.3.4 Unburned Fuel Loss

Coal and other solid fuel combustion leads to many challenges to the operation and maintenance of a boiler. Unburned fuel or the combustibles content of the ash is a loss that is generally negligible for other fuel types but it can be significant in coal-fired boilers. This discussion is not concerned with the partial combustion of fuel forming carbon monoxide in the flue gas but the amount of fuel remaining in ash unburned.

Ash content of coal varies widely from less than 5% to more than 20% of the total mass of the fuel. If a sample of ash is analyzed after the fuel has been burned, the amount of carbon can be measured in a laboratory. Once the amount of carbon in the ash is known, the loss to the system can be calculated. The equation to accomplish this is provided below.

$$\lambda_{\text{unburned fuel}} = \lambda_{uf} = \varphi_{uf} \cdot \dot{m}_{fuel} \cdot HHV_{carbon} \cdot T\kappa_{fuel}$$

The factor φ_{uf} is the fraction of fuel that is unburned as determined by the laboratory analysis. To complete the analysis, the amount of ash in the fuel must be known. This is supplied from a laboratory analysis as well. The equation for φ_{uf} is provided below.

$$\varphi_{uf} = \frac{m_{uc}}{m_{ash}} \cdot \left(\frac{m_{ash}}{m_{fuel}} \right)$$

where m_{uc}/m_{ash} is the fraction of unburned carbon in the ash sample, and m_{ash}/m_{fuel} is the fraction of ash in the original fuel sample.

Generally, unburned carbon losses are expected to be less than 0.5% of the total fuel input energy. Expected unburned carbon content would be less than 5% unburned carbon in the ash. Unburned carbon is a function of many factors with the major factors being related to combustion and fuel conditioning.

5.3.6.4 Heat balance in combustion chamber

Walls made from tubes surrounded the fire chamber in the boiler to absorb heat.

Different types of construction (development):

- bare tubes tangent to the refractory
- bare tubes embedded in the refractory
- studded tubes
- membrane wall

The membranes act as FINS to increase the heat transfer as well as to afford a continuous rigid and pressure tight construction for the furnace. Nowadays membrane wall is generally used.

Types of heat received by water walls:

- Radiation (most heat is received by radiation)
- Luminous flame cause radiation:
- emit all wavelengths and strong visible radiation
- particulates such as soot particles during combustion (combustion process and fuel type have influence on soot formation; e.g. coal and oil + fuel rich burning zones)
- particular triatomic components of flue gas (CO_2, H_2O, SO_2) are selective radiators: emit and absorb radiation in certain ware lengths.

Radiation energy density at a certain temperature can be gained with integration from zero to endless this function (Stefan-Boltzman rule).

Heat balance equation of the combustion chamber:

$$Q_{in} = Q_r + Q_{fgout}$$

Q_{in} is the heat flow into the combustion chamber

Q_r: heat transfer to the water walls by radiation

Qf_{gout}: outflowing heat towards superheater economizer and air preheater

Boiler efficiency is not constant throughout the operating range of a typical boiler. Generally, boiler efficiency decreases when the boiler is operating at less than 50% of its design load because of many factors; the main factors are increased excess air requirements to maintain complete combustion and constant magnitude shell losses. The upper end of the operating range generally presents a decrease in efficiency also because of increased flue gas exit temperature. Systems with multiple boilers should incorporate system controls designed to operate the combined system at the maximum overall efficiency. Excess boiler capacity on-line can result in boilers operating at reduced efficiency. In contrast, insufficient boiler capacity online can significantly diminish reliability.

Many boilers are operated in an "on-off' or "load-unload" mode. This type of operation should be investigated from the standpoint of parasitic losses. Each time the boiler loads, the combustion control system purges the boiler with ambient air to remove any residual combustibles. This is required from a safety and operational standpoint. However, the purge air is absorbing energy from the water inside the boiler; therefore, it presents a loss to the boiler. A secondary loss occurs while the boiler is off-line. Any air allowed to draft through the boiler will absorb energy from the hot water. In general, a natural draft will result for most boilers. These parasitic losses should be considered in a detailed system analysis. The possibility of allowing boilers to operate in a modulation-off control mode may provide overall efficiency improvement.

Boiler Fuel Flow

An estimate of boiler fuel flow can be developed by determining boiler efficiency by the indirect efficiency method. This method assumes boiler efficiency is **100%** minus the sum of the losses. The primary losses have been previously identified as shell losses, blowdown losses and stack losses.

$$\eta_{\text{indirect}} = 100\% - \lambda_{\text{stack}} - \lambda_{residuals} - \lambda_{\text{shell}}$$

The loss categories are in general in line with EN 12953-11 and EN 12592-15, where

λ_{stack} translates to losses in the flue gas

λ_{shell} translates to losses due to radiation and convection

$\lambda_{residuals}$ translate to losses due to enthalpy and unburned combustibles in ash and flue dust for solid fuels for shell boilers (as per EN 12953-11:2003) **or** to losses due to enthalpy and unburned combustibles in tap and flue dust for watertube boilers (as per EN 12952-15:2003).

Other miscellaneous losses exist, but these are generally the main losses. In fact, the major loss associated with the boiler operation is typically stack loss. Therefore, indirect efficiency can be estimated from flue gas temperature and oxygen content. After an estimate of boiler efficiency has been obtained, the definition of boiler efficiency can be used along with steam production to estimate fuel flow.

$$\dot{m}_{\text{fuel}} = \frac{\dot{m}_D \cdot (h_u - h_w) + \dot{Q}_{reheat}}{\eta_{indirect} \cdot HHV}$$

*HHV: Fuel's High Heating Value→ Energy Content per unit of fuel mass or volume (experimental data)

Task 5: Environment & economics

6 Task 5: Environment & economics

6.1 Objectives

According to methodology, the objective of Task 5 is the evaluation of environmental impacts of the steam boilers. Representative product category as the "Base-case" for the whole of the EU-28 will be defined. On these Base Cases the environmental and Life Cycle Cost analyses will be built throughout the rest of the study.

The description of the Base Case is the synthesis of the results of Tasks 1 to 4 and the point-of-reference for tasks 6 (improvement potential) and 7 (policy, scenario, impact and sensitivity analysis).

For the Calculation of the Base Case Environmental Impact Assessment we will use the EcoReport 2011 tool.

6.2 Approach

The Subtasks listed in Table 59 are foreseen in order to achieve the foregoing mentioned objective. In Subtask 5.1 relevant product specific inputs are presented. Based on these data the environmental impact per Base Case will be estimated in Subtask 5.2. Then Life Cycle Costs are estimated for each Base Case in Subtask 5.3. Finally the environmental impact is being calculated for each Base Case for the EU in Subtask 5.4 taking stock estimations into account. These values are being set in relation to EU total values in Subtask 5.5.

Table 59 - Subtask structure in Task 5

Subtask	Input
Subtask 5.1: Product specific inputs	Bill Of Material (BOM), identifying materials fraction at the level of EuP EcoReport Unit Indicators, as proposed by the Methodology
	Volume of packaged product
	Annual resources consumption (energy), e.g. user data
Subtask 5.2: Base Case Environmental Impact Assessment	Selection of relevant Unit indicators from EcoReport / MEEuP
	Environmental Impact Assessment per Base Case unit
Subtask 5.3: Base Case Life Cycle Cost	Combination of results from Task 2 and Task 3 for the Life Cycle Cost Assessment

Subtask 5.4: EU total impacts	Aggregation of the Base Cases environmental impact data (Subtask 5.2) to EU28 level, using stock data coming from Task 7[53].
Subtask 5.5: EU 28 Total systems impact	Using the estimates of Subtask 5.4 to evaluate the total environmental impact of the product system and compare EU total values.

6.3 Subtask 5.1: product specific inputs

Subtask 5.1 describes the inputs setting up the reference for the environmental and economic improvements to be defined in Task 6 (Design Options) and Task 7 (Scenarios). This section will be built on ten Base Cases, shown in Table 60. These Bases Cases aim to cover several aspects relevant for this study. First the thermal output of the scope from 1 MWth to 50 MWth is being covered by four differing values ranging from 2,5 MWth output up to 35 MWth output. No values above 35 MWth output has been chosen as stakeholder mentioned that sizes above 35 MWth are very rare for industrial steam boilers. Furthermore stakeholder mentioned that thermal efficiencies are dependent on pressure level. Therefore two different pressure levels have been chosen in order to address this. This circumstance results in five base cases with a lower pressure, where the efficiency is higher than in these base cases with the higher pressure level. The chosen thermal efficiencies are estimations based on estimations from our technology experts as part of Task 4. The underlying values are listed in Table 60.

53 We use the stock data from Task 7 due to consistency reasons.

Table 60 - Overview of the Base Cases

Base Case No.	Description	Thermal output (MWth)	Thermal efficiency [%]*	Operational pressure [bar]	Steam production [t/h]	Average thermal efficiency [%]**
1	Very small sized industrial steam boiler fired with natural gas, medium pressure	2,5	87	15	3,2	91,1
2	Very small sized industrial steam boiler fired with natural gas, high pressure	2,5	86	25	3,2	90,1
3	Small sized industrial steam boiler fired with natural gas, medium pressure	7	87	15	9,0	91,1
4	Small sized industrial steam boiler fired with natural gas, high pressure	7	86	25	9,0	90,2
5	Medium sized industrial steam boiler fired with natural gas, medium pressure	20	87	15	25,8	91,2
6	Medium sized industrial steam boiler fired with natural gas, high pressure	20	86	25	25,7	90,2
7	Large sized industrial steam boiler fired with natural gas, medium pressure	35	87	15	45,1	91,3
8	Large sized industrial steam boiler fired with natural gas, high pressure	35	86	25	44,9	90,4
9	Large sized industrial steam boiler fired with natural gas, medium pressure **(Watertube design)**	35	85	15	45,1	89,4
10	Large sized industrial steam boiler fired with natural gas, high pressure **(Watertube design)**	35	84	25	44,9	88,4

**: Without any design options (cf. Task 6).*

***: For the stock. Assuming that the stock is equipped with design options as per assumed technology shares in stock (cf. Task 7). Used for modelling the environmental impact with the EcoReport 2011 tool (from the EC) in order to guarantee consistency with Task 7.*

6.3.1 Subtask 5.1.2: Manufacturing Phase (BOMs)

The material composition is described by the 'bill of materials' (BOM). The BOMs are constructed on the basis of data gathered from European Heating Association (EHI).

Table 59 gives the inputs that will be used for the environmental impact assessment, the Life Cycle Costs calculation and EU Totals.

Table 61 - BOM of Base Cases

Base Case	Boiler	Steel	Isolation	Paintwork	Brick lining
		kg	kg	kg	kg
1	Very small sized industrial steam boiler fired with natural gas, medium pressure	9000	na	na	na
2	Very small sized industrial steam boiler fired with natural gas, high pressure	11000	na	na	na
3	Small sized industrial steam boiler fired with natural gas, medium pressure	23000	530	10	1330
4	Small sized industrial steam boiler fired with natural gas, high pressure	27000	530	10	1310
5	Medium sized industrial steam boiler fired with natural gas, medium pressure	45000	1160	30	2840
6	Medium sized industrial steam boiler fired with natural gas, high pressure	50000	1160	30	2870
7	Large sized industrial steam boiler fired with natural gas, medium pressure	69000	1560	40	5400
8	Large sized industrial steam boiler fired with natural gas, high pressure	77000	1560	40	5400
9	Large sized industrial steam boiler fired with natural gas, medium pressure (watertube design)	n.a. – assumed like No. 7			
10	Large sized industrial steam boiler fired with natural gas, high pressure (watertube design)	na – assumed like No.8			

Source: rounded figures, based on BDH estimation

It should be observed that from the listed components only steel will be taken into account for conducting the analysis with the EcoReport 2011 tool. This is based in the fact that the materials of the other components are not identified in a proper way to be used in the EcoReport 2011 tool.

6.3.2Subtask 5.1.2: Distribution phase

The EcoReport 2011 tool requires the product volume as an input for transportation and warehouse. These have been estimated as listed in Table 62.

Table 62 - Distribution inputs for Base Cases

Pos nr	Mat/ Process	Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5	Base Case 6	Base Case 7	Base Case 8
208	Is it an ICT or Cons. Electr. Product <15 kg?	NO	NO	NO	NO	NO	NO	NO	NO
209	Is it an installed appliance?	YES	YES	YES	YES	YES	YES	YES	YES
210	Volume of packaged final product (M3)	50	50	80	80	180	180	290	290

6.3.3Subtask 5.1.3: Use phase

The environmental impacts in the use phase of industrial steam boiler consist mainly of:

- Electricity consumption
- Consumption of fossil fuel
- Consumption of water
- Consumption of consumables (e.g. Gaskets, Insulation material)

Only consumption of fossil fuel during the use phase will be quantified. The other positions are excluded due to several reasons.

The electricity consumption of steam boilers is mainly caused by the consumption of the feedwater pump and the electric drive for the air-blower. As the feedwater pump is not defined to be within the strict product scope, the appropriate electricity consumption has to be omitted. Furthermore water pumps are also in scope of Lot 29 - another on-going Eco-Design process. The electricity consumption of the electric drive for the air blower is being estimated in Task 6 and Task 7 for the policy scenarios. However, the impact of such drives had been assessed in Lot 11. Based on Lot 11 Ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW are already in force (cf. COMMISSION REGULATION (EU) No 327/2011). We thus omit the electric drives for the air blower in Task 5.

The consumption of water can differ among facilities strongly, based in the fact that steam can be consumed within the process. Therefore water consumption has been omitted too.

The consumption of consumables has been omitted as this might also differ among facilities based in varying site conditions. Since useful data on that topic is not available, the consumption of consumables has been excluded as well.

Finally the use profile for the Base Cases relevant for consumption of fossil fuel is derived by defining annual operation hours and machine lifetime. The assumptions on annual operation hours are derived from considerations made in Task 7[54]. The machine life time is assumed to be 25 years. The appropriate values are summarized below.

Operation hours per year per Base Case*

Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5	Base Case 6	Base Case 7	Base Case 8	Base Case 9	Base Case 10
1250**									

**: The machine lifetime is assumed to be 25 years for all cases*

***: In a previous version the operation hours had been listed disaggregated per Base Case. These obsolete values had been derived from scientific literature (cf. Task 3) and for Base Case 7 to 10 from stakeholder comments. Given the stock data presented in Task 7 the estimated energy consumption of the EU stock + new models sold in the reference year would be around 7900 PJ based on the obsolete values.*

However according Odyssee (which refers to Eurostat) the gas consumption of industry is between 3500 and 3750 PJ for the years between 2009 and 2013. Thus the first estimation seemed to be by far too high. This might have the following reasons (we respond to each possible reason directly afterwards):

1) The stock is overestimated: As we received stock data from the BDH we do not adjust these values. These values represent best guesses from industry.

2) The boilers in scope are also widely common in the tertiary sector: Although this might be for smaller sizes we do not assume this to be common. Boilers in the tertiary sector are usually boiler for central heating systems – producing hot water, not steam.

3) The Base Cases do not represent the real size distribution: We assume the stock to be distributed identical to the sales figures derived from EHI (presenting sales for the following clusters: 1 – 5MW, 5 – 25 MW and 25 – 50 MW). We then assume a continuous distribution between thermal size and stock numbers resulting in a probability density function with a positive skew. Afterwards we correct our Base Cases with a correction factor so that they fit to the probability density function. However this approach is based on the assumption that stock behave like sales – which might not be the case in reality.

4) The operation hours are overestimated: In industry a common configuration is to operate base load machines and to have back-up machines serving as peaker (cf. Task 3). These machines might have much lower operation hours. **Therefore we reduce the operation hours for all cases down to 1250 hours. This results in a more realistic energy consumption of stock. Please refer to Task 7 on that topic.**

6.3.4 Subtask 5.1.4: End-of-life phase

Due to the lack of data, we can provide the following assumptions:

[54] Please note that this changed towards the last version where the operation hours were based on considerations from Task 3. The explanation is given in the box on the operation hours.

- the EU sales 20 years ago was 34% of today values[55];
- the recycling rate of metals is 95% as defined in EcoReport model.

6.4 Subtask 5.2: Base Case Environmental Impact Assessment

For the Calculation of the Base Case Environmental Impact Assessment we used the EcoReport 2011 tool. The relevant date to be filled in the tool has been presented in the foregoing sections.

The table below summarizes the outcome indicating the environmental impact per Base Case for one single product per case.

55 The 20 years ago value on sales has been assumed by Eurostat data (1995 and 2012 EU sales), adjusted proportionally to the EU sales gathered from BDH (current data).

Table 63 - Environmental impact of Base Case units over their lifetime per unit

Environmental impact of Base Case units over their lifetime per unit											
Materials	unit	Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5	Base Case 6	Base Case 7	Base Case 8	Base Case 9	Base Case 10
Total	t	0	0	0	0	0	0	0	0	0	0
of which											
PRODUCTION (total)	t	16	20	23	27	45	50	69	77	77	77
USE	t	0	0	0	0	0	1	1	1	1	1
DISTRIBUTION	t	0	0	0	0	0	0	0	0	0	0
END OF LIFE (Disposal)	t	0	0	0	0	1	1	1	1	1	1
END OF LIFE (Recycled)	t	5	6	8	9	15	16	23	25	25	25
END OF LIFE (Stock)	t	11	13	16	18	30	33	46	51	51	51
Other Resources& Waste											
Total Energy (GER)	GJ	364.316	368.377	1.147.698	1.160.078	2.557.128	2.585.481	6.044.134	6.109.588	2.587.566	2.616.735
of which, electricity (in primary PJ)	GJ	450	461	1.722	1.735	5.282	5.300	14.445	14.468	6.198	6.198
Water (process)	mln. m³	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.
Water (cooling)	ltr	17.756	17.756	73.274	73.274	228.532	228.532	632.338	632.338	264.749	264.749
Waste, non-haz./ landfill	kg	9.045	11.021	13.774	16.042	27.386	30.495	45.693	49.773	45.511	45.511
Waste, hazardous/ incinerated	kg	7	7	27	27	83	83	228	228	97	97
Emissions (Air)											
Greenhouse Gases in GWP100	t CO2 eq.	20.143	20.368	63.441	64.126	141.328	142.898	334.011	337.632	143.012	144.625
Acidification, emissions	t SO2 eq.	6	6	19	19	42	43	100	101	43	43
Volatile Organic Compounds (VOC)	kg	276	279	874	883	1.978	1.999	4.716	4.764	2.023	2.044
Persistent Organic Pollutants (POP)	ng i-Teq	132.410	161.871	196.064	229.866	379.727	426.073	603.423	664.243	644.944	644.944
Heavy Metals	mg Ni eq.	33.888	40.242	60.510	67.801	136.657	146.653	275.466	288.584	204.958	204.958
PAHs	mg Ni eq.	13.682	13.875	39.977	40.414	92.370	93.287	216.319	218.314	100.666	101.483

Environmental impact of Base Case units over their lifetime per unit											
Materials	unit	Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5	Base Case 6	Base Case 7	Base Case 8	Base Case 9	Base Case 10
Particulate Matter (PM, dust)	kg	285	289	616	623	1.380	1.392	2.781	2.805	1.789	1.798
Emissions (Water)											
Heavy Metals	mg Hg/20	18.927	22.777	32.257	36.674	70.281	76.337	135.909	143.857	108.255	108.255
Eutrophication	g PO4	502	598	936	1.045	2.165	2.316	4.539	4.737	3.174	3.174

6.5 Subtask 5.3: Base Case Life Cycle Cost for consumer

This section is to present the life cycle costs per base case.

The life cycle costs for consumer are calculated using the LCC equations according to the ecodesign methodology:

LCC = PP + PWF * OE + EoL

Where

LCC is Life Cycle Costs to end-users in €,

PP is the purchase price (including installation costs) in €,

OE is the annual operating expense in €

EoL: End-of-life costs (disposal cost, recycling charge) or benefit (resale) in €,

PWF (Present Worth Factor) is {1 – 1/(1+ r) N }/r,

n which N is the product life and r is the discount (interest-inflation) rate minus the growth rate of running cost components (e.g. energy, water rates).

the LCC formula for MEErP can be simplified to

LCC= PP + N*OE + EoL

Where

N is the product life in years and

As for inputs for LCA, according the methodology the following values should be gathered:

Purchase price. the installation costs (specify end-of-life disposal costs comprised in product price);

Repair and maintenance costs;

Unitary rates for energy, water and/or other consumables;

Discount, inflation, interest rates to be applied;

Product service life.

The estimation on costs and prices comes from Task 2 (paragraph 3.8).

In particular, such estimation is based on information on costs from gathered from stakeholder (Case studies).

In Table 64 the overview of costs and sale price of Base Cases.

Table 64 – Costs and prices of Base Case

Base cases	Size (MWth)	Steam production [kg/h]	Boiler unit cost (€)	Main accessories cost (€)	Installation cost (€)	Overall cost of the product (€)	O&M (€) (not included in the sale)	O&M accessories (€) (not included in the sale)	Product sale price (€)
1	2,5	3290	59.100	36.000,00	20.000,00	115.100	2.300,00	2.400,00	138.100
2	2,5	3260	59.100	36.000,00	20.000,00	115.100	2.300,00	2.400,00	138.100
3	7	9200	97.000	75.000,00	100.000,00	271.100	4.000,00	3.000,00	326.380
4	7	9130	97.000	75.000,00	100.000,00	272.000	4.000,00	3.000,00	326.380
5	20	26280	135.600	115.000,00	136.000,00	386.600	6.000,00	4.000,00	463.955
6	20	26070	135.600	115.000,00	136.000,00	386.600	6.000,00	4.000,00	463.955
7	35	46000	156.200	130.000,00	150.000,00	436.200	7.000,00	5.000,00	523.480
8	35	45630	156.200	130.000,00	150.000,00	436.200	7.000,00	5.000,00	523.480

The Boiler Unit Cost will be the input for the Cost Analysis carried out in Task 6, Subtask 6.2.

6.5.1 Subtask 5.3.1. Assumptions for costs and sale prices of base cases

Looking at the formation gathered by a producer (Case Studies in Task 2), they can be considered reliable although they do not fit with the theoretical base cases, since the case studies are built around small scale steam boilers. Nonetheless, the full description of components and the direct relationship with boilers, accessories costs, installation costs and O&M is granted. We have based on this the estimation of all these costs to be assigned to the proposed Base Cases, using the following approximation related to the thermal capacity:

x= thermal capacity

y= boiler costs

Available data from the Case Studies are the following:

x	y
1,7	29.000,00
2,8	84.700,00
11,6	110.000,00

The following relationship has been applied

$y = 25344 + 36814 \ln(x)$

The results are shown in Table 64.

Such estimations are consistent to data on production gathered from the Delphi Survey (see paragraph New data collection) since for the 1-5MW size range, BDH's data show an average value of 44.000 Euros. The more detailed information on real cases provide a larger range, from 65.000 Euros (1,7 MWth) to 169.700 Euros (2,8 MWh). The first one appears to be not far from the BHD 1-5 MW average, while the second is closer to the second group (5-25 MW) where the average is around 146.700 Euros.

Finally, as to the sale prices, it has been estimated a markup of 20% on the overall cost of product.

6.5.2 Subtask 5.3.2. Base Case Life Cycle Cost for consumer

The Base Case Life Cycle Cost only considering Boiler unit costs and costs for natural gas (10.57 EUR/GJ)[56] are finally derived by the EcoReport 2011 tool assuming a discount rate of 4%. The results are listed in Table 65.

56 Eurostat average for the EU 28 for the year 2013

Table 65 Base Case LCC for consumer

Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5
4.087.800	4.135.000	11.372.300	11.503.700	32.346.200
Base Case 6	Base Case 7	Base Case 8	Base Case 9	Base Case 10
32.721.000	56.522.500	57.178.300	57.848.900	58.535.400

LCC [EUR]

6.6 Subtask 5.4: EU totals for the Base Cases

This section describes the environmental impacts of the Base Cases at EU level.

6.6.1 Subtask 5.4.1.: Assumptions on EU Sales and EU stock for Base Cases

As shown in Task 2 (Section New data collection), new market data on steam boilers with a power output between 1 and 50 MW provided production values for three different ranges of size of boilers, for water tube boilers, vapour-generating boilers and super-heated boilers (Table 66 and Table 67).

Table 66 – Production of steam boilers – pieces

Size of boiler (MW)	Water tube boilers (Prodcom 25.30.11.10)	Vapour generating boilers (Prodcom 25.30.11.50)	Super-heated boilers (Prodcom 25.30.11.70)
1-5 MW	400	1.500	25
5-25 MW	300	750	175
25-50 MW	300	250	50
Total	1000	2.500	250

Source: BDH

Table 67 – Production of steam boilers – value (€)

Size of boiler (MW)	Water tube boilers (Prodcom 25.30.11.10)	Vapour generating boilers (Prodcom 25.30.11.50)	Super-heated boilers (Prodcom 25.30.11.70)
1-5 MW	50.000.000	66.000.000	3.000.000
5-25 MW	200.000.000	110.000.000	9.000.000
25-50 MW	250.000.000	44.000.000	18.000.000
Total	500.000.000	220.000.000	30.000.000

Source: BDH

It can be observed that two base cases (as defined in defined in paragraph 5.3.1) fall into the small scale category, four base cases are in the medium scale range and two fall into the large scale category.

Size of Boiler (MW)	Base Cases	Size of Base case
1-5 MW	Very small sized industrial steam boiler fired with natural gas, medium pressure	2,5
	Very small sized industrial steam boiler fired with natural gas, high pressure	2,5
5-25 MW	Small sized industrial steam boiler fired with natural gas, medium pressure	7
	Small sized industrial steam boiler fired with natural gas, high pressure	7
	Medium sized industrial steam boiler fired with natural gas, medium pressure	20
	Medium sized industrial steam boiler fired with natural gas, high pressure	20
25-50 MW	Large sized industrial steam boiler fired with natural gas, medium pressure	35
	Large sized industrial steam boiler fired with natural gas, high pressure	35

In order to align the production values (available for the ranges of steam boilers) and the Base Cases, the following assumptions have been made:

1. Production of Base Cases is distributed in the respective ranges of size in the way that for each cluster two thirds of sales are medium pressure boiler and one third of sales are high pressure steam boilers for each cluster[57].
2. Steam boilers production is equivalent to the sales. The overall steam boilers sales in EU can be calculated from Production + Imports – Exports (Y+M-X), representing the apparent consumption;
3. Exports can be estimated as 20% of the production, while imports show values not-relevant to our analysis.
4. We then assume a continuous distribution between sales figures and thermal capacity where we align the function in the way that 10% of sales are within the range of 25 to 50 MW, 30% of sales are within the range of 5 to 25 MW and 60 % are within the range of 1 to 5 MW. This results in a density function with a positive skew. We then choose the pieces per

[57] According to a stakeholder comment from the 2nd stakeholder meeting.

cluster in the way that the average thermal capacity of each cluster is closest to the thermal capacity of each corresponding Base Cases (this is e.g. for Base Case No. 1 and No. 2 the cluster from 1 to 6 MW). We address this in Task 7 by weighting the consumption of each Base Cases with a correction factor balancing the difference between average thermal capacity of each chosen cluster and the thermal capacity of each Base Case.

Given the above assumptions, the derived values are listed in Table 68, .

Table 68 - Annual production and Exports of base cases

	Annual Production	Export
	pieces	pieces
Vapour generating boilers (Prodcom 25.30.11.50)	2500	500
Water tube boilers (Prodcom 25.30.11.10)	1000	200

Source: PwC on BDH data

Table 69 EU-Sales of Base Cases

Base Case	Base Case size (MWth)	Pieces
1	2,5	842
2	2,5	421
3	7	80
4	7	40
5	20	317
6	20	159
7	35	94
8	35	47
9	35	533
10	35	267
Total		**2800**

Source: PwC on BDH data

The assumed stock data for the Base Cases have been derived from calculations presented in Task 7[58]. We present the assumed stock in for each Base Case and compare it with the data from BDH presented in paragraph 3.6.1 afterwards.

Table 70 – Stock data of base cases

Base Case	Base Case size (MWth)	pieces
1	2,5	17.936
2	2,5	8.940
3	7	1.675

58 Please note that in a previous version another approach to estimate the stock has been presented. The approach has been adjusted in order to guarantee consistency with Task 7.

Base Case	Base Case size (MWth)	pieces
4	7	839
5	20	6.779
6	20	3.385
7	35	2.012
8	35	984
9	35	11.347
10	35	5.699
Total	**-**	**59.596**

Source: PwC on BDH data

In paragraph 2.6.1. a total amount of 70.109 steam boilers (of all size) is estimated for the EU by the BDH. We assume that these figures refer to the three Prodcom classes presented in Table 66. Assuming that the stock is identical distributed as the production values presented in Table 66 the pieces for each Prodcom class are presented in the following:

- Water tube boilers (Prodcom 25.30.11.10): 18696
- Vapour generating boilers (Prodcom 25.30.11.50): 46739
- and Super-heated boilers (Prodcom 25.30.11.70): 4674 .

Assuming that our Base Cases and thus stock only represents the Prodcom classes for Water tube boilers and Vapour generating boilers the appropriate share accounts to 65.435 pieces. This means that the estimation by the BDH is approximately **10%** higher than our estimation (i.e. the stock presented in Table 66). This is from our point of view a reasonable tolerance guaranteeing a consistent modelling of the scenarios in Task 7.

6.6.2 Subtask 5.4.2.: New products placed on the market

The environmental impact for new products placed at the market within the reference year 2013 is then listed in Table 71.

Table 71 - EU Impact of New Models sold in reference year over their lifetime

EU Impact of New Models sold in reference year over their lifetime											
Materials	unit	Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5	Base Case 6	Base Case 7	Base Case 8	Base Case 9	Base Case 10
Total	kt	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
of which											
PRODUCTION (total)	kt	13,43	8,22	1,86	1,10	14,13	7,98	6,50	3,60	40,79	20,43
USE	kt	0,13	0,08	0,02	0,01	0,14	0,08	0,06	0,04	0,41	0,20
DISTRIBUTION	kt	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
END OF LIFE (Disposal)	kt	0,23	0,14	0,03	0,02	0,24	0,14	0,11	0,06	0,70	0,35
END OF LIFE (Recycled)	kt	4,39	2,69	0,61	0,36	4,62	2,61	2,13	1,18	13,35	6,69
END OF LIFE (Stock)	kt	8,94	5,47	1,24	0,73	9,41	5,31	4,33	2,39	27,14	13,60
Other Resources& Waste											
Total Energy (GER)	PJ	306,75	155,09	91,82	46,40	810,61	411,09	568,15	287,15	1.379,17	698,67
of which, electricity (in primary PJ)	PJ	0,38	0,19	0,14	0,07	1,67	0,84	1,36	0,68	3,30	1,65
Water (process)	mln. m^3	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.
Water (cooling)	mln. m^3	0,01	0,01	0,01	0,00	0,07	0,04	0,06	0,03		0,07
Waste, non-haz./ landfill	kt	7,62	4,64	1,10	0,64	8,68	4,85	4,30	2,34	24,26	12,15
Waste, hazardous/ incinerated	kt	0,01	0,00	0,00	0,00	0,03	0,01	0,02	0,01	0,05	0,03
Emissions (Air)											
Greenhouse Gases in GWP100	Mt CO_2 eq.	16,96	8,58	5,08	2,57	44,80	22,72	31,40	4,75	76,23	38,61
Acidification, emissions	kt SO_2 eq.	5,04	2,55	1,51	0,76	13,38	6,78	9,40	0,22	22,88	11,59
Volatile Organic Compounds (VOC)	kt	0,23	0,12	0,07	0,04	0,63	0,32	0,44	0,03	1,08	0,55
Persistent Organic Pollutants (POP)	g i-Teq	0,11	0,07	0,02	0,01	0,12	0,07	0,06	0,01	0,34	0,17
Heavy Metals	ton Ni eq.	0,03	0,02	0,00	0,00	0,04	0,02	0,03	0,01	0,11	0,05
PAHs	ton Ni eq.	0,01	0,01	0,00	0,00	0,03	0,01	0,02	0,13	0,05	0,03

EU Impact of New Models sold in reference year over their lifetime											
Materials	unit	Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5	Base Case 6	Base Case 7	Base Case 8	Base Case 9	Base Case 10
Particulate Matter (PM, dust)	kt	0,24	0,12	0,05	0,02	0,44	0,22	0,26	0,00	0,95	0,48
Emissions (Water)		0,00	0,00	0,00	0,00	0,00	0,00				
Heavy Metals	ton Hg/20	0,00	0,01	0,00	0,00	0,02	0,01	0,01	0,01	0,06	0,03
Eutrophication	kt PO4	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

6.6.3 Subtask 5.4.3.: Annual impact of production

The overall combined environmental impact for the products placed on the market is indicated below. It describes the production phase impacts of all products placed on the market (value similar to that presented for new products, combined with the impacts from energy consumption of not only the new products but also the other products already present in the filled (installed base or stock energy consumption). It therefore represents the annual impacts of the complete product group, new and existing on the market.

Table 72 - EU Impact of Products in reference year (produced, in use, discarded), i.e. EU Stock

EU Impact of Products in reference year (produced, in use, discarded)***											
Materials	unit	Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5	Base Case 6	Base Case 7	Base Case 8	Base Case 9	Base Case 10
Total	kt	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
of which		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
PRODUCTION (total)	kt	13,43	8,22	1,86	1,10	14,13	7,98	6,50	3,60	40,79	20,43
USE	kt	0,13	0,08	0,02	0,01	0,14	0,08	0,06	0,04	0,41	0,20
DISTRIBUTION	kt	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
END OF LIFE (Disposal)	kt	0,23	0,14	0,03	0,02	0,24	0,14	0,11	0,06	0,70	0,35
END OF LIFE (Recycled)	kt	4,39	2,69	0,61	0,36	4,62	2,61	2,13	1,18	13,35	6,69
END OF LIFE (Stock)	kt	8,94	5,47	1,24	0,73	9,41	5,31	4,33	2,39	27,14	13,60
Other Resources& Waste											
Total Energy (GER)	PJ	249,21	125,59	73,24	37,09	661,08	333,70	463,76	287,15	1.119,62	568,73
of which, electricity (in primary PJ)	PJ	0,34	0,17	0,11	0,06	1,39	0,70	1,12	0,68	2,77	1,39
Water (process)	mln. m3	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.	not ev.
Water (cooling)	mln. m3	0,01	0,01	0,00	0,00	0,06	0,03	0,05	0,03	0,11	0,06
Waste, non-haz./ landfill	kt	11,00	6,72	1,56	0,91	12,13	6,80	5,82	2,34	34,34	17,21
Waste, hazardous/ incinerated	kt	0,00	0,00	0,00	0,00	0,02	0,01	0,02	0,01	0,04	0,02
Emissions (Air)											
Greenhouse Gases in GWP100	Mt CO_2 eq.	13,78	6,95	4,05	2,05	36,54	18,44	25,63	15,87	61,89	31,44
Acidification, emissions	kt SO_2 eq.	4,11	2,08	1,21	0,61	10,93	5,52	7,68	4,75	18,64	9,47
Volatile Organic Compounds (VOC)	kt	0,19	0,10	0,06	0,03	0,51	0,26	0,36	0,22	0,88	0,45
Persistent Organic Pollutants (POP)	g i-Teq	0,16	0,10	0,02	0,01	0,17	0,10	0,08	0,03	0,50	0,25
Heavy Metals	ton Ni eq.	0,04	0,02	0,01	0,00	0,05	0,03	0,03	0,01	0,14	0,07

EU Impact of Products in reference year (produced, in use, discarded)***											
Materials	unit	Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5	Base Case 6	Base Case 7	Base Case 8	Base Case 9	Base Case 10
PAHs	ton Ni eq.	0,01	0,01	0,00	0,00	0,02	0,01	0,02	0,01	0,05	0,02
Particulate Matter (PM, dust)	kt	0,23	0,12	0,04	0,02	0,40	0,20	0,23	0,13	0,89	0,45
Emissions (Water)											
Heavy Metals	ton Hg/20	0,02	0,01	0,00	0,00	0,03	0,02	0,01	0,01	0,08	0,04
Eutrophication	kt PO_4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

6.6.4 Subtask 5.5: EU-total system impact

This section presents the total impacts of the product as a fraction of the EU-27 impacts. For this the normalisation factors as shown in the table below are used.

Main life cycle indicators	EU totals	Unit	Reference
Materials			
Plastics	48	Mt	Ref: Plastics Europe (demand by EU converters) [1]
Ferrous metals	206	Mt	Ref: Iron & Steel Statistics Bureau [1]
Non-ferrous metals	20	Mt	Ref: www.eaa.net et al. (Al 12,5+Cu 4,7 + Zn 0,8 + Pb 0,8 + Ni 0,3)
Other resources & Waste			
Total Energy (GER)	75.698	PJ	Eurostat, Gross Inland Consumption EU-27, 2007, in Net Calorific Value
Of which electricity	2.800	TWh	Final end-use. Ref: Eurostat
Water process*	247.000	mln. m3	Ref: http://ec.europa.eu/environment/water/quantity/pdf/exec_summary.pdf [1]
Waste, non-haz./ landfill*	2.947	Mt	Ref: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php?title=File:Gen
Waste, hazardous/ incinerated *	89	kton	eration_of_waste,_total_arising_and_by_selected_economic / activities
Emissions (Air)			
Greenhouse Gases in GWP100	5.054	Mt CO_2eq.	Ref: EEA3 (CO_2 4187 + CH_4 416 + N_2O 374 + HFCs 63 + PFCs 4 + SF_6 10)
Acidifying agents (AP)	22.432	kt SO_2eq.	Ref: EEA1 (NO_x 11 151 + SO_x 7 339 + NH_3 3 876)
Volatile	8.951	kt	Ref: EEA1

Main life cycle indicators	EU totals	Unit	Reference
Org. Compounds (VOC)			
Persistent Org. Pollutants (POP)	2.212	g i-Teq.	Ref: EEA1 (dioxins and furans only)
Heavy Metals (HM)	5.903	ton Ni eq.	Ref: EEA1 (Cd 118 + Hg 89 + Pb 2157 t); EEA2 (As 337 + Ni 2843 t); CML (Cr 517 + Cu 589 + Zn 6510 t)
PAHs	1.369	ton Ni eq.	Ref: EEA1
Particulate Matter (PM, dust)	3.522	kt	Ref: EEA1 (1400 kt PM2,5 + 2122 kt PM10)
Emissions (Water)			
Heavy Metals (HM)	12.853	ton Hg/20	Ref: CML (As 17+Cd 21,3 + Cr 271 + Cu 1690 + Pb 2260 + Hg 14,3 + Ni 551 t + Zn 11200 t)
Eutrophication (EP)	900	kt PO_4	Ref: EEA2 (Baltic 861 N/5,4 P + North Sea 761 N/14,4 P + Danube/Black Sea 270 N/ 14,2 P)

**=caution: low accuracy for production Phase*

EEA1, European Environmental Agency, National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention), EU-27 (national territory), 2007. (extract Feb. 2011);

EEA2, Source apportionment of nitrogen and phosphorus inputs into the aquatic environment, 2005. [Compare: CML value for EU-15 1995 is 1 263 kt PO_4 eq. based on 1 370 kt N and 224 kt P; no data for aquatic emissions BOD, COD, DOC, TOC reported];

EEA3: EEA, Annual European Community greenhouse gas inventory 1990–2007 and inventory report 2009, Submission to the UNFCCC Secretariat, 2009. Total without LULUCF (Land-Use, Land-Use Change & Forestry);

EC1, European Commission (DG ENV), Ambient air pollution by AS, CD and NI compounds, Position Paper, 2001. [data sources stem from ca. 1990, EU-15 recalculated by VHK to 2007, EU-27 using multiplier 1,3 for EU-expansion and 55% emission reduction (e.g. Cd) 1990- 2007; data are roughly in line with CML];

Eurostat, Energy Balance Sheets 2007-2008, European Commission, edition 2010;

CML, Centrum voor Milieukunde Leiden,Characterisation and Normalisation factors (CML-IA xls file Nov. 2010; extract Feb. 2011); data for EU-15, 1995. Assumed that EU expansion to EU-17 and emission decrease 1995-2007 will balance;

[1] from intermediate source: AEA, ENTR Lot 3 Sound and Imaging Equipment, preparatory Ecodesign study, Nov. 2010.

It should be noted that the normalization factors above are related to year 2010, while reference year both for stock and sales values is 2013. The values for the Base Cases are listed in Table 73.

Table 73 - Environmental Impacts EU-Stock in reference year (2013), Values for Base Cases in % of EU totals – needs to be updated

Summary Environmental Impacts EU-Stock in reference year, Values for Base Cases in % of EU totals												
Main life cycle indicators	unit	EU totals	Base Case 1	Base Case 2	Base Case 3	Base Case 4	Base Case 5	Base Case 6	Base Case 7	Base Case 8	Base Case 9	Base Case 10
Materials												
Plastics	Mt	48	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
Ferrous metals	Mt	206	0,007%	0,004%	0,001%	0,001%	0,007%	0,004%	0,003%	0,002%	0,020%	0,010%
Non-ferrous metals	Mt	20	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
Other resources & waste												
Total Energy (GER)	PJ	75.697	0,329%	0,166%	0,097%	0,049%	0,873%	0,441%	0,613%	0,303%	1,479%	0,751%
of which, electricity	TWh	2.800	0,001%	0,001%	0,000%	0,000%	0,006%	0,003%	0,004%	0,002%	0,011%	0,006%
Water (process)*	mln.m³	247.000	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
Waste, non-haz./ landfill*	Mt	2.947	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,001%	0,001%
Waste, hazardous/ incinerated*	kton	89	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
Emissions (Air)												
Greenhouse Gases in GWP100	Mt CO_2eq.	5.054	0,273%	0,137%	0,080%	0,041%	0,723%	0,365%	0,507%	0,250%	1,225%	0,622%
Acidifying agents (AP)	kt SO_2eq.	22.432	0,018%	0,009%	0,005%	0,003%	0,049%	0,025%	0,034%	0,017%	0,083%	0,042%
Volatile Org. Compounds (VOC)	kt	8.951	0,002%	0,001%	0,001%	0,000%	0,006%	0,003%	0,004%	0,002%	0,010%	0,005%
Persistent Org. Pollutants (POP)	g i-Teq.	2.212	0,007%	0,005%	0,001%	0,001%	0,008%	0,004%	0,004%	0,002%	0,023%	0,011%
Heavy Metals (HM)	ton Ni eq.	5.903	0,001%	0,000%	0,000%	0,000%	0,001%	0,000%	0,000%	0,000%	0,002%	0,001%
PAHs	ton Ni eq.	1.369	0,001%	0,000%	0,000%	0,000%	0,002%	0,001%	0,001%	0,001%	0,003%	0,002%
Particulate Matter (PM, dust)	kt	3.522	0,006%	0,003%	0,001%	0,001%	0,011%	0,006%	0,007%	0,003%	0,025%	0,013%
Emissions (Water)												
Heavy Metals (HM)	ton Hg/20	12.853	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,001%	0,000%
Eutrophication (EP)	kt PO4	900	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%

Task 6: Design options

7 Task 6: Design options

7.1 Objectives

The objective of task 6 is to identify technological design options (Best Available Technology BAT/Best Not yet Available Technology BNAT) for improving the performance of steam boilers as compared to the base case scenario and to analyse the Least Life Cycle Costs (LLCC) of BAT.

Experience in past ErP/EuP studies shows that there often is a considerable cost-effective improvement potential for many technological products. The analysis carried out in this task is required to determine how technological improvements impact on the user's and societal overall expenditures in the case of steam boilers. It further points out in how far LLCC and BAT differ and to what extend this difference allows a further product differentiation respectively competition.

7.2 Approach

The following subtasks will be carried out to achieve the overall objective:

- identification of design options and assessment of their impacts
- analysis of costs
- analysis of BAT and LLCC
- long term potential (BNAT) & system analysis

The analysis will approach real life conditions and draw on standard test conditions where applicable.

7.3 Subtask 6.1: Identification of design options and assessment of their impacts

The aim of this subtask is to break down product improvements into individual design options that may improve the environmental performance of the considered products as compared to the base case analysis. The main steps carried out in this subtask are to identify relevant design options and to describe them.

There are a number of different technological design options for steam boilers. They vary depending on the product scope. Apart from design options efficiency improvements can also be achieved through maintenance and sound operation.

Task 3 has already given an overview of the different levels on which efficiency can be improved from the users' perspective. Efficiency improvements can either be achieved on the level of the strict product scope, the extended product approach or the technical system approach.

The strict product approach includes all parts belonging to the steam boiler itself. It therefore focuses only on the generation part of the steam system. It also excludes feedwater treatment. As mentioned in Task 3, the strict product scope includes optional parts like an economizer or an air preheater as they are commonly used efficiency options. Efficiency improvements included in this approach focus on the improvement of certain technologies and can most commonly be added to the category of technology add-ons or replacements.

The extended product approach includes the same parts as the strict product scope however focuses on varying loads, controllability and auxiliary devices. Important factors that have to be considered are on the one hand the varying operation hours per year. They depend on the industry sector and shift model. On the other hand the wide range of pressure and steam flow covered has to be taken into account.

The former will be considered by defining operation hours per year for each base case. The operation hours had been set based on plausibility considerations from energy statistics (cf. Task 5)[59]. The latter often leads to costumer specific product designs.

In contrast to the strict product scope, efficiency improvements in the extended product approach are in many cases organizational. This is caused by the fact that steam and combustion parameters have to be checked regularly to assure a sound operation. However the sound operation can also be achieved by installing instrumentation and controls which belong to the category of technology add-ons.

The technical system approach includes the whole system starting from steam generation to the distribution and steam using process and if possible the condensate recovery. It is important to bear this last approach in mind as there are significant energy efficiency potentials. However as shown in Task 3 the steam using processes vary greatly and are therefore excluded from this study. Other efficiency improvements belonging to this category are measures related to the feedwater treatment, the condensate recovery and the distribution of steam. As the aim is to improve the performance of steam boilers compared to defined base cases, the technical system approach does not play a relevant role in this study. However due to high saving potentials possible efficiency measures will be listed for further guidance.

For the identification of the relevant design options, we will start with a review of literature on improvement potentials for industrial steam boilers. Relevant sources are (among others) relevant technical literature, user guidelines on steam boilers), reference documents on best available technology or studies on overall industrial energy saving potentials. Based on this literature analysis, we compile a list of relevant design option.

7.3.1 Efficiency measures within the technical system approach

As the technical system approach covers the whole steam system, the amount of improvement options is high. Table 74 lists different measures that resulted from our literature review. It excludes measures to improve steam using processes as they vary greatly between the different industrial sectors.

Although saving potentials exist, the measures of the technical system approach will not be identified as possible design options. However they can be used as a guidance how to increase energy efficiency even further.

Installing a condensate return system decreases the use of fresh feedwater and chemicals used for water treatment. It also enables the recovery of the remaining energy in the waste steam. However not all steam systems can be equipped with a condensate return system. The reason for that is that there is either no steam left after the steam using process or that the steam is polluted. According to the IEA[60] already 75% of all systems in OECD countries are equipped with a condensate return system. In addition it is difficult to summarize saving potentials as they are highly site specific[61].

Other relevant measures include the adequate attention to routine maintenance of steam traps resulting in savings of up to 5% [62]. Vapor recompression is an effective way of heat recovery and can result in savings of up to 20% according to the IEA.

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59 In a previous version of this report they had been based on figures from U.S. stock data for the industrial steam population in a previous version of this report. This is obsolete (cf. Task 5).

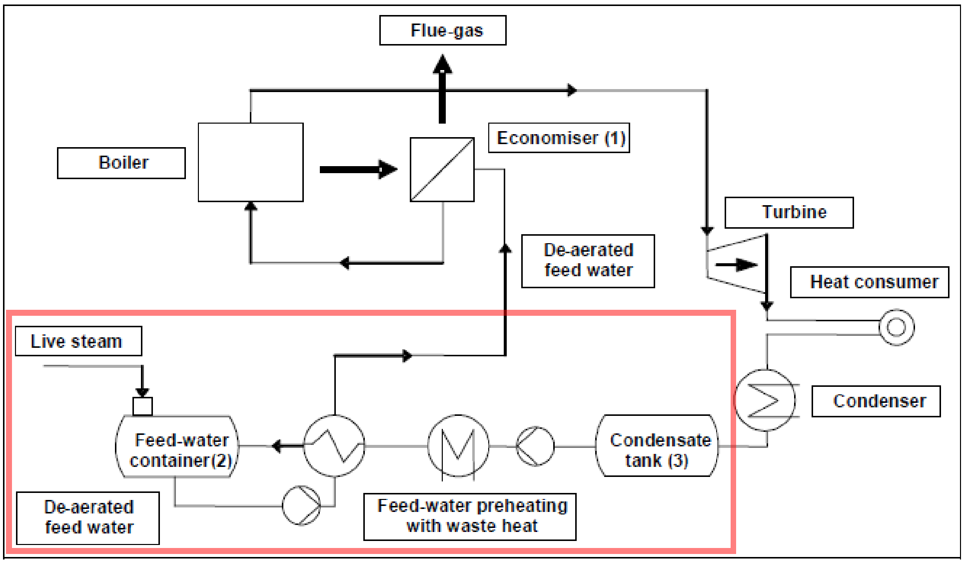
60 International Energy Agency (2007): Tracking Industrial Energy Efficiency and CO2 Emissions

61 EPA – United States Environment Protection Agency (2010): Available and emerging technologies for reducing greenhouse gas emissions from industrial, commercial, and institutional boilers.

62 International Energy Agency (2007): Tracking Industrial Energy Efficiency and CO2 Emissions

Apart from using economizers other options to preheat feedwater exist. Contrary to the economizer they are not included in the strict product scope as the preheating either takes place during the feedwater treatment or because the waste heat originates from other industrial processes. Preheating the feedwater by waste heat from industrial processes requires a systemic analysis of process boundaries (as sometimes cooling down of waste heat might be restricted by other factors such as the environment) and additional equipment. Preheating during the feedwater treatment can be done by using the heat contained in the deaerated feedwater. Feedwater coming from the condensate is usually mixed up with live steam to be deaerated resulting in a water temperature which is higher than at the condensate outlet. Thus the deaerated feedwater is being used to preheat feedwater coming from the condensate tank. By cooling down the deaerated water (which will be fed into the economizer) the efficiency of the steam generation can be increased (see Figure 70). This is based in the fact that by decreasing the temperature of the feedwater entering the economizer, more heat from the flue gas can be recovered to preheat the water[63] (see Figure 69).

Figure 69: Preheating the feedwater within feedwater treatment



Source: Carbon Trust (2012): Steam and high temperature hot water boilers.

63 European Comission (2009): BREF Reference Document on Best Available Techniques for Energy Efficiency

Table 74 - List of possible improvement options within the technical system approach

Improvement option	Description	Category
Condensate return system	Minimizes the amount of fresh feedwater and recovers remaining energy in the steam. Not applicable for all processes. [64]	Technology Add-On
Flue-gas isolation dampers[65]	Used to prevent boiler heat loss during downtime and stand-by modes. Only relevant for backup boilers.	Technology Add-On
Insulation of the generation and recovery system	Reduces heat loss during distribution and recovery.	Organizational/ Technology Add-On
Preheat feedwater	- With heat generated during stripping, - with deaerated feedwater, or - with waste heat from industrial processes[66].	Technology Add-On
Re-use flash steam	Flash steam forms during an expansion of condensate at high pressure. Flash steam enables the usage of the remaining energy in the condensate recovered. [67]	Technology Add-On
Steam Line Maintenance	Different organizational measures (e.g. Maintain steam traps, leaks and insulation)	Organizational
Steam Trap installation	Avoids that steam enters the condensate system.	Technology Add-On
Utilize backpressure turbines instead of PRVs (Pressure relief valve)	Reduction of exergy lost during throttling[68].	Technology Add-On
Vapor recompression	Enables the recovery of low-pressure waste steam[69].	Technology Add-On

64 EPA – United States Environment Protection Agency (2010): Available and emerging technologies for reducing greenhouse gas emissions from industrial, commercial, and institutional boilers

65 European Comission (2009): BREF Reference Document on Best Available Techniques for Energy Efficiency and

Carbon Trust (2012): Steam and high temperature hot water boilers.

66 European Comission (2009): BREF Reference Document on Best Available Techniques for Energy Efficiency.

67 European Comission (2009): BREF Reference Document on Best Available Techniques for Energy Efficiency and

International Energy Agency (2007): Tracking Industrial Energy Efficiency and CO2 Emissions.

68 European Comission (2009): BREF Reference Document on Best Available Techniques for Energy Efficiency

69 IEA – International Energy Agency (2007): Tracking Industrial Energy Efficiency and CO2 Emissions

7.3.2 Efficiency measures within the extended product approach and the strict product scope

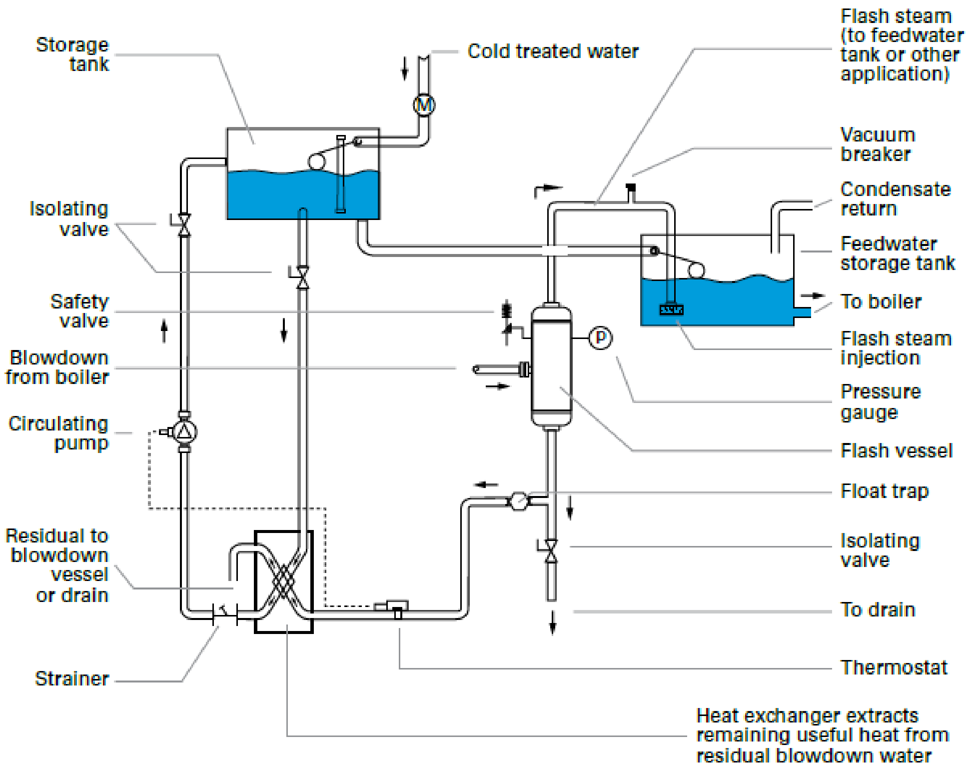
It is difficult to clearly separate measures belonging to the strict product scope from those belonging to the extended product approach. This chapter will therefore present measures for both approaches. Rough tendencies on how to separate the measures can be found in Table 75 and Table 76. The measures listed in both tables, are measures that were mentioned in different studies and literature. It is possible that more measures exist. As mentioned in Task 3 the relevant measures for our study should belong to the strict product scope or the extended product approach and should not be organizational as this cannot be changed by an improved product design.

Table 75 lists variable speed drives as a possible improvement option. These drives are attached to the burner. The resulting efficiency improvement is excluded from the definition of the thermal efficiency within the strict product approach. The definition of the thermal efficiency within the strict product scope is based on European Standards for acceptance tests. They only take thermal energy flows into account. As variable speed drives result in a lower electricity demand at part load, these savings cannot be included in the underlying efficiency figure.

Another example for an efficiency measure which can hardly be estimated by the underlying efficiency figure is the blowdown heat recovery. Although it is affecting the thermal energy flow of the boiler, the efficiency increase is not covered by the efficiency figure derived by applying standards for acceptance tests of steam boiler (see, EN 12953-11:2003). When water is vaporized to steam in a boiler it leaves behind suspended solids and dissolved salts [Carbon trust, 2012]. This leads to crystallization and corrosion on the boilers heat exchanger surface. Thus there are threshold values for the total quantity of mineral salts that can be tolerated. In order to not exceed these values a portion of the boiler water at steam temperature has to be replaced with cooler make-up water. This is called boiler blowdown and can be done manually by the operator period-wise. To do so the operator checks the level of total mineral salts at a sample device directly at the boiler and proceeds boiler blowdown when necessary.

There are also automatic blowdown systems which rely on common control devices. Within these systems the boiler blowdown is carried out by opening a blowdown valve automatically as soon as certain thresholds are trespassed. Manual control leads to excessively low levels of the total quantity of mineral salts because certain safety margins are redeemed to prevent damages caused by human error. Automatic systems have lower safety margins and thus lead to lower blowdown ratios. During blowdown, heat within the boiler is lost. An automatic control system leads to lower heat losses and a higher efficiency for the whole system. Furthermore the heat contained in the blowdown water can be recovered by a heat exchanger and then be fed back to the system. This increases the thermal efficiency of the system as well. The possible efficiency increase for both efficiency options referring to boiler blowdown (automatic boiler blowdown and blowdown heat recovery) is driven by customers (users) boundary conditions. This is based on the fact that boiler blowdown is dependent on the feed water quality which determines how much blowdown is required.

Figure 70 - Preheating the feedwater within feedwater treatment70.



Although improved combustion measures are part of the extended product approach, they are relevant options for this study. According to EPA (2010) savings of up to 3% points can be achieved. Improved combustion can either be achieved by organizational measures as tuning or with instrumentation and controls. The latter can be used as a possible design option.

Although all options within the strict product scope can be realized as a technology add-on not all options listed in Table 75 can be used as design options. Clean heat transfer surfaces are important for the efficiency but a solution can either be part of the regular maintenance of a company or solved by e.g. an improved water treatment which belongs to the technical system approach.

Insulation options cannot be included due to the fact that the chosen base cases presented in Task 5 do not contain information on the status of insulation.

More details on chosen design options are listed in 7.4.

[70] Carbon Trust (2012): Steam and high temperature hot water boilers.

Table 75 - List of possible improvement options within the strict product scope

Improvement Option	Description	Category
Air Preheater	Transfers heat from flue gas to the air entering the burner. Heated combustion air accelerates ignition.[71].	Technology Add-On
Blowdown heat recovery	Boiler blowdown heat exchanger Flash tank Combination of 1. and 2. The recovered heat can be used in terms of low-pressure steam.	Technology Add-On
Automatic Blowdown Control System	Minimizes blowdown automatically and leads to reduced energy losses.	Technology Add-On
Boiler Insulation	Minimizes radiation losses.	Technology Add-On
Economizer	Preheats feedwater and cools down flue gases. Increases overall boiler efficiency.	Technology Add-On
Condensing economizer		Technology Add-On
Insulate Valves and Fitting	Reduces radiation losses.	Technology Add-On
Improve water quality	Reduced TDC reduces the amount of necessary blowdown. This reduces energy losses.	Organizational/Technology Add-On
Keep heat transfer surfaces clean	Improved water and fuel treatment Use soot blowers or intelligent sootblowing systems[72],[73]	Organizational/Technology Add-On
Removable insulating pads for valves and fittings	Prevents damaged or missing insulation.	Technology Add-On
Replace/Upgrade Burners		Technology Add-On/ Technology replacement
Improve heat transfer	Improve heat transfer by technological means. An example is to use a turbulator avoiding laminar flow of the combustion gases in fire tube boilersand improving heat transfer in firetube boilers.	Technology Add-On

71 Beitz, W. and Grote, K-H. (2011): Dubbel: Taschenbuch für den Maschinenbau. 23. Aufl., Berlin: Springer.

72 EPA – United States Environment Protection Agency (2010): Available and emerging technologies for reducing greenhouse gas emissions from industrial, commercial, and institutional boilers.

73 Sootblowing systems are not useful for gas-fired systems. They make sense for liquid and solid-fired systems.

Table 76 - List of possible improvement options within the extended product approach

Improve Boiler Operating Practices	**Important if the boiler is not used continuously. Reduces losses during downtime or standby.**	**Organizational**
Maintenance	2. regularly maintenance of boiler (per year)[74]	Organizational
Improved Combustion Measure	Instrumentation and Controls (e.g. digital control systems, temperature sensors, oxygen monitors, CO monitor, oxygen trim controls)[75] Optimization (either manual or automatic testing and optimization) Tuning (manual)	Organizational/Technology Add-On
Variable speed drives (VSD) for combustion air fans	Electricity consumption can be reduced. Useful if the boiler load is below maximum. [76]	Technology Add-On
Reduce air leakages (Boiler)	Reduces amount of fuel needed to generate the same amount of steam.[77]	Organizational

74 Derived by a stakeholder comment as recommendation.

75 EPA – United States Environment Protection Agency (2010): Available and emerging technologies for reducing greenhouse gas emissions from industrial, commercial, and institutional boilers.

76 Carbon Trust (2012): Steam and high temperature hot water boilers.

77 Not suitable for fire tube boiler.

The options presented in this chapter are based on literature research and on studies from the years 2007 to 2013. Because some studies drew their information from older studies, it is important to recheck with the stakeholders whether all options are still effective and if there are still enough steam boilers for which such an option would be feasible. In case that the information is based on US studies it might be possible that a design option for the US is already a commonly used design option in the European Union and therefore not relevant for this study anymore.

7.3.3 Conclusion from the literature analysis

For the selection of design options, we follow the MEErP methodology and define design options that:

- do not imply a significant change in product functionality and in primary and secondary performance parameters and, if applicable, product quality,
- promise a signification potential for improving at least one Ecodesign parameter without deteriorating other relevant parameters,
- do not entail excessive costs.

A description of the design options comprises a technical description of each option based on the collected information is given in Task 4.

In the foregoing passage it has already been mentioned that not all efficiency options within the strict product scope can be modelled as design options in Task 6 for this study.

The efficiency for a steam boiler presented in Task 4 only takes thermal energy flows into account. This definition was based in standards for acceptance tests (EN 12952-15 and EN 12953-11). One option that was excluded due to this reason in a prior version of this report is the installation of variable speed drives. They reduce the energy consumption of the air blower but don't change the thermal energy flow. This was criticized heavily in the second stakeholder meeting. In order to respond to these comments we now evaluate the electric energy consumption of the electric motor for the air blower for the different Base Cases. We do that by first estimating the required power needed at the shaft for the blower. We then choose the appropriate electric motor size according EN 50347 for each Base Case. Finally we assume an average load of 75% for each Base Case. The resulting relative energy savings by VSD are then derived by the blow curve behaviour as follows:

$P_2 = P_1 \cdot (\frac{n_2}{n_1})^3$, where P_1 is the power needed at full load, P_2 is the power needed at part load and n_2 and n_1 are the appropriate number of revolutions. As the air flow without VSDs is regulated by throttling, the relative saving due to VSDs are then $P_1 - P_2$ for each Base Case. The appropriate motor sizes and the relative savings are given in Table 77.

Table 77 - Energy savings VSD

Output Power [kW]	Assumed efficiency (weighted for stock)	Power demand at average load with throttle [kW]	Power demand at average load with VSD [kW]	Relative savings [kW]
1,5	0,78	1,9	0,8	1,1

Output Power [kW]	Assumed efficiency (weighted for stock)	Power demand at average load with throttle [kW]	Power demand at average load with VSD [kW]	Relative savings [kW]
1,5	0,78	1,9	0,8	1,1
5,5	0,85	6,5	2,7	3,8
5,5	0,85	6,5	2,7	3,8
22,0	0,90	24,5	10,3	14,2
22,0	0,90	24,5	10,3	14,2
45,0	0,92	49,2	20,7	28,4
45,0	0,92	49,2	20,7	28,4
45,0	0,92	49,2	20,7	28,4
45,0	0,92	49,2	20,7	28,4

assumed average load = 75%.

We then address these saving potentials in Task 7. However we do not model VSDs in Subtask 6.2 which is dealing with the evaluation of costs (i.e. the LCC for consumer). This is based in the fact that the modelling of cost of VSDs is in scope of the appropriate LOTs dealing with electric motors. Nevertheless industry publishes a set of sources that VSDs are applied cost effectively in various projects/guidelines[78]. Therefore we assume that VSDs are cost effective for the modelling in Task 7. Finally we note that current test standards for steam boiler do not address the electricity consumption harmonized. In EN 12953-11:2003 it is written that the analysing of the electricity consumption is not part of the standard. In E12952-15:2003 it is written that the electricity consumption for electrical drives within system boundary has to be measured. Thus a harmonization of the test standards on electric energy is worth consideration. Furthermore the test standards do not address part load behaviour. The presented efficiency test standards (EN 12952-15 and EN 12953-11) only focus on the evaluation of energy efficiency in full load operation, while steam boilers often operate in part load. To address the boiler performance in real conditions it is also worth consideration to expand the test standards so that they include part load behaviour. Stakeholder from ECOS proposed the following: "An average energy efficiency could combine full and part load conditions". The overall efficiency could be a weighted average of 50% of the efficiency at full load, 25% of the efficiency at 70% load and 25% of the efficiency at 40% load. $Eta_{on} = 0.5*Eta_{100\%} + 0.25*Eta_{70\%} + 0.25 * Eta_{40\%}$"[79]. We think this propose is a good start to discuss the necessary weights for such extension. Nevertheless to manage this process and to figure out industrial needs which weights should be applied is from our point of view in scope of the standardization bodies.

78 cf. Schult, Meyer (2013): A Better Use of Energy: A Practical Handbook for Combustion, p.38 ff. / cf. Viessmann GmbH (2011). Planungshandbuch Dampfkessel, p.118 ff.

79 cf. Stakeholder comments sheet, published at www.eco-steamboilers.org.

Other excluded options are those options concerning the boiler blowdown. Although referring to thermal energy flows they cannot be modeled within the efficiency definition named in the acceptance tests (see EN 12953-11:2003) as there are no passages on that topic foreseen. This might be based in the fact that, as already mentioned, the blowdown ration depends on the customers feed water quality. Stakeholder argued in the second stakeholder meeting to include the boiler blowdown in the analysis. We understand the point that efficiency options concerning boiler blowdown are important for energy savings within steam systems. However we do not see the European Union's Ecodesign Directive to be the framework enforcing these measures as these measures are systemic measures outside the system boundary defined in Task 1 and Task 3. Although it could be arguable to extend the system boundaries, we do not see it worthwhile within the prep study based in the market structure for industrial steam systems. The market for industrial steam system not only includes manufacturer of steam boilers. Manufacturer of equipment to reduce reduction of heat loss from blown down water are not always the same as the manufacturer of steam boiler. When a new steam system is being set up there are basically three configurations thinkable:

1. Plant engineering company sets up the steam system (as turnkey provider): Within this configuration the equipment is being sold to the plant engineering company or the end-customer (operating the steam system). The system integration is then being done by the plant engineering company having turnkey responsibilities. Within this configuration the equipment might be sourced from several manufacturer (steam boiler: manufacturer a, recovery system: manufacturer b, etc.).
2. End-customer sets up the steam system: The end-customer buys the equipment from several manufacturers and sets up the steam system on his own with own staff.
3. Steam-Boiler manufacturer sets up the steam system: Within this configuration the manufacturer of the core device (i.e. the steam boiler manufacturer) would provide all the equipment and hold the turnkey responsibilities to set up the steam system.

We assume configuration 1) to be customary. We assume 2) and 3) to be not so common. However as one can see a requirement to equip steam systems always with the proposed energy efficiency measures concerning blowdown would represent an in-depth market intervention. When we define steam boiler within a wider system boundary, providers of steam boilers have to make sure that they are capable to source the additional equipment needed. This would shift the responsibilities to source the needed additional equipment towards the steam boiler manufacturer in configuration 1) with the consequence that the plant engineering company has less possibilities to choose components. We doubt that this shift would effectively support the goal to increase energy efficiency. Plant engineering companies – especially system provider with no core components – have extensive knowledge in setting up steam systems. Especially in the case when no core component, but just the integration services are offered, an adequate, efficient integration of the components is a competitive factor. As a consequence an effective way to support an increase of energy efficiency in steam systems might be to shift the responsibility to equip steam systems with certain systemic devices towards the end-customer, i.e. end-user of steam systems. The European Union's Ecodesign Directive seems not to be the appropriate framework for that.

Furthermore there are efficiency options which are not applicable for all industrial steam boilers as they depend on the design on the steam boiler. An example is the air preheater. As industrial stakeholder mentioned in the second stakeholder meeting air preheater are very uncommon for steam boiler of smaller size classes. This is based in the applied burner design (Monoblock or Duoblock). When being equipped with a Monoblock designed burner, the blower is directly mounted at the burner. In Duoblock design the blower is located separately from the burner. For Monoblock designed burner it is not possible to apply an air preheater system being evaluated in this study as there is no space to mount the heat exchanger in the channel where the air is being sucked in (stakeholder information, BDH). Nevertheless this is possible for burner in Duoblock design. It might be discussable whether only Duoblock burner should be applied for that reason. However to prefer a specific design for the burner would need a Life Cycle Analysis and an analysis of the technical performance of both designs. Thus we model the air preheater only exemplary in Task 6 in technical terms and in terms of LCC for customer. In Task 7 we do not model this design option to be supported by any policy mechanism. This is based in possible technical restrictions as mentioned above.

Another factor which has to be taken into account is the onsite condition of customers. This is usually excluded or corrected by calculation schemes in standards for acceptance tests. One example is the air temperature at the system boundary which is taken into account by deriving the thermal efficiency during the acceptance test (see EN 12953-11:2003). This makes sense from a manufacturer's point of view as manufacturer can hardly be responsible for onsite conditions.

On the whole this leads to the conclusions that there are at least remarkable, cost effective saving options which cannot be included in the analysis as they are not within the strict product scope or they cannot be modelled properly due to heterogeneous conditions driven by customer requirements.

Finally we analyzed all efficiency options within the literature research whether they were within the strict product scope or not. We then derived six options. Three of them can be modelled within the definition of the thermal efficiency as per standards for acceptance tests. Table 78summarizes which options are within strict or extended product scope and whether the efficiency improvement can be modelled by increasing the efficiency figure. Furthermore Table 78 summarizes whether the options are being modelled in Task 6 and/or Task7.

Table 78 - Design options in strict or extended product scope

Design option	Comment	In efficiency value [Y/N]*	Technical in Task 6 [Y/N]**	LCC in Task 6 [Y/N]***	Modelled in Task 7 [Y/N]****
Economizer (standard and condensing technology):	Reduces flue gas losses	Y	Y	Y	Y
Air preheater[80]	Reduces flue gas losses	Y	Y	Y	Y
Combustion control by O2 and CO measurement	Reduces excess air of combustion	Y	N	Y	Y
Blow down heat recovery system	-	N	N	N	N
Insulation	-	Y[81]	N	N	N
Variable speed drive for air blower	-	N	Y	N	Y
* Included in thermal efficiency definition as per Task 4 [Y/N].					
** Modelling of potential efficiency increase for the Base Cases (thermal efficiency).					
*** Modelling of decrease in LCC for customer by applying this measure.					
**** Modelling supporting policy mechanisms for this measure.					

80 The technical feasibility to apply an air preheater might be restricted for a fraction of Steam Boiler. This might be especially the case for smaller steam boiler as indicates in the second stakeholder meeting on held at the 3rd of July 2014 in Brussels.

81 In a former version N had been listed. This was done with the background that we are not going to model better insulation as a design option in the following, assuming that industrial steam boiler are insulated as good as possible. Industrial stakeholder indicated that the efficiency improvement which can be derived by better insulation is negligible for industrial steam boiler during the second stakeholder meeting (cf. MoM, published on www.eco-steamboilers.org).

7.4 Subtask 6.2: analysis of costs

The efficiency increase which can be achieved by installing an economizer and an air preheater depends on the installed heat exchanger surface. We assume the efficiency increase to be case sensitive to a certain degree. However industrial stakeholder indicated during the second stakeholder meeting that there is no strong dependency of the efficiency increase which can be achieved by an economizer and the thermal capacity of the steam boiler. Industrial stakeholders assume the efficiency increase caused by an economizer to be between 5 and 6%pt. usually.

In a previous version of this report the efficiency increase of an economizer and an air preheater has been derived by case sensitive calculations. Some of the estimated values did not lie within the range of 5 to 6 %pt. mentioned above. Thus we present our approach and extend the approach by a comparison indicating whether the range named above and our values differ strongly.

Within our approach we assume the efficiency increase which can be achieved by an economizer or air preheaters to be case-sensitive[82]. Therefore we evaluated case specifically which efficiency increase can be achieved by installing an economizer and an air preheater. To do so we applied thermodynamic calculations for each of the base cases. Our base case efficiency was defined in line with the case definition of Task 5. Furthermore this efficiency is in line with the thermal efficiency defined in the foregoing passages.

As a first step we design the economizer for each of the base cases. Afterwards we include the air preheater. This is based on the fact that the heat capacity of water is higher than the heat capacity of air. Therefore the heat recovery with an economizer is less material intensive and thus more cost efficient.

This approach results in the first two design configurations. The first configuration is the base case for which only the economizer is added as an additional technological improvement. Within the second design configuration the air preheater is added additionally to the economizer. For estimating the sizes of the economizer and the air preheater for each base case we apply design approaches which will be presented in the following.

For designing the economizer we increase the surface of the economizer stepwise and estimate the potential savings of fuel respective to the energy contained in the fuel for each step. We then derive the investment for each of these steps. These investments are being annualized for the period of our assumed machine life-time (20 years) by applying a calculation interest of 10%. The annuity rate (AR) is defined by $AR = C \cdot a$, with C as the total investment and a as the annuity factor.

The annuity factor will be derived by $a = \frac{1}{\sum_{t=1}^{t=n} \frac{1}{q^t}} = \frac{q^n \cdot (q-1)}{q^n - 1}$ with

$q=1+i/100$ as discount factor,

i as calculation interest in %/year and

n as life-time.

The specific costs of energy savings ($sces$) are then derived by: $sces = \frac{AR}{SP}$, with SP=energy savings in GJ per year.

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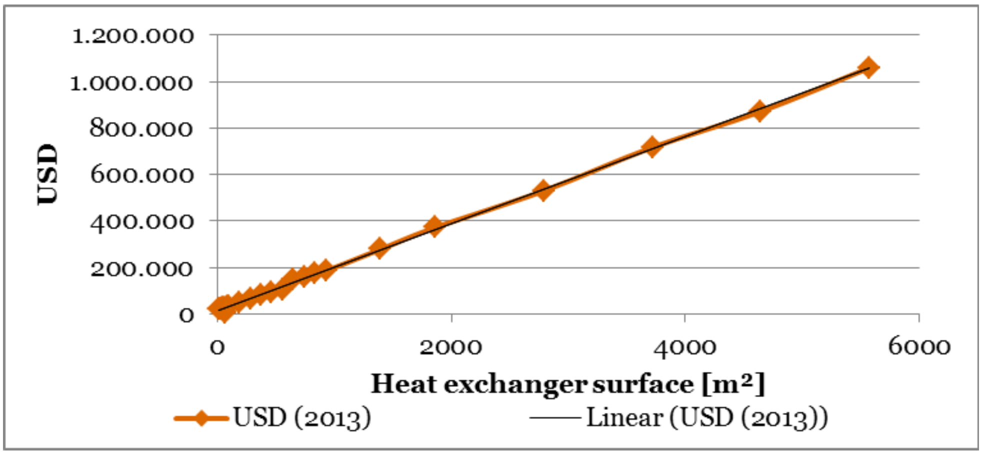
82 Industrial stakeholder indicated during the second stakeholder meeting that there is no strong dependency of the efficiency increase which can be achieved by an economizer and the thermal capacity of the steam boiler. Industrial stakeholders assume the efficiency increase caused by an economizer to be between 5 and 6%pt. usually. However as a range is given and in literature also other values occur we decided to compare our approch and the resulting cost with the approch to achieve an efficiency increase of 5.5%pt. – indicating the average efficiency increase given by industrial stek

Finally we choose the size of the economizer where the specific costs of energy savings are minimal. This approach results in the highest interest rate of return (IRR) for the evaluated economizer sizes when the gas price is being set constant for the next 20 years (10.57 EUR/GJ)[83]. Furthermore this approach prevents unrealistic large economizer which would hardly occur in practical application and might be restricted by size within the plant. For estimating the cost of heat exchangers we use the following linear relation which is based on cost data from the most updated planning manual for chemical engineers we could find: $K(s) = 187,29 \cdot s + 13913$, where s is the surface in m^2 and K the investment in USD (compare Figure 71) [84].

Figure 71 - Assumed investment correlation for the heat exchanger



The specific costs of energy savings are exemplary visualized in Figure 72 for the Base Case no. 4, where the thermal output is 7.5 MW and the generated steam has a pressure of 25 bar. In this figure the minimum specific costs of energy savings occur when the heat exchanger surface of the economizer is 90 m^2. The shape of the curve is characteristic for all cases. The IRR for the same case is visualized in Figure 73 (note: the gas-price is being set constant for the next 25 years). The shape is as well characteristic for all cases.

83 Eurostat average for the EU 28 for the year 2013

84 USDOE (2002): Process Equipment Cost Estimation Final Report, DOE/NETL-2002/1169

Figure 72 - Specific cost of energy saving for the economizer for the case no.4

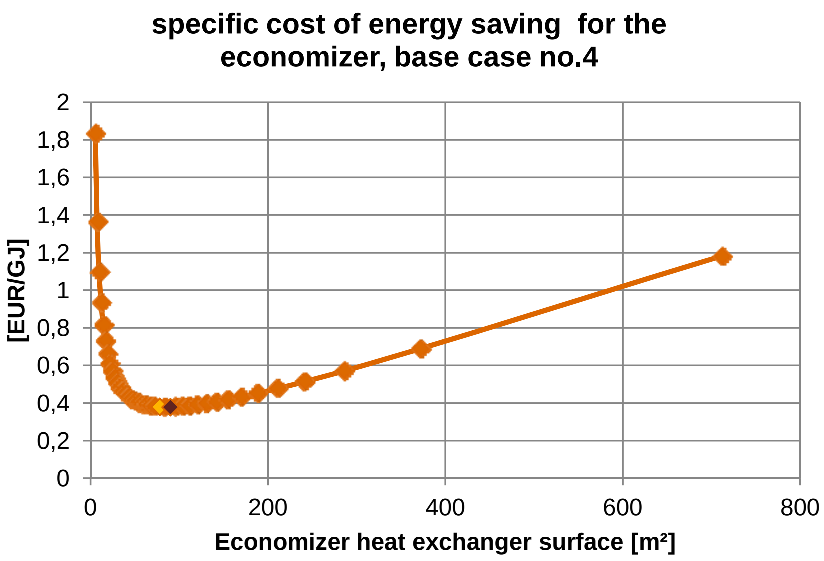
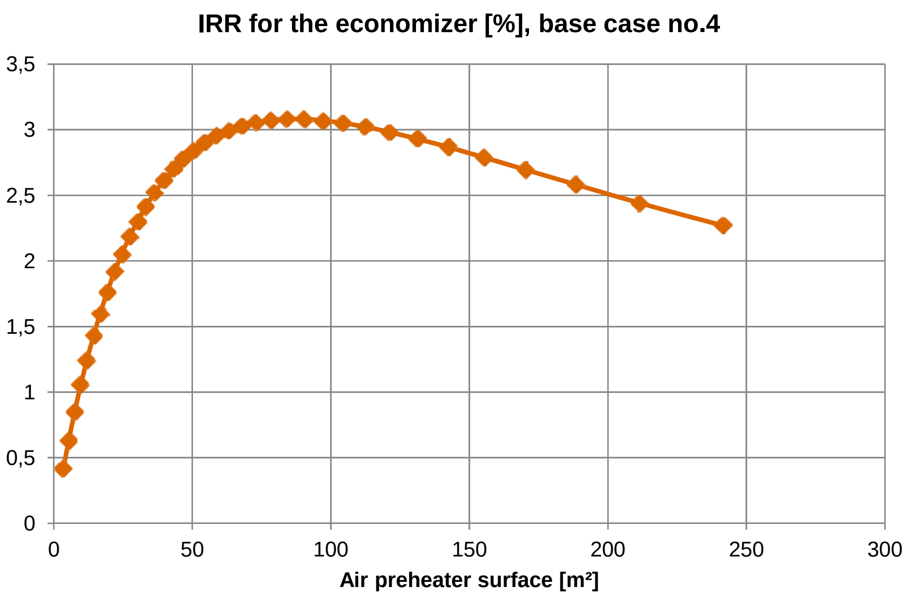


Figure 73 - IRR for the economizer, base case no.4



In order to compare our approach with the range given by industrial stakeholder we estimate the heat exchanger surface to derive an efficiency increase of 5.5%pt. and the appropriate investment cost with the function presented above. We present the design points in Figure 72 and Figure 73, where the yellow point represents the surface to achieve an efficiency increase of 5.55%pt., and the red point represents the surface where *sces* are minimal. Someone can see that our approach (minimum *sces*) leads by tendency to

- larger economizer for Base Cases with low thermal capacity, and to
- smaller economizer for Base Cases with high thermal capacity

compared to the approach to achieve an efficiency increase of 5.5%pt..

This might be based in several reasons. One reason might be that we overestimate heat exchanger cost for low heat exchanger surfaces and underestimate heat exchanger cost for high heat exchanger surfaces. As we assume our cost function to be linear this would indicate that the real cost function might have a more logarithmic shape. However other reasons might lie in technical reasons, e.g. when the space for a heat exchanger is limited for small steam boiler. We finally compare the differing investment figures for both approaches in Table 79. It can be seen that the investments differ up to 50%. Nevertheless we assume the figures for the approach to increase the efficiency up to 5.5%pt. to be realistic covering the range industrial stakeholder named and proceed with these figures for the Life-Cycle-Analysis.

Table 79 - Investment delta btw. design approach minimum sces and eff.inc = 5,5 % pt.

Investment delta btw. design approach minimum sces and eff.inc = 5,5 % pt.

rounded figures	*(Investment.5,5 minus Investment.min.sces)*	*Investment 5.5*	*(Investment.5,5 minus Investment.min.sces)/ Investment 5.5 [%]*
base case no.2	-3.000	14.000	-21%
base case no.1	-2.000	15.000	-13%
base case no.4	-2.000	21.000	-10%
base case no.3	1.000	23.000	4%
base case no.6	10.000	42.000	24%
base case no.5	14.000	48.000	29%
base case no.10	24.000	65.000	37%
base case no.8	27.000	66.000	41%
base case no.7	37.000	75.000	49%
base case no.9	39.000	80.000	49%

Figure 74 - sces for the economizer for base case 1 to 4 – comparison of two design approaches

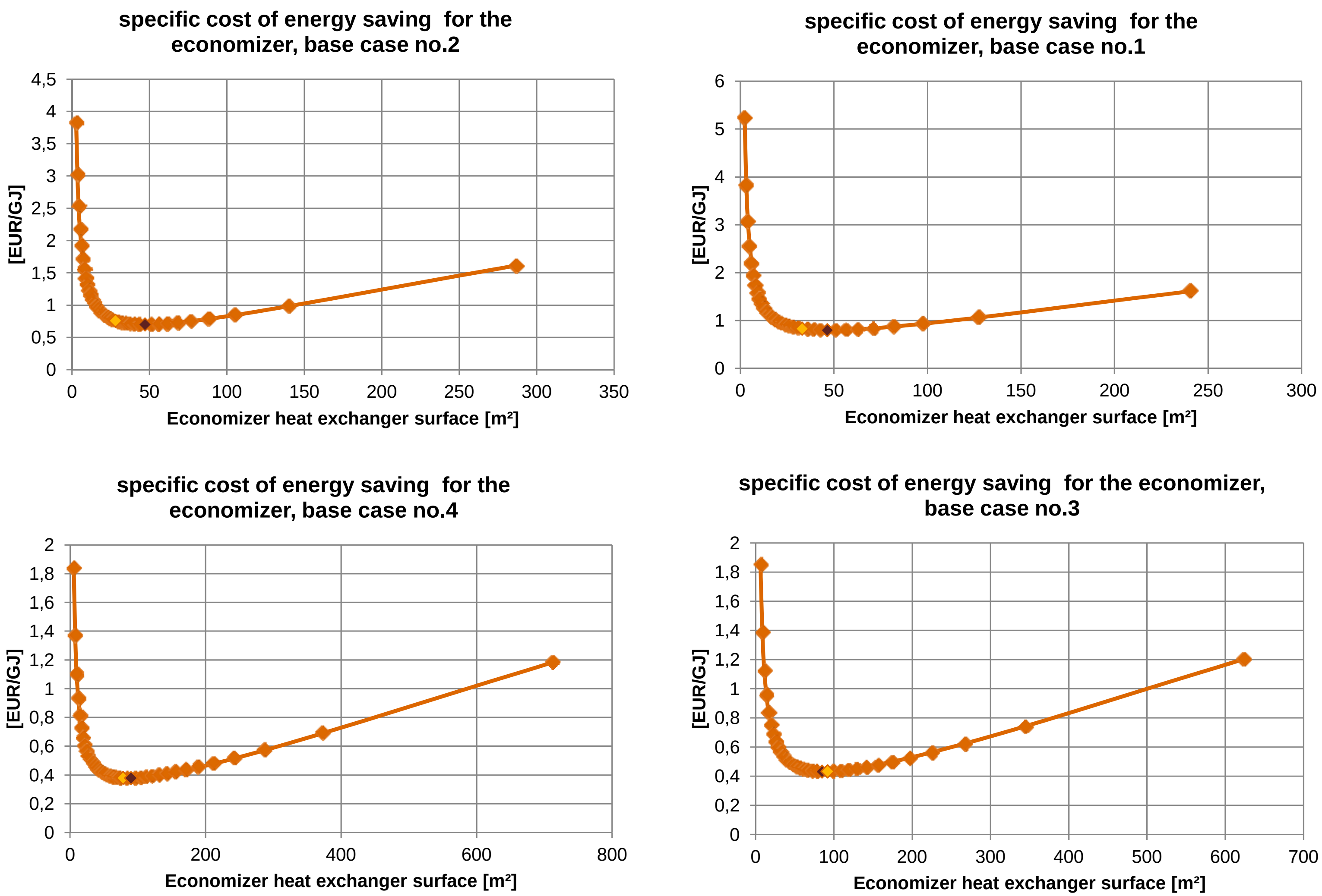


Figure 75 - sces for the economizer for base case 5 to 8 – comparison of two design approaches

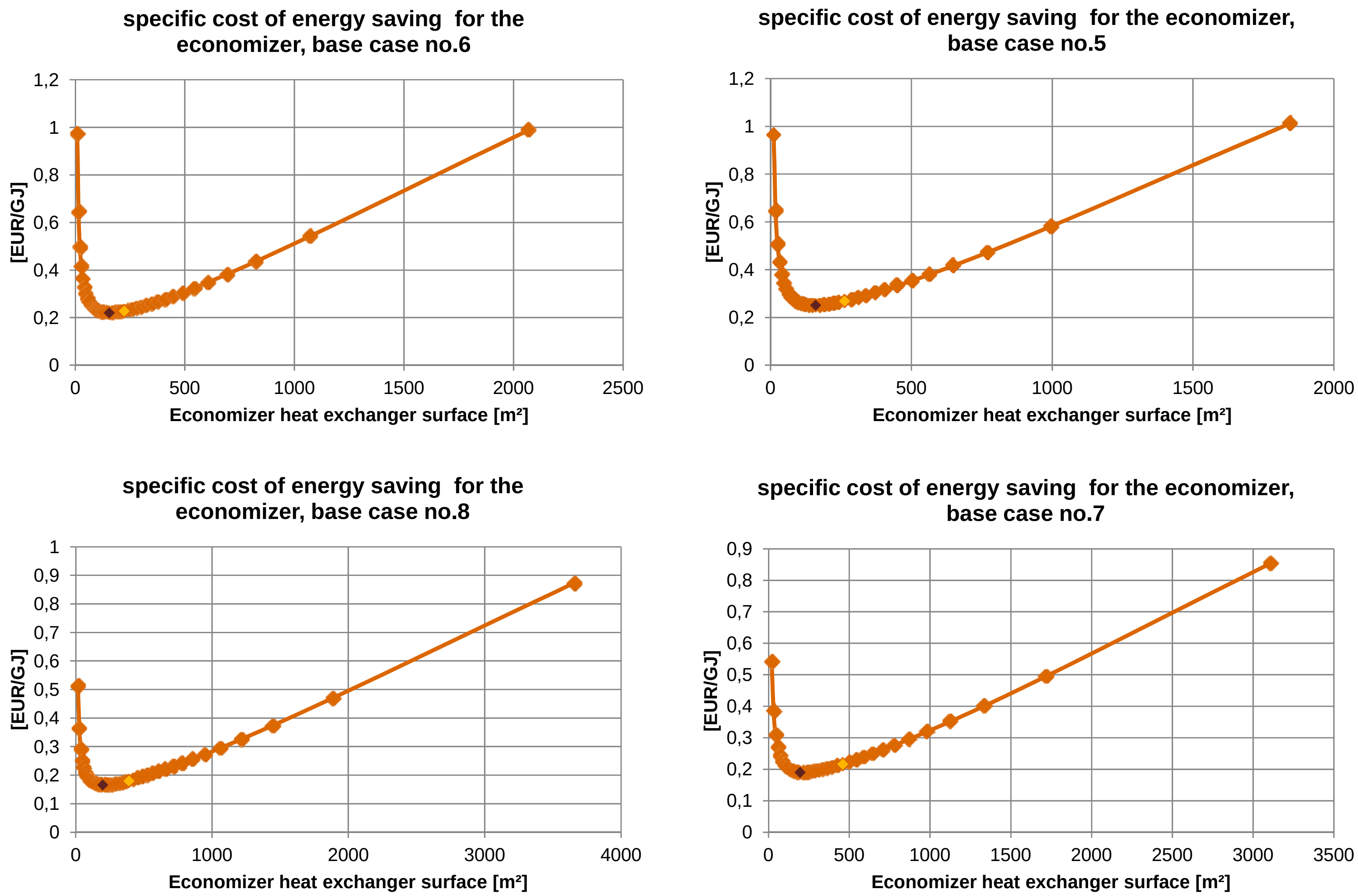
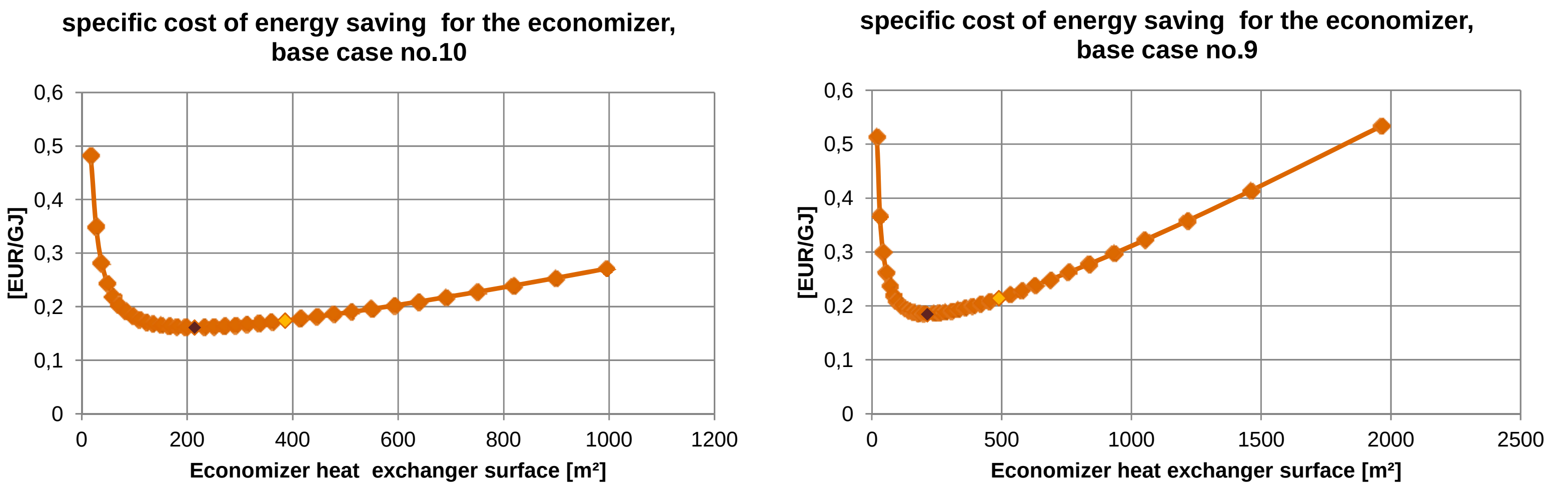


Figure 76 - sces for the economizer for base case 9 to 10 - comparison of two design approaches



Based on the sized economizer we then evaluate the air preheater as the second technological design option. Thus the economizer size is fixed and will only be varied slightly (up to 1 m²) which is based in thermodynamic boundaries to derive feasible configurations. With the economizer as a foundation for each base case we start to vary the heat exchanger surface of the air preheater and derive the assigned costs in order to derive the specific costs of energy savings for the air preheater. As already mentioned the heat capacity of air is lower than the one of water. This results in larger heat exchanger surfaces to recover the same amount of energy leading to higher specific costs of energy savings for the air pre-heater. This means that, when we define specific costs of energy savings for both measures together an increase of the size of the air preheater would lead to higher specific costs of energy savings by tendency as can be seen exemplary in Figure 77. This would mean that when designing the air preheater size by referring to the minimum combined specific costs of energy savings, the air preheater would have to be very small (around 1 m²). This is assumed to be unrealistic.

Therefore we also evaluate the development of specific costs of energy savings for the air preheater separately. Thus we estimate the difference between the energy saving where the Base Case is equipped only with the economizer and where the Base Case is equipped with economizer and air preheater. Finally we derive the specific costs of energy savings by the same methodology as introduced for the economizer exclusively for the air preheater. The specific costs have then a minimum like in the case for the economizer. However this minimum occurs at unrealistic large sizes for the air preheater so that the air preheater would be larger than the economizer. This is uncommon. This tendency increases with higher thermal outputs. In order to prevent this unrealistic, too large sized air preheater we choose the air preheater with the lowest specific cost of energy saving where the air preheater is still smaller than the economizer. For Base Case No. 4 this would exemplary mean that the air preheater has to be smaller than 78 m². As industrial stakeholders indicate an efficiency increase of 1%pt. to be common for air preheater we again compare our design approach with the appropriate cost to achieve an efficiency increase of 1%pt.

The comparison is shown in Table 80.

It can be seen that the differences between the approaches are negligible on average. The average efficiency increase with the approach to choose lowest sces, where the economizer is still larger than the APH is 1,1%pt. for high pressure 1,0%pt. for medium pressure[85]. Therefore we choose the figures for the approach to achieve the efficiency increase of 1.0%pt. for further analysis. The air preheater would still have a highly positive net present value (NPV) then. Assuming constant gas prices for 25 years and a calculation interest of 10% the net present value is around 40,000 EUR for the base case no. 4. This is why omitting the air preheater is no alternative, even when comparing to the economizer where the NPV is around 540,000 EUR for the same assumptions at the design point.

85 The specific cost for the heat exchanger surface for the air preheater has been increased by the factor 3 in response to stakeholder comments from the second stakeholder meeting held in Brussels at the 3rd of July 2014.

Figure 77 - Combined specific cost of energy saving for the economizer and air pre-heater, example for base case no. 4

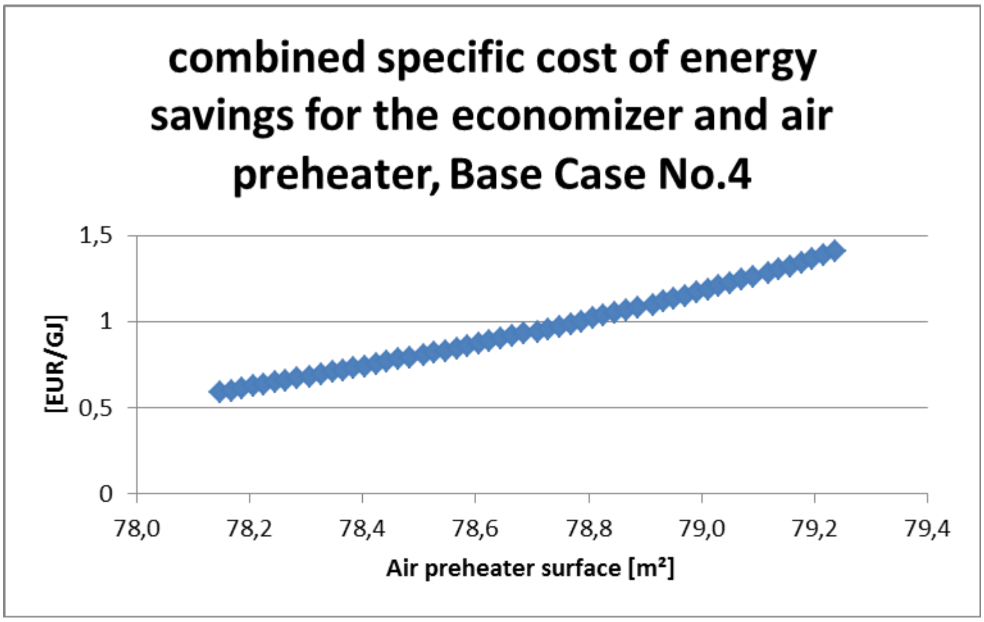


Table 80 - Comparison of design approaches - APH

	high pressure			***medium pressure***		
Approach	Efficiency increase in [% pt]	Investment [EUR]	Flue Gas Temperature above 60 °C [Y/N]	Efficiency increase in [% pt]	Investment [EUR]	Flue Gas Temperature above 60 °C [Y/N]
	Base Case 4			***Base Case 3***		
1) minimum sces	1,9	96.000	Y	1,5	85.000	Y
2) lowest sces, where eco surface > APH surface	1,2	64.000	Y	1,2	70.000	Y
Efficiency increase = 1 % pt.	1,0	59.000	Y	1,0	62.000	Y
	Base Case 6			***Base Case 5***		
1) minimum sces	1,3	211.000	Y	1,0	128.000	Y
2) lowest sces, where eco surface > APH surface	1,1	174.000	Y	1,0	128.000	Y
Efficiency increase = 1 % pt.	1,0	169.000	Y	1,0	128.000	Y
	Base Case 8			***Base Case 7***		
1) minimum sces	0,9	103.000	Y	0,8	106.000	Y
2) lowest sces, where eco surface > APH surface	0,9	103.000	Y	0,8	106.000	Y
Efficiency increase = 1 % pt.	1,0	106.000	Y	1,0	124.000	Y
	Base Case 10			***Base Case 9***		
1) minimum sces	1,1	265.000	Y	1,0	201.000	Y
2) lowest sces, where eco surface > APH surface	1,1	265.000	Y	1,0	201.000	Y
Efficiency increase = 1 % pt.	1,0	255.000	Y	1,0	201.000	Y
Average (1 & 2)	**1,2**			**1,1**		
Average (1)	**1,3**			**1,1**		
Average (2)	**1,1**			**1,0**		

Finally we assume an efficiency increase by improving combustion control which is based in measurement devices in the exhaust gas and additional control technology. As already mentioned the measurement devices measure the CO and O2-content in the exhaust gas. This information is then used by a control device via feed-back loop to improve fuel injection so that less fuel is needed. This is especially relevant for part load cases. The efficiency increase which can be achieved by such additional control measures varies between 0,5 and 2,5% in literature sources. In case studies from the BDH costs of around 30.000 EUR for the hardware are mentioned. We apply an efficiency increase of 1,75% pt. and costs of 30.000 EUR for each of the base cases as we do not assume that installing control devices is case-sensitive. These approaches finally lead to an efficiency increase per design option per base case as summarized in Table 81**.** These values are the input for the LCC analysis.

Table 81 - Efficiency increase and investment per case per design option (rounded figures)

				Economizer		Air-pre heater		Combustion control				
Base case no.	Base case size (MWth)	Thermal efficiency [%]	Operational pressure [bar]	Efficiency increase [%pt.]	Investment [EUR]	Efficiency increase [%pt.]	Investment [EUR]	Efficiency increase [%pt.]	Investment [EUR]	New efficiency with all options [%]	Boiler base cost [EUR]	Boiler cost with all options
1	2,5	87	15	5,5	15.000	1,0	21.000	1,75	30.000	95,25	59.100	125.100
2	2,5	86	25	5,5	14.000	1,0	30.000	1,75	30.000	94,25	59.100	133.100
3	7	87	15	5,5	23.000	1,0	62.000	1,75	30.000	95,25	97.000	212.000
4	7	86	25	5,5	21.000	1,0	59.000	1,75	30.000	94,25	97.000	207.000
5	20	87	15	5,5	48.000	1,0	128.000	1,75	30.000	95,25	135.600	341.600
6	20	86	25	5,5	42.000	1,0	169.000	1,75	30.000	94,25	135.600	376.600
7	35	87	15	5,5	75.000	1,0	124.000	1,75	30.000	95,25	156.200	385.200
8	35	86	25	5,5	66.000	1,0	106.000	1,75	30.000	94,25	156.200	358.200
9	35	85	15	5,5	80.000	1,0	201.000	1,75	30.000	93,25	156.200	467.200
10	35	84	25	5,5	65.000	1,0	255.000	1,75	30.000	92,25	156.200	506.200

7.5 Subtask 6.3: analysis of BAT and LLCC

The aim of this subtask is to compare BAT to the base cases as defined in Task 5 with regard to the LLCC. The assessment of the LLCC will follow the detailed LLCC methodology as provided in the MEErP methodology. In a first step, this assessment includes:

- a determination of possible positive or negative side-effects due to the implementation of the design options,
- a ranking of individual design options sorted by LCC and efficiency improvement potential,
- a graphical analysis of cumulated least life-cycle costs as suggested in the MEErP methodology.

A conclusion includes a detailed discussion of the resulting improvement potential. We will among others detail on the suitability of using the results for setting minimum requirements for example at the LLCC or at the BAT point.

7.5.1 Side-effects and Ranking

The best available technologies that will be compared in this sub-task are the economizer, the air-preheater as well as an improved combustion control. Possible positive and negative side-effects that result from implementing these options are listed in Table 82.

Table 82 - Possible positive and negative side-effects due to the implementation of the design options.

Design Option	Positive side-effects	Negative side-effects
Economizer	Improved efficiency Reduced fuel consumption Decreased flue gas temperature Less pollutants	Increased design complexity Increased space requirements
Air Preheater	Improved efficiency Reduced fuel consumption Decreased flue gas temperature	Increased design complexity Increased space requirements Increase complexity in designing pollutant control
Combustion Control	Improved efficiency Reduced fuel consumption	

In comparison to the base cases the LCC decrease with the implementation of each design option. The reduction of the LCC depends on the order in which the design options are implemented. The highest reduction can be achieved with the first measure. We ranked three configurations of options as follows[86]:

- Economizer
- Economizer and Air Preheater
- Economizer and Air Preheater and improved Combustion Control

The side effects only play a minor role in this ranking as their impact is low.

86 Note: In a previous version the options had been ranked according to their ability to increase the efficiency and lower LCC. This is now not the case due to changed figures.

7.5.2 Graphical analysis

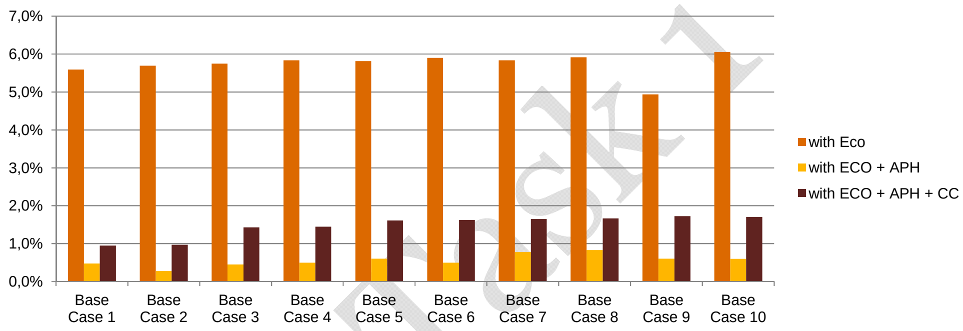
Figure 78 illustrates how the LCC change compared for the Bases Cases 1 to 10 applying the presented design options before. All calculations are based on a discount rate of 4%.

The figure shows that the LCC decreases for all Base Cases after installing an economizer, air preheater or combustion control. As the efficiency improvement is assumed to be identical per option (in contradiction to a previous version of this report) the slight differences in the reduction of LCC are caused by different Base Case efficiencies without design options and the thermal capacity of the machines.

The decrease in LCC behaves as follows:

- for the economizer the reduction ranges between 4,9 and 6,1 %pt.,
- for the air preheater the reduction ranges between 0;3 and 1 %pt., and
- for the combustion control the reduction ranges between 0,9 and 1,7%pt.

Figure 78 - LCC curve illustrating the change of LCC compared to the Base Case configuration (Eco: Economizer; APH: Air-Preheater; CC: Combustion Control)

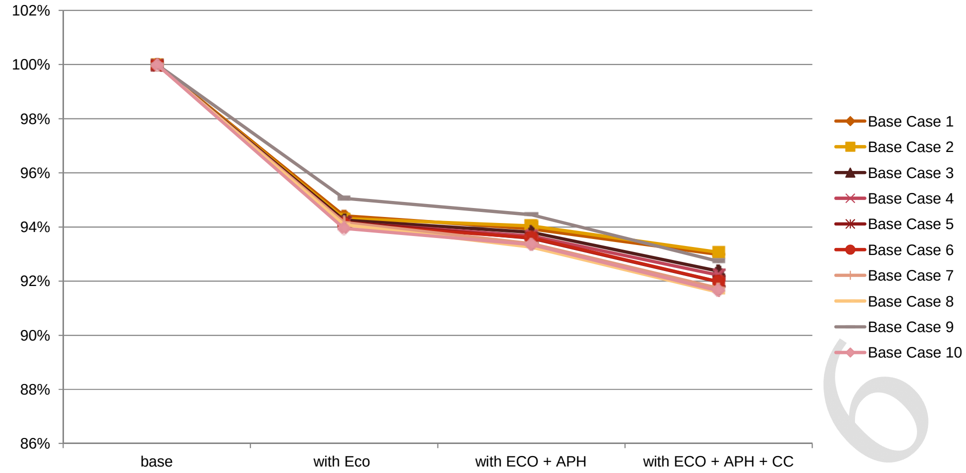


It shows the same results as Figure 78 but from another perspective. The LCC of the base cases are assumed to be 100%. Therefore it illustrates which Base Case leads to the highest relative change of LCC. It underlines the fact that those Base Cases with the lower efficiency (the one with the higher pressure, i.e. 86% for firetube boiler and 84 % for watertube boiler) lead to higher savings compared to those of the same size but a thermal efficiency of 87% for firetube or 85% for watertube boiler.

- The highest change can be achieved with Base Case 10. The LCC can be decreased from 100% to 91,6%. This is a reduction of 8,4%pt..
- The lowest change can be achieved with Base Case 2. The LCC can be decreased from down to 93,1%. This is a reduction of 6,9%pt..

Finally all evaluated measures are cost effective.

Figure 79 - LCC curve illustrating the change of LCC compared to the Base Case configuration (Eco: Economizer; APH: Air-Preheater; CC: Combustion Control).



7.5.3 Conclusion

The analysis has shown that there is no difference between the LLCC and the BAT point. The curve with the cumulated LCC only decreases. Therefore the efficiency improvement potentials that were presented in Figure 79 stay the same for both approaches to estimate LCC. The reason for this is that the calculations are dominated by fuel costs. All measures lead to reduced fuel consumption. Other auxiliaries were not taken into account based in the reasons mentioned in Task 5.

7.6 Subtask 6.4: long term potential (BNAT) & system analysis

Technological progress and Ecodesign measures may foster long-term technological innovations and bring forward new products (BNAT) that can help to improve the environmental impact of the considered products. Furthermore, new or alternative steam systems may yield new technical potentials in the long term. However within our literature research we could not find any best not yet available technologies within strict or extended product approach. One reason may lie in the long existing period of industrial steam boilers resulting in efficiency options which are more or less common and state of the art. However manufacturers promote efficiency improvements by using more advanced control technology. It might be that these options include improved control schemes which go beyond improved combustion control. Anyhow these measures might be in scope of cooperate secret.

8 Task 7: Scenarios

8.1 Objectives

The present task is to provide an understanding of the impacts of future scenarios in line with policy measures that could be introduced at EU-level. The scenarios task is a key task: it requires the combination of the results of all previous tasks and estimates the actual impact to different policy and design options aiming at provide a basis for decision making process. A qualitative analysis is provided on scenario market penetration and the consequences for the environment, users and industry.

To this end, a stock model has been developed to estimate future sales and stocks of steam boilers within different policy scenarios. The outcomes are then compared with reference to different baselines.

8.2 Subtask 7.1: Policy analysis

From the previous tasks, different sets of clearly defined sets policy options have to be developed. These options entered into the modelling approach and need to be translated to product details (subtask 1.1 and others).

In more depth, the stakeholders' positions need to be summarised and taken into account as well as existing barriers to market penetration of efficient boilers. Existing standards and legislation are included and modelled together with different additional policy options.

8.2.1 Stakeholder opinion during preparatory study

8.2.1.1 Stakeholders" consultations

As deeply described in Task 2 paragraph 3.9, a specific **stakeholders' consultation** has been launched in order to gather useful data and information from the field and to map the major players in Europe. The selection of the main producers has been drawn up focusing on the three Prodcom codes, according to the scope of the study (Task 1). More than 30 **relevant Producers and Associations** were identified (see tables below), representing a starting point for the product mapping aiming at analysing the main features of the steam boilers market. Due to the specific conditions of this market – which is highly concentrated – and since Eurostat data (the official EU source of information) includes all the steam boilers in the scope of work without differentiating by power output, **second round of market operators' consultation has been carried out in order to countercheck statistical data with information directly coming from the field**.

Following the stakeholder meeting held in Brussels, on March 6, 2014, a new survey has been launched in order to better target the reference market on **steam boilers with a power output between 1 and 50 MW**.

The new Survey has been built on a shorter questionnaire with a more specific focus on **market data**, aiming at having back an expert opinion on the internal composition, by installed power and output capacity.

During the 2nd stakeholder's consultation - run between February and March 2014 - we collected contributions from **European Heating Association (EHI),** providing figures on production of steam boilers in Europe, and from the **Swedish Energy Agency,** related to the Swedish market. Given the authority of EHI and the European scope of the study, the following section contains a new market analysis based on EHI data.

8.2.1.2 Stakeholders' meetings

Given the high relevance of market data for the scenarios design and options definitions, a **second stakeholders' meeting** has been organized in July in Brussels in order to focus on the discussion of the new market analysis (included in Task 2) and the new elements (included in Task 5 and 6) of the report and to collect Stakeholders' view on policy options preliminary definition (included in Task 7).

The following stakeholders attended the meeting: ICF International, ECOS, Viegang Maggøe, Energy Authority Finland, Bosch Industriekessel GmbH, European Heating Association (EHI), BDH, International Network for Sustainable Energy and Oekopol Institute on behalf of the German Federal Environmental Agency.

During the discussion, the following key issues have been pointed out:

- As to dataset, it has been underlined that the new data collection can be considered more reliable than Eurostat data gathering. Give the high relevance of market data, it has been underlined that sensitivity analyses will be included and further assumptions on the stock would have been added.
- Cost data first criticized. However in meeting at site of Bosch confirmed for the scope (only boiler with burner, blower and control devices).
- It has been pointed out that three different kinds of boilers exist whereas the base cases only include fire-tube boilers. Moreover, solid fuel boilers should be added to the study's base cases. Solid-fuel boilers have properties that are substantially different from the gas-fuelled boilers included in the current draft.
- Technical configuration has been challenged. Some stakeholders have observed that not 90% of the current stock of steam boilers (70.000) is equipped with an economizer but only the newly sold units (2.500 per year). According to some stakeholders, the assumed share of 50% for annual sold boilers with an APH is too high. It should be corrected to 5-10% (This number is based on market of sold units in 2013).
- As to the historical trends for scenarios setting, it has been observed that a stock of 70.000 units (1. 35.000 units: not state of the art; 2. 35.000 units: state of the art) can be assumed. It has been decided that historical and potential future diffusion rate of all design options would have been taken into account in the scenario analysis.
- It has been mentioned that lifetime depends on the size of the boiler. Bigger boilers have a longer lifetime but due to the inclusion of smaller boilers a span of 20 to 25 years is realistic. Thus a lifetime of 25 years is assumed.
- A large quantity of the steam boilers installed and being sold normally operates at part load conditions. The reason for this is many, such as seasonal variation, total load on the production facility, safety margin, and opportunity for increased production. The standard used for testing boilers, does not have a part load condition. This means that the test standard does not reflect the real life operation.
- Steam boilers are regulated by other EU regulations including the Industrial Emissions Directive (IED) and the upcoming Medium Combustion Plant Directive (MCPD). These two directives do not target energy efficiency, but industrial emissions. In addition there is a need to optimise the entire steam system. Therefore, finding synergies between the

different regulatory tools are recommended. It has been observed that energy efficiency requirements on steam boilers could complement and support the IED and MCP directives.

- Finally, despite Ecodesign process focuses on newly sold products, it has been underlined that the mayor savings can be achieved by improving the current stock and not the newly sold products and this might lead to the fact that costumers will not be able to afford new products. Costumers might start repairing old products multiple times to avoid buying new ones.

8.2.2 Barriers (and opportunities) for Ecodesign measures

Industrial steam boilers are business to business products. They are being used in several industrial branches, producing steam for various applications (cf. Task 3). As part of a steam generation system they are embedded in a distribution and recovery system, where the generated steam is being distributed to the user and condensed afterwards so that water is being recovered and fed back to the steam generating boiler (in the case the steam is not being bounded by the user, cf. Task 3). The heterogeneity of applications has the consequence that configurations of industrial steam boilers vary. Nevertheless standardized planning processes for industrial steam boilers exist, where manufacturer present standardized size classes and configuration possibilities to design an industrial steam boiler according to customer needs[87]. However these size classes and the possibilities to configure industrial steam boilers might differ from manufacturer to manufacturer. Therefore customers of industrial steam boilers are usually accompanied by sales departments from manufacturer of steam boilers and plant engineering companies when planning and procuring industrial steam boiler and/or steam generation systems[88]. To sum it up the following consequences can be drawn from the applications and the nature of trade for industrial steam boiler:

- Industrial steam boilers are being configured in accordance to customer needs. Nevertheless size classes and typical configurations exist.
- The planning and procurement of industrial steam generation system is accompanied by sales departments of plant engineering companies and manufacturer of industrial steam boilers.

Among several other factors, the steady state efficiency of industrial steam boilers is also driven by factors resulting from customer requirements (cf. Task 4). The most important are:

- Pressure requirements: The efficiency of industrial steam boilers increases with lower generating pressures by tendency.
- Type of fuel: The efficiency of industrial steam boilers depends on the type of fuel applied. This is based in the fact that the achievable maximum efficiency of the burner is also dependent on the type of the fuel applied. As the efficiency of the burner is included in the figure for the efficiency of industrial steam boiler defined in test standards for acceptance tests (cf. Task 1, Task 3 and Task4) the type of fuel applied plays a role.

Having in mind that customers operate industrial steam boilers differently at various part loads (cf. Task 3) during a year this is an additional factor affecting the energy balance of a steam boiler during a year. Therefore it should also be subject of Ecodesign measures for industrial steam boilers.

Ecodesign measures limit the possibilities of regulations to be set more or less on the system boundaries defined in the Preparatory study of the appropriate product.

87 cf. Viessmann GmbH (2011): Planungshandbuch Dampfkessel

88 As indicated in an interview with a sales engineer from a Steam boiler manufacturer.

As already mentioned in Task 3, studies for steam generation systems and databases on industrial efficiency indicate that there are large potentials to increase energy efficiency in steam generation systems which are not located within the generation system itself i.e. the system boundary set within this study. Nevertheless industrial guidelines present various measures to increase the efficiency of the steam boiler itself. Many of these measures seem to be well known by manufactures and plant engineering companies as they are being advertised in planning manuals and guidelines[89]. These measures had been identified and presented in Task 6 with the outcome that the common measures are beneficial in terms of Life Cycle Cost from users view.

To sum it up the following Barriers[90] and Opportunities for Ecodesign measures result from the product and application characteristic:

Barriers:

- Several heterogeneous configurations for industrial steam boiler exist, resulting in differing maximum achievable steady state efficiencies. Ecodesign measures have to address this complexity.

Opportunities:

- Several technical solutions to increase the efficiency of industrial steam boilers are state of the art (cf. Task 6).
- Efficiency increase potentials for steam boiler are well known in industry as they are offered as sales options and advertised in several industrial guidelines.

8.2.3 Pros and cons of Ecodesign measures

The pros and cons of applying Ecodesign measures result directly from the barriers and opportunities of Ecodesign measures for industrial steam boilers. As already mentioned in the previous sub-chapter the efficiency of a steam boiler is dependent on several factors driven by customer requirements. The most important are pressure requirements, type of applied fuel and operational behaviour. With this background we discuss the pros and cons of measures under the Ecodesign Directive (Directive 2009/125/EC) listed in the following:

1. Implementing measures
    a. Applying Minimum Energy Performance Requirements for industrial steam boilers.
    b. Applying mandatory design features for industrial steam boiler.
2. Self-regulatory measures
    c. Applying a voluntary program coordinated by an industry association. Within this program minimum thresholds are set for the fraction of new sold industrial steam boiler to be equipped with energy efficiency improving design option per year.

1.a. Applying Minimum Energy Performance Requirements for industrial steam boilers:

Applying a Minimum Energy Performance Requirement (MEPR) for industrial steam boilers would at least have the need to address the pressure level and the type of applied fuel in a proper way. Having in mind that customers operate industrial steam boilers differently at various part loads (cf. Task 3) during a year,

89 cf. Schult, Meyer (2013): A Better Use of Energy: A Practical Handbook for Combustion,
cf. Viessmann GmbH (2011). Planungshandbuch Dampfkessel,
cf. Bosch GmbH (2012): Fachbericht: Brennwerttechnik.

90 The term Barriers is not in line within the scientific definition of barriers for the adaption of energy efficient technology in here.

the part load behaviour should also be subject of MEPRs for industrial steam boilers[91]. These requirements lead to further efforts needed as listed in the following with the benefit described afterwards.

- In depth technical analysis of the energetic performance of industrial steam boiler: An MEPRs requires an in depth technical analysis of the energetic performance of industrial steam boiler. In this study a technical analysis of the energetic performance of industrial steam boilers has been conducted. However only gas as fuel type had been analyzed. This decision was made on the basis of duly motivated reasons, among which, the fact that most industrial steam boilers in Europe are firetube steam boilers92 and that natural gas is mostly used in firetube boilers (on average approx. 95% for the EU[93]
- Additional analyses on steam boilers fuelled by other sources than gas can be carried out in the Impact Assessment study.
- Updating of performance test standards: Applying MEPS for industrial steam boiler would have the need to create a regulatory infrastructure to measure efficiencies in accordance to the MEPS set. When the efficiency at part load would also be subject within MEPS, the relevant standards for acceptance tests at the customers' site would have to be updated by the national organisations for standardization.

Even though there are efforts to apply an MEPS for industrial steam boilers the benefit would be a comprehensive analysis of industrial steam boilers in detail.

<u>1.b. Applying mandatory design features for industrial steam boiler:</u>

Applying mandatory design features for industrial steam boilers requires an analysis of design options improving the environmental balance of industrial steam boiler. This has been conducted in Task 6 with a focus on energy efficiency. As a result beneficial measures had been presented to be modelled in Task 7.

The advantage of applying mandatory design features is that not all possible configurations of industrial steam boilers have to be examined in detail. Basically the issues listed in the following have to be examined:

1. Is the design option cost effective in terms of customers LCC?
2. Is the application of the design option technical restricted?
3. Are there any negative environmental consequences from applying the design measure?

The benefit of this approach is a reduced complexity while retaining possibilities for technical regulation.

<u>2.a. Applying a voluntary program coordinated by an industry association:</u>

The criteria for self-regulation mechanisms are listed in Annex VIII of the Ecodesign directive. They are explained also in the guideline for Voluntary agreements under the Ecodesign Directive 2009/125/EC[94]. In the following we refer to criteria listed in there, where from our point of view major advantages or disadvantages occur for our product:

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91 In current test standards for acceptance tests of industrial steam boilers it is not required to evaluate the part load behaviour.

92 Minutes of the meeting for the stakeholder meeting held on the 6th of March 2014 in Brussels, published on www.eco-steamboilers.org.

93 during the second stakeholder meeting (Minutes of the meeting for the second stakeholder meeting held on the 3rd of July 2014 in Brussels, www.eco-steamboilers.org), it had been pointed out that this assumption might vary among European member states due to different regional fuel supply infrastructure . Thus, including other types of fuel could add completeness to the study, nevertheless the study's results are not affected by this choice.

94 cf. Voluntary agreements under the Ecodesign Directive 2009/125/EC (2010): EDWG 2010 Doc03.

- Criterion 3: representativeness:
  - o The EHI represented Steam Boilers manufacturers in the stakeholder meetings. However right now we cannot evaluate how many European manufacturers are covered by the EHI.
  - o Another problem which occurs within this context is when steam boilers are being imported from outside of Europe. It might be that these manufacturers have no agreements with the EHI. Anyhow Task 2 shows that imports for Steam Boilers are low at the current moment.
- Criterion 4: quantified and staged objectives
  - o As we understand the market shares for steam boilers sold to be equipped with certain design options derived by EHI are best guesses from industry. Thus a scheme has to be developed to quantify sold steam boilers being equipped with certain design options in any year in a proper way. These figures have to be collected by a representative association or similar then.
- Criterion 7: cost-effectiveness of administering a self-regulatory initiative
  - o The advantage could be that a self-regulatory mechanism might be cost effective. One reason is that the personnel in the representative associations have extensive experience with the product in scope. As a consequence they could be capable to develop an effective self-regulatory framework fulfilling the criteria in Annex VIII.

As a conclusion the major efforts of the modelled self-regulating mechanism lie in the collection of market data. To this purpose, it worth to underline that market data available on Eurostat are gathered without differentiating by power output and taking into account confidentiality and market relevance. Considering such limits, which have had a relevant weight in the steam boilers sector, a market operators' consultation have been carried out in order to verify statistical data and check them with information directly coming from the field. The response rate was very low, in particular from market operators. Some of them declared to be not interested in participating and others sent partial contributions providing not enough detailed data to be taken into account for further market analyses. Following the stakeholder meeting,[95], a new simplified survey has been launched in order to better focus the reference market on steam boilers (Power output between 1 and 50 MW) to gather specific values on production, import-export and stock data.

Only two contributions arrived: one from the European Heating Association (EHI), providing figures on production of steam boilers in Europe, the other one by the Swedish Energy Agency, related to the Swedish market.

As a consequence, all market data used rely on EHI's contribution, judged the most reliable and representative of large share of Steam Boilers manufacturer.

We finally sum up the major advantages and disadvantages of the above discussed policy mechanisms below.

Pros	**Cons**
Applying Minimum Energy Performance Requirements for industrial steam boilers.	
• Transparent for customer.	• Further technical evaluation of

[95] Held in Brussels on March 6, 2014

Pros	Cons
	Steam Boilers necessary. • Market figures far below the 200k threshold. • Risks of incompatibility with the MCP directive (see also next paragraph).
Applying mandatory design features for industrial steam boiler.	
• Efficiency improving options can be more easily addressed from the regulatory point of view than in (a). • Transparent for customer.	• Market figures far below the 200k indication.
Applying a voluntary program coordinated by an industry association. Within this program minimum thresholds are set for the fraction of new sold industrial steam boiler to be equipped with energy efficiency improving design option per year.	
• Cost effective framework possible due to personnel / know-how.	• An association to represent Steam boiler manufacturers should be recommended at EU level. • Efforts needed to establish a structure for collection of market data.

8.2.4 Policy measures for further analysis

Based on the foregoing presented pros and cons of the presented Ecodesign measures we choose the following measures for further analysis:

1. Implementing measures
    a. Applying mandatory design features for industrial steam boiler.
2. Self-regulatory measures
    a. Applying a voluntary program coordinated by an industry association. Within this program minimum thresholds are set for the fraction of new sold industrial steam boiler to be equipped with energy efficiency improving design option per year.

Thus we exclude the application of MEPS for industrial steam boiler for further analysis. This is based in the fact that as mentioned above a technical analysis covering many cases (depending on fuel and/or pressure) would be required, with a very high degree of complexity (ten base cases were under analysis, and a detailed analysis of the possible different configurations would exponentially increase this number). From our point of view efforts are allocated more efficient when focusing on applying mandatory design features for industrial steam boilers leading to a higher efficiency of new sold boilers. This is based in the fact that the options assessed in Task 6 all had been cost efficient in terms of LCC for customer and only one option might be technical restricted and/or cause negative environmental side effects. The conclusions for each option are listed in Table 83.

Table 83 - Questions for applying mandatory design features

Question:	ECO	CC	VSD	APH
Is the design option cost effective in terms of customers LCC?	YES	YES	YES*	YES
Is the application of the design option technical restricted?	NO	NO	NO	NO **
Are there any negative environmental consequences from applying the design measure?	NO	NO	NO ****	Possible ***

** This is an assumption based on guidelines from industry.*

*** Industrial steam boilers equipped with Monoblock designed burner can only be equipped with an air preheater with some restrictions on the material selection. According to expert opinions industrial steam boilers equipped with an air preheater are mostly Duoblock burners.*

**** The thermal NOx formation increases with higher temperatures of the combustion air. In most cases NOx thresholds can be achieved. This is especially the case when an economizer is being used before the APH. Nevertheless there might configuration where we cannot eliminate this risk. With the background of the upcoming MCPD (Medium Combustion Plant Directive) this might lead to a conflict of interests.*

***** In special cases VSDs might be not economically reasonable. However this is not considered as technical restriction.*

- *ECO: Economizer*
- *CC: Combustion Control*
- *VSD: Variable Speed drives*
- *APH: Air-Preheater*

Info: NOx emissions and APH

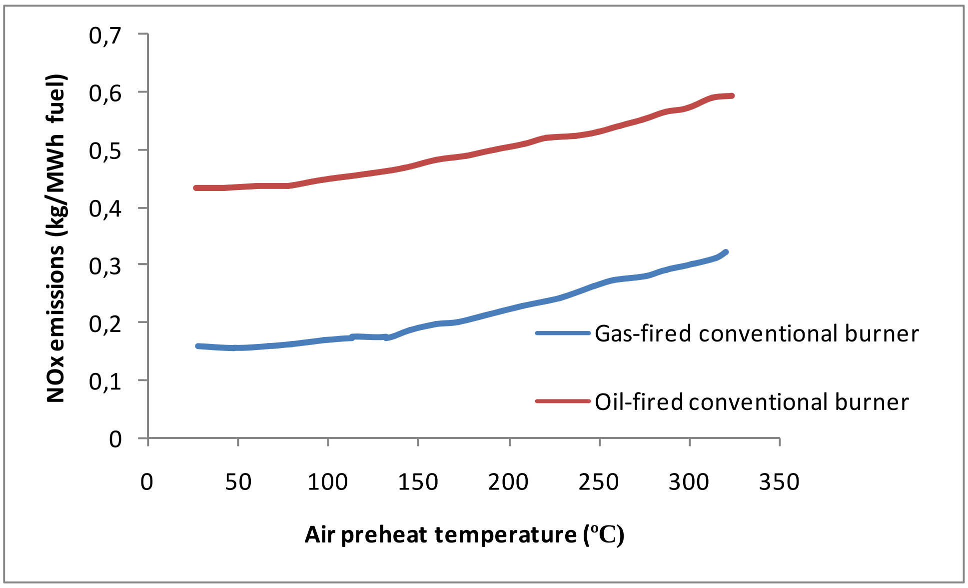
The utilization of the flue gas energy content in order to increase the temperature of the combustion air can lead to increased steam boiler thermal efficiency. However, air preheating can dramatically increase NO_x emissions because of the strong temperature dependence of NO formation. The relationship between the NO_x emissions level and the temperature of the combustion air in the burner is depicted in Figure #. For the calculations a fixed excess air value of 10% has been assumed. For air preheating temperatures exceeding 100°C, a rapid increase of the NO_x emissions can be observed. As a result, an increase in the overall thermal efficiency of the system through the incorporation of an air-preheater can lead to an undesirable increase of the total amount of NO_x emissions if the fuel consumption is not substantially reduced.

For this reason, and having in mind the upcoming Medium Combustion Plant Directive (MCP), we omit to include the APH for the further analysis in Task 7[96].

Figure 80 - Relationship between the specific NOx emissions (kg/MWh of fuel) and the air preheating temperature of the combustion air for

[96] Calculations on potential NOx emissions of the Base Cases under the given configurations are very uncertain; nevertheless, feedbacks from industrial stakeholders at the second stakeholder meeting held in Brussels, confirm that they see the danger that existing NOx emission values (on national level) might be trespassed due to the application of Air-Pre-Heater under certain configurations.

conventional gas-fired and oil-fired burners (excess air is assumed to be 10%)



source: Industrial Combustion Pollution and Control, Charles E. Baukal, Jr. Marcel Dekker, Inc, New York Basel, 2004

Based on this conclusion we evaluate the effect of supporting policy mechanisms for the application of economizer (ECO), improved combustion control (CC) and variable speed drives (VSD) in the next paragraphs. As these measures are cost effective, not technical restricted and cannot cause any environmental side-effects to prescribe design features within the Ecodesign Directive (Directive 2009/125/EC) is worth consideration.

8.3 Subtask 7.2: Scenario analysis

Subtask 7.2 provides the scenarios according to the policy measures described in Subtask 7.1. To this purpose, the analyses on the previous tasks have been extended to the defined scenarios in comparison with the Business-as-Usual (reference) Scenario.

8.3.1 Scenarios overview

Different scenarios have been drawn up to illustrate quantitatively the improvements that can be achieved at EU level by 2030 with suitable Ecodesign policy actions against the Business-as-Usual scenario.

The three main technical improvement options considered in Task 6 are defined as follows[97]:

- **Economiser (ECO):** Preheats feedwater and cools down flue gases. Increases overall boiler efficiency reducing flue gas losses.
- **Combustion Control (CC):** digital control systems, temperature sensors, oxygen monitors, CO monitor, oxygen trim controls: reduces excess air of combustion.
- **Variable Speed Drives (VSD):** Electricity consumption can be reduced. Useful if the boiler load is below maximum.

[97] Please note that we do not evaluate the APH. This is based in the fact than an APH might be technical restricted and might cause higher NOx-Emissions.

The Business-as-Usual scenario considers **autonomous market diffusion** of products equipped with new improvement options in future based on historical data from EHI (based on the new data described in Task 2).

The energy saving potential of Steam boilers was assessed for the following three scenarios:

- **Autonomous diffusion (Auto diff):** it assumes the increase of the percentage of new sales to be equipped with the design features Economiser (ECO), Air-Pre Heater (APH), Combustion Control (CC) and Variable Speed Drives (VSD, evaluated separately) to follow fitted S-curves.
- **Voluntary agreement diffusion (Voluntary diff):** it assumes the increase of the percentage of new sales to be equipped with the design features as above to be faster than in the Auto diff. Thus we increase the values from the S-curve by multiplying with assumed figures as presented in the graphs.
- **Ecodesign diffusion (Ecodesign diff)**: it assumes the design features Economiser (ECO), Air-Pre Heater (APH), Combustion Control (CC) and Variable Speed Drives (VSD, evaluated separately) to be mandatory for every new sold steam boiler from 2015 onwards.

8.3.2 Approach

The expected trends (**annually energy savings by applying design measures**) for industrial steam boilers per policy option up to 2030 are presented in the following chapter.

The stock is estimated by backcasting the sales for the period from 1988 to 2012 which results in an assumed stock for 2013. The underlying sales figures for backcasting are based on the presented production figures in Task 5 (Table 46, Table 47, Table 48). We assume these figures to represent the sales in 2013. They are categorized in water tube boilers (1.000 pcs.), vapour generating boilers (2500 pcs.) and superheated boilers (250 pcs.). We assume vapour generating boilers to represent fire tube boilers and we omit superheated boilers in the further analysis. We furthermore assume an export rate of 20%. This results in the following intra-EU sales figures:

- Fire tube boilers = 2500 – (0,2*2500) = 2000 pcs. in 2013,
- Water tube boilers = 1000 – (0,2*1000=) 800 pcs. in 2013.

These are then the input figures used for stock building. We split/assign these figures to each Base Case. For that we consider that the sales had been given for cluster of power ranges. We furthermore address that 2/3 of sales are low/medium pressure and the rest are high pressure. The assumed sales figures per Base Case are presented in Table 89. With these sales figures we build the stock in 2013 by calculating previous sales 25 years backwards as described in the following equation:

$$\left.\begin{array}{l} GDP.GR_{i+1} \geq 0 \Rightarrow Sales_i = \dfrac{Sales_{i+1}}{(1+GDP.GR_{i+1})} \\ GDP.GR_{i+1} < 0 \Rightarrow Sales_i = \dfrac{Sales_{i+1}}{(1-GDP.GR_{i+1})} \end{array}\right. , \text{ with } GDP.GR \in [-1,1]$$

$GDP.GR$ = Annual Growth Rate of GDP in the EU 28 for year i.

Assuming that machines are being discarded or exchanged after 25 years a stock of approx. 60.000 steam boilers (including all Base Cases) is the result for 2013. Furthermore the age distribution is given. In order to forecast the assumed stock we estimate sales for the period from 2013 to 2030. The sales for the period of 2013 to 2030 are calculated as follows:

$$Sales_{i+1} = Sales_i \cdot (1 + GDP.EGR_{i+1}), \text{with } GDP.EGR \in [0,1]$$

$GDP.EGR$ = Estimated Annual Growth Rate of GDP in the EU 28 for the year i.

We assume a *GDP.EGR* of 1,5% per year from 2013 onwards up to 2030. The resulting stock and sales assumptions are visualised in Figure 81 and Figure 82. Here it has to be mentioned that the sum of assumed sales is **under 200.000 pieces** per year, which is an indicative threshold set by the Ecodesign Directive defining criteria for implementing measures within the framework (cf. Ecodesign Directive (Directive 2009/125/EC), Article 15, Paragraph 2a).

Figure 81 - Assumed sales per Base Case

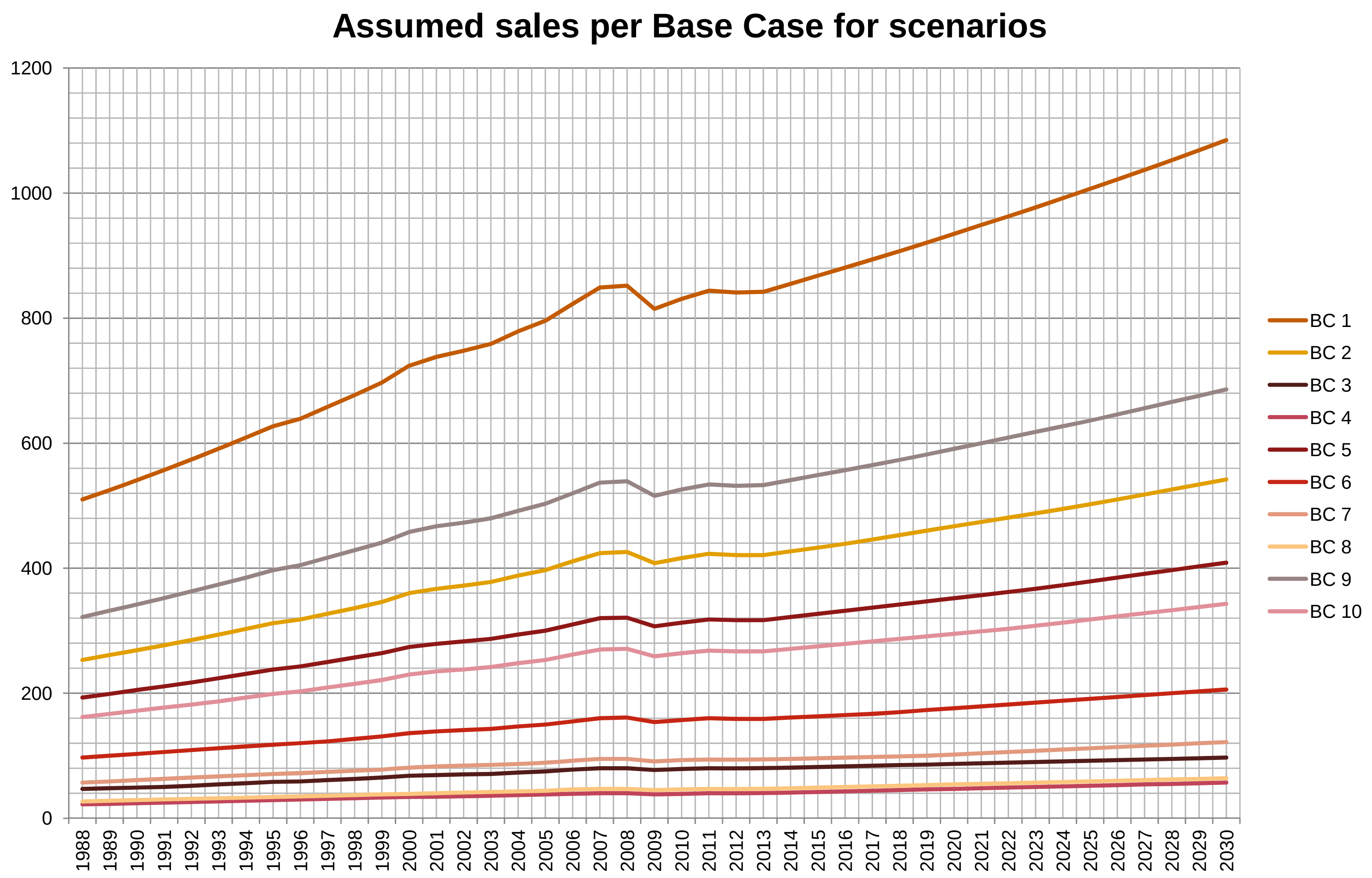
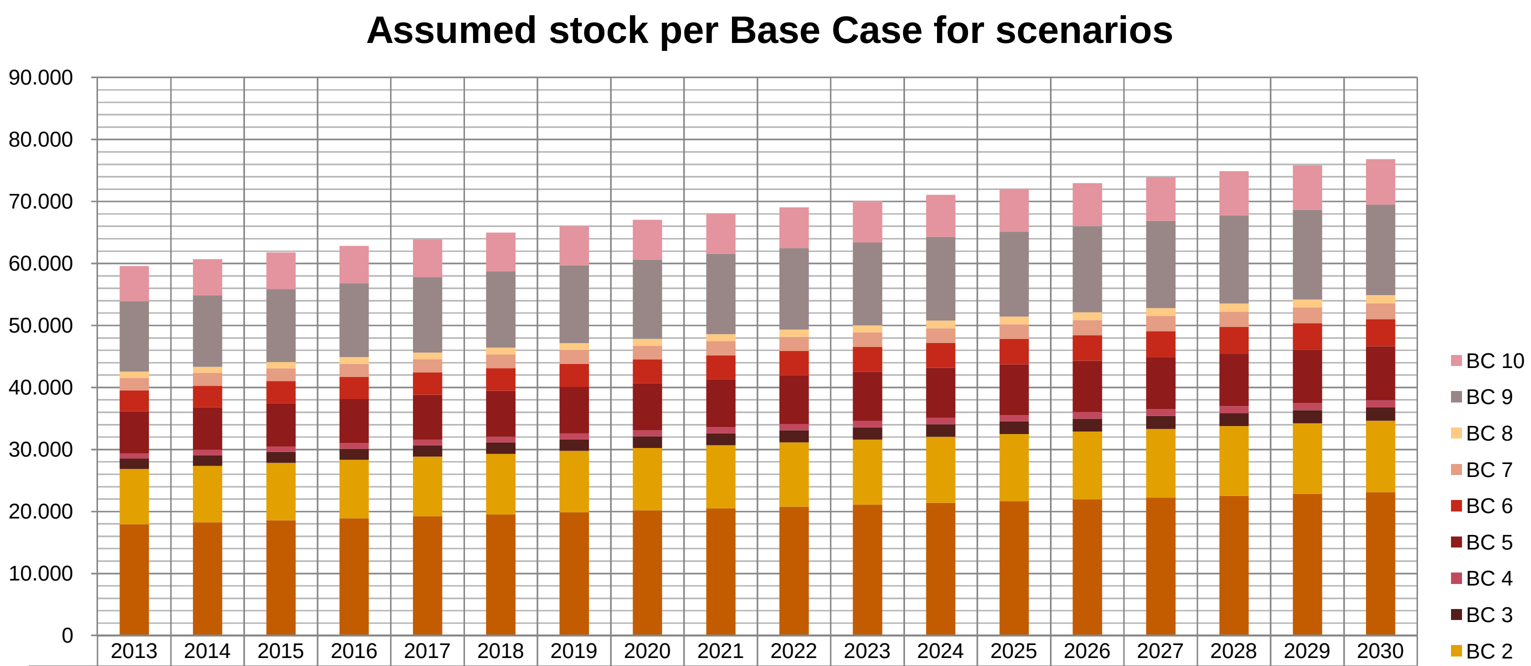


Table 84 Assumed sales per Base Case (the orange marked row indicates the input values)

Base Case No. Sales	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	510	525	541	557	574	591	609	627	639	658	677	697	724	738	748	759	779	796	823	849	852	815
2	253	261	269	277	285	294	303	312	318	327	336	346	360	367	372	378	388	397	411	424	426	408
3	47	48	49	50	52	54	56	58	59	61	63	65	68	69	70	71	73	75	78	80	80	77
4	22	23	24	25	26	27	28	29	30	31	32	33	34	35	35	36	37	38	39	40	40	38
5	193	199	205	211	217	224	231	238	243	250	257	264	274	279	283	287	294	300	310	320	321	307
6	97	100	103	106	109	112	115	118	120	123	127	131	136	139	141	143	147	150	155	160	161	154
7	57	59	61	63	65	67	69	71	72	74	76	78	81	83	84	85	87	89	92	95	95	91
8	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	46	47	47	45
9	322	332	342	352	363	374	385	397	405	417	429	441	458	467	473	480	492	503	520	537	539	516
10	162	167	172	177	182	187	193	199	203	209	215	221	230	235	238	242	248	253	262	270	271	259

Base Case No. Sales	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
1	831	844	841	842	855	868	881	894	907	921	935	949	963	977	992	1.007	1.022	1.037	1.053	1.069	1.085	
2	416	423	421	421	427	433	439	446	453	460	467	474	481	488	495	502	510	518	526	534	542	
3	79	80	80	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	
4	39	40	40	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	
5	313	318	317	317	322	327	332	337	342	347	352	357	362	367	373	379	385	391	397	403	409	
6	157	160	159	159	161	163	165	167	170	173	176	179	182	185	188	191	194	197	200	203	206	
7	93	94	94	94	95	96	97	98	99	100	102	104	106	108	110	112	114	116	118	120	122	
8	46	47	47	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	
9	526	534	532	533	541	549	557	565	573	582	591	600	609	618	627	636	646	656	666	676	686	
10	264	268	267	267	271	275	279	283	287	291	295	299	303	308	313	318	323	328	333	338	343	

Figure 82 - Assumed stock per Base Case (2013-2030)



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BC 10	5.699	5.803	5.906	6.008	6.109	6.209	6.307	6.403	6.499	6.593	6.686	6.778	6.866	6.954	7.044	7.135	7.225	7.315
BC 9	11.347	11.556	11.763	11.968	12.170	12.369	12.566	12.760	12.955	13.147	13.336	13.522	13.700	13.879	14.062	14.248	14.432	14.615
BC 8	984	1.004	1.024	1.044	1.064	1.084	1.104	1.124	1.144	1.164	1.184	1.204	1.224	1.244	1.264	1.284	1.304	1.324
BC 7	2.012	2.048	2.083	2.117	2.150	2.182	2.213	2.244	2.276	2.308	2.340	2.372	2.403	2.434	2.466	2.499	2.532	2.565
BC 6	3.385	3.446	3.506	3.565	3.623	3.681	3.739	3.797	3.856	3.915	3.973	4.030	4.085	4.140	4.196	4.253	4.309	4.365
BC 5	6.779	6.902	7.024	7.145	7.265	7.383	7.499	7.613	7.727	7.839	7.949	8.058	8.163	8.269	8.377	8.487	8.596	8.705
BC 4	839	857	875	893	911	929	947	965	983	1.001	1.019	1.037	1.055	1.073	1.092	1.111	1.130	1.149
BC 3	1.675	1.708	1.741	1.774	1.806	1.837	1.867	1.896	1.925	1.953	1.980	2.006	2.030	2.054	2.078	2.102	2.125	2.147
BC 2	8.940	9.106	9.270	9.432	9.593	9.752	9.909	10.064	10.220	10.374	10.526	10.675	10.817	10.960	11.106	11.254	11.400	11.545
BC 1	17.936	18.266	18.593	18.917	19.237	19.553	19.865	20.173	20.483	20.788	21.088	21.383	21.666	21.950	22.239	22.533	22.823	23.112

We then calculate the diffusion rates for the autonomous (**BAU**) market diffusion of the chosen design options. For that we assume the increase in the percentage of sales being equipped with the appropriate design option to be S-shaped. **This is an assumption** based on the idea that the adaption of new technology behaves like in a so called epidemic model where the diffusion process is driven basically by so called **word of mouth** communication. The underlying idea is that when new hardware is being adopted so called software knowledge is being built by using the technology. It is then supposed that existing user contact non-user independently with a certain probability infecting the non-user to adopt the new technology. Furthermore a maximum number of users is assumed. The number of users at any time is then dependent on the number of users which already adopted the new technology, the number of users which still could adopt the new technology and the probability with which non-user contact user[98]. This leads to a function where the "population of users gradually rises, increasing the aggregate stock of software information that can be passed on until it hits a maximum and then it declines (as non-users get increasingly hard to find, therefore, to infect)" (cf. Geroski (2000)). This function is a logistic function having the characteristic S-shape[99]. We assume this adaption behaviour to represent the diffusion of the chosen design options (i.e. technologies) among sales of industrial steam boilers. Thus the S-curves represent the share of sold industrial steam boiler to be equipped with the appropriate design options.

We fit the S-curves based on values for the estimated share of sales being equipped with each design option for the years 1993 and 2013 (see Table 85). These values had been provided by the BDH. They represent best guesses from industrial stakeholder. Furthermore we assume a maximum diffusion rate for each Base Case and technology. The aggregated assumed values for all Base Cases are listed in Table 85.

Table 85 - Assumptions for modelling of market shares

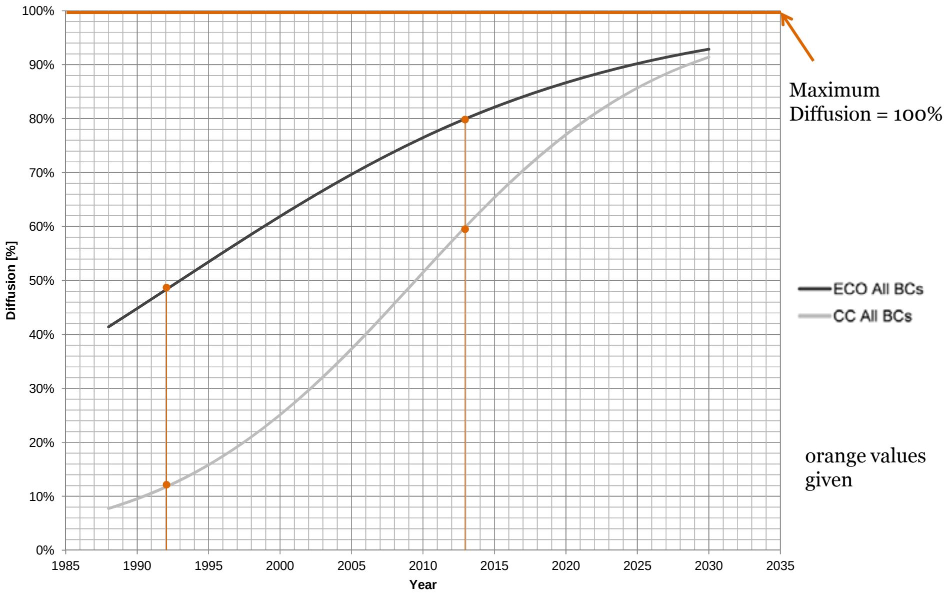
Technology option	Market share [%], 1993	Market share [%], 2013
Economizer	50	80
Combustion control	13	60
Variable speed drives*	5	50

* Own assumptions (not from BDH). This assumption represents our expert opinion based on conservative assumptions. A lower market share of VSDs in 2013 would result in higher estimated savings caused by mandatory policy measures. However within the scenarios the sensitivity towards VSD savings is not high (cf. Table 90, Sensitivity Case No. 6 and 7).

98 Another common epidemic model is the central source model, where the knowledge about the existence of a new technology among potential users drives the adoption of the technology (cf. Geroski (2000)). This model leads to an exponential shape. However the word of mouth model seems to be more valid for industrial goods.

99 cf. Geroski (2000): Models of technology diffusion, in Research Policy 29 (2000) 603-625.

Figure 83 - Assumed s-curve for the Economizer (ECO) and Combustion Control (CC)



This approach leads to "market shares" for each technology in the evaluated time frame from 2013 to 2030 of the autonomous (**BAU, i.e. Autodiff**) market diffusion scenario. Based on this we calculate the market shares of each technology for the **Voluntary agreement diffusion (Voluntary diff)** market scenario. Therefore we assume the increase of the percentage of new sales to be equipped with the design features as above to be faster than in the Auto diff. We implement this concept by multiplying the market shares from the Autodiff scenario with assumed figures. For example the market share of the ECO in the Voluntary diff scenario for 2016 is derived by multiplying the Auto diff rate with 1,1 (multiplier). We then increase the multiplier per year with an assumed constant rate. E.g. for the ECO the assumed market share in 2017 is derived by multiplying the Auto diff rate with 1,11 (1,10 + 0,01). As the multiplier are assumptions in the market share for the Voluntary diff scenario, the resulting shares consequently represent ratings from the project team which market shares should be achieved by Self-regulatory measures (resulting to the estimated energy savings presented in the following sub chapter). Finally in the **Ecodesign diffusion** scenario (Ecodesign diff) we assume the design features Economiser (ECO), Air-Pre Heater (APH), Combustion Control (CC) and Variable Speed Drives (VSD) to be mandatory for every new sold steam boiler from 2016 onwards. This represents a measure within the Ecodesign Directive (Directive 2009/125/EC) prescribing mandatory design features for industrial steam boilers. The resulting market shares for the different technologies and the scenarios are visualised in Figure 84 to Figure 86.

Figure 84 - Market share of ECO on new sales [% equipped of new sales]100

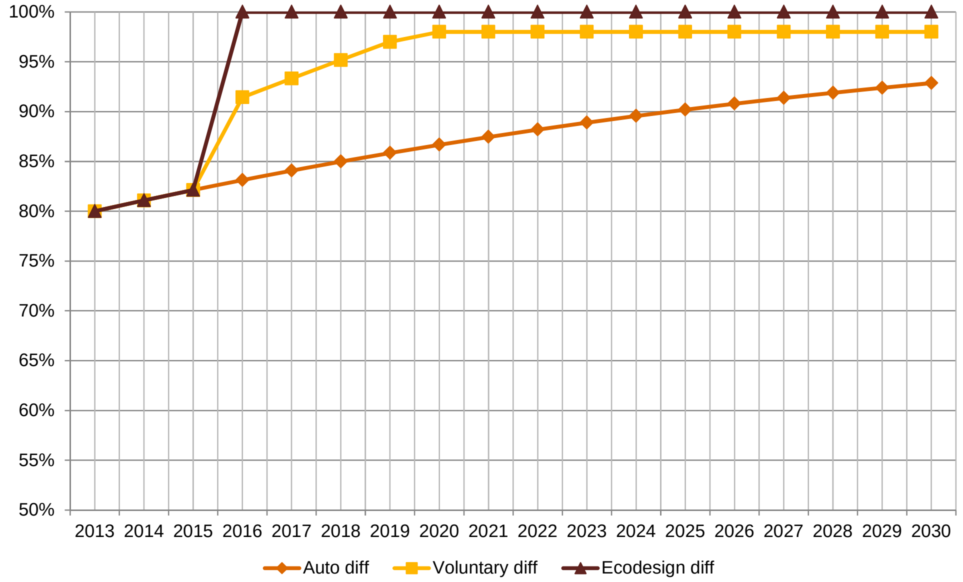
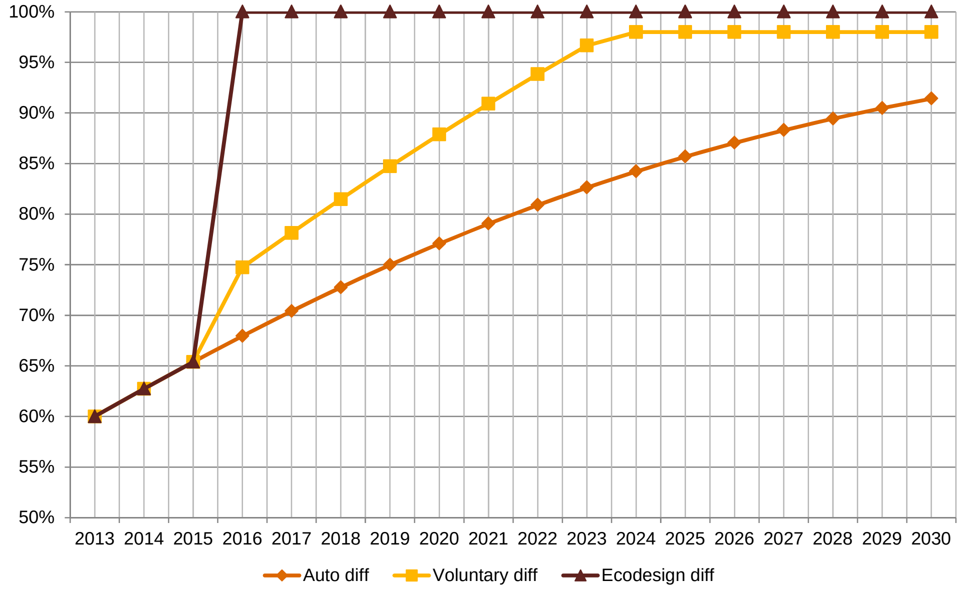


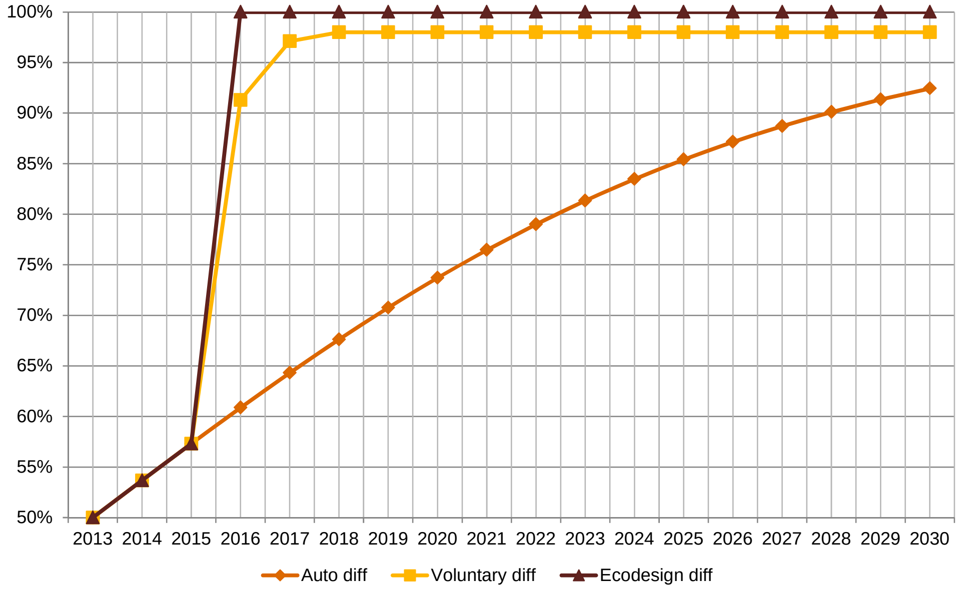
Figure 85 - Market share of CC on new sales [% equipped of new sales]101



100 The Voluntary diff results from multiplying the Auto diff rate with 1,1 in 2016 and then increasing the multiplier by 0,01 p.a. until reaching a market share of 98%.

101 The Voluntary diff results from multiplying the Auto diff rate with 1,1 in 2016 and then increasing the multiplier by 0,01 p.a. until reaching a market share of 98%.

Figure 86 - Market share of VSD on new sales [% equipped of new sales]102



Keeping in mind that machines are being replaced after an age of 25 years the share of each technology in stock can be calculated, as the prediction of sales and the age structure of the current stock is given. The technology share is then:

$TS_{A,BC,i} = \frac{M_{A,BC,i}}{S_{BC,i}}$, where $TS_{A,BC,i}$ is the technology share of technology *A* for the Base Case with number *BC* in year *i*, $M_{A,BC,i}$ is the number of Machines in year *i* of Base Case with number *BC* being equipped with technology *A* and $S_{BC,i}$ is finally the number of machines of Base Case with number *BC* in year *i*. The resulting shares of each technology in stock – aggregated for all Base Cases – is then visualised in Figure 87 to Figure 89.

In order to evaluate the thermal energy consumption of the Steam boiler stock for each Base Case a weighted stock efficiency is being calculated based on the technology shares mentioned above. As we model three technologies increasing the stock efficiency *A* is replaced with ECO for the economizer and with CC for the combustion control. The weighted stock efficiency per Base Case is then:

$\eta_{BC,i} = \eta_{BC,o} + (TS_{ECO,BC,i} \cdot EI_{ECO}) + (TS_{CC,BC,i} \cdot EI_{CC})$, where EI is the efficiency improvement for the appropriate technologies and $\eta_{BC,o}$ is the efficiency of Base Case with number *BC* without any technology option.

Finally the energy consumption (electric and thermal) is derived by assuming operation hours as listed in Task 5 for each Base Case. The thermal energy consumption is then:

$EconT_{BC,i} = \frac{S_{BC,i} \cdot O_{BC} \cdot H_{BC}}{\eta_{BC,i}}$, with H_{BC} being the heat delivered to steam and O_{BC} being the operation hours per year for Base Case with number *BC*.

[102] The Voluntary diff results from multiplying the Auto diff rate with 1,5 in 2016 and then increasing the multiplier by 0,01 p.a. until reaching a market share of 98%.

Differing energy consumptions per year for the different scenarios result then consequently from different weighted stock efficiencies for the scenarios. The thermal energy consumption for electricity is then derived by taking the stock share of VSDs into account:

$$EconE_{BC,i} = S_{\mathrm{BC},i} \cdot O_{BC} \cdot P_{BC} \cdot (1 - TS_{\mathrm{VSD},BC,i}) + S_{\mathrm{BC},i} \cdot O_{BC} \cdot P_{BC} \cdot TS_{\mathrm{VSD},BC,i} \cdot (\mathrm{APL}_{BC})^3$$

, where P_{BC} is the power needed at full load and $\mathrm{APL}_{BC} \in [0,1]$ is the assumed average load for Base Case with the number *BC* (cf. Subtask 6.1). In our model APL_{BC} equals to 0,75 for all cases as we assume the average part load to be 75%. The differing electric energy consumptions are then consequently also derived by differing technology shares between the scenarios. The resulting electric energy consumption is then converted to primary energy assuming an conversion factor of 2,5.

The energy savings per policy option (per year) are finally the differences between the consumption in each scenario (per year) and the consumption of the **Autodiff** scenario in the same year.

Figure 87 - Share of Economiser-technology in stock [% on population]

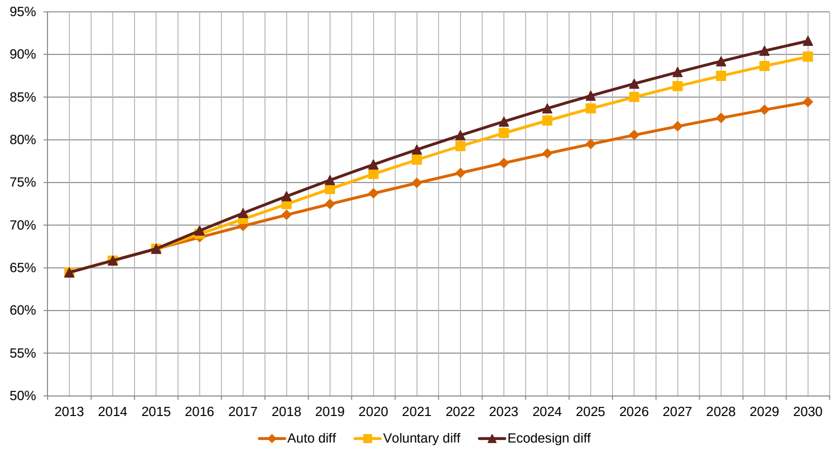


Figure 88 - Share of Combustion-Control-technology in stock [% on population]

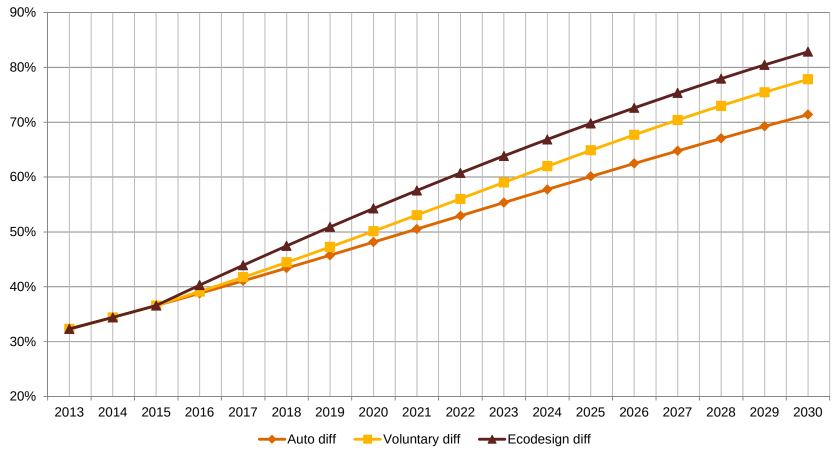
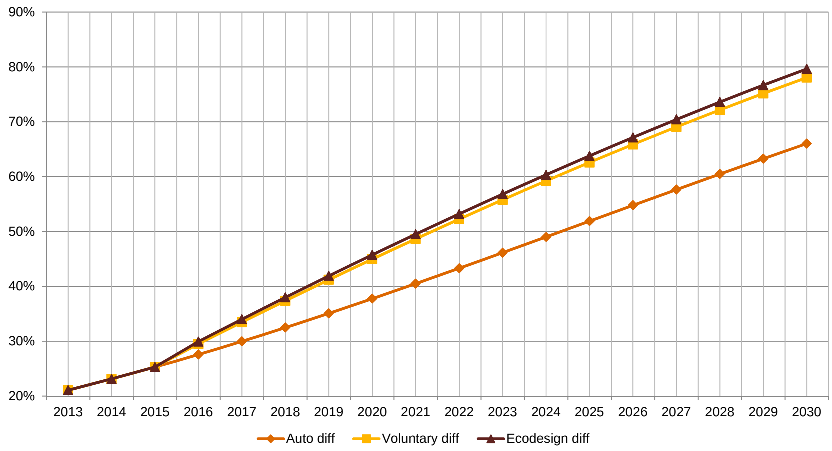


Figure 89 - Share of VSD-technology in stock [% on population]



We finally validated the resulting energy consumption for 2013 – which is majorly driven by the assumed stock model and operation hours set – by a comparison of our consumption figures with energy balances from Eurostat. An overview is given in Table 86. Although the stock is fully valid only from 2013 onwards (based in methodology) the figures down to 2009 can be used as indication. By assuming that 95% of the Steam Boilers in stock are fired with Natural Gas and 5% with oil the resulting share on the overall consumption of industry is

- 81% for gas in the year 2012, and
- 12% for oil in the year for 2012.

The overall share on the final energy consumption of industry is 27%. From our point of view these values seem reasonable as scientific literature indicates that steam generation account for about one third of overall industrial energy demand in the U.S., which might have an industry structure comparable to the European industry (cf. Therkelsen et al. (2013))[103].

103 Therkelsen et al. (2013): Implementation and rejection of industrial steam system energy efficiency measures , Energy Policy57(2013) 318–328.

Table 86 - Validation table

	Item code	Unit	Source(s)	2009	2010	2011	2012	2013
Oil products consumption of industry	petcfind	PJ	Eurostat	1.555,58	1.525,41	1.409,70	1.336,72	n.a.
Gas consumption of industry	gazcfind	PJ	Eurostat	3.514,66	3.852,16	3.786,39	3.748,48	n.a.
Final consumption of industry	toccfind	PJ	Eurostat	11.293,59	12.167,78	12.114,77	11.836,09	n.a.
Date of export: 2014-09-08								
Source : Odyssee								
				2009	2010	2011	2012	2013
Energy consumption - Base Cases		PJ		2741,22	2889,98	3040,86	3191,06	3247,28
Energy consumption - Oil	5%	PJ		137,06	144,50	152,04	159,55	162,36
Energy consumption - Gas	95%	PJ		2604,16	2745,49	2888,82	3031,51	3084,91
Share Oil	%			9%	9%	11%	12%	
Share Gas	%			74%	71%	76%	81%	
Share Industry	%			24%	24%	25%	27%	

8.3.3 Results

The results of the scenarios are presented in the following. Given the afore presented approaches and assumptions the primary energy consumption rises from 908 TWh in 2013:

- up to 1146 TWh in 2030 for the Auto diff,
- up to 1140 TWh in 2030 for the Voluntary diff (-0,5%), and
- up to 1138 TWh in 2030 for the Ecodesign diff (-0,7%) (cf. Figure 90).

The rising energy demand is based in the assumption that sales are coupled to GDP growth and we assume an GDP increase of 1,5 p.a. % for the European Union up to 2030. This assumption omits possible changes in industry structure which might lead to different production patterns leading to a decreasing steam and therefore steam boilers demand. Furthermore the life time of the steam boilers is fixed in the model omitting that life time extension might lead to lower steam boilers demand.

Nevertheless it can be shown that under the given assumptions the chosen policy options can decrease the forecasted increase in energy demand. For the direct energy consumption of fossil fuel at the burner (i.e. fuel consumption of the steam boiler) the energy consumption rises from 904 TWh in 2013

- up to 1143 TWh in 2030 for the Auto diff,
- up to 1137 TWh in 2030 for the Voluntary diff (-0,5%), and
- up to 1135 TWh in 2030 for the Ecodesign diff (-0,6%).

Thus an up to 0,6% lower energy demand p.a. can be achieved compared to the Autodiff with the assessed policy measures (cf. Figure 91). For the electric energy consumption the energy consumption translated to primary energy falls from 3575 GWh in 2013

- down to 3243 GWh in 2030 for the Auto diff,
- down to 2877 GWh in 2030 for the Voluntary diff (-11%), and
- down to 2830 GWh in 2030 for the Ecodesign diff (-13%).

Therefore an up to 13% lower energy demand p.a. can be achieved compared to the Autodiff with the assessed policy measures (cf. Figure 92).

Figure 90 – Primary energy consumption

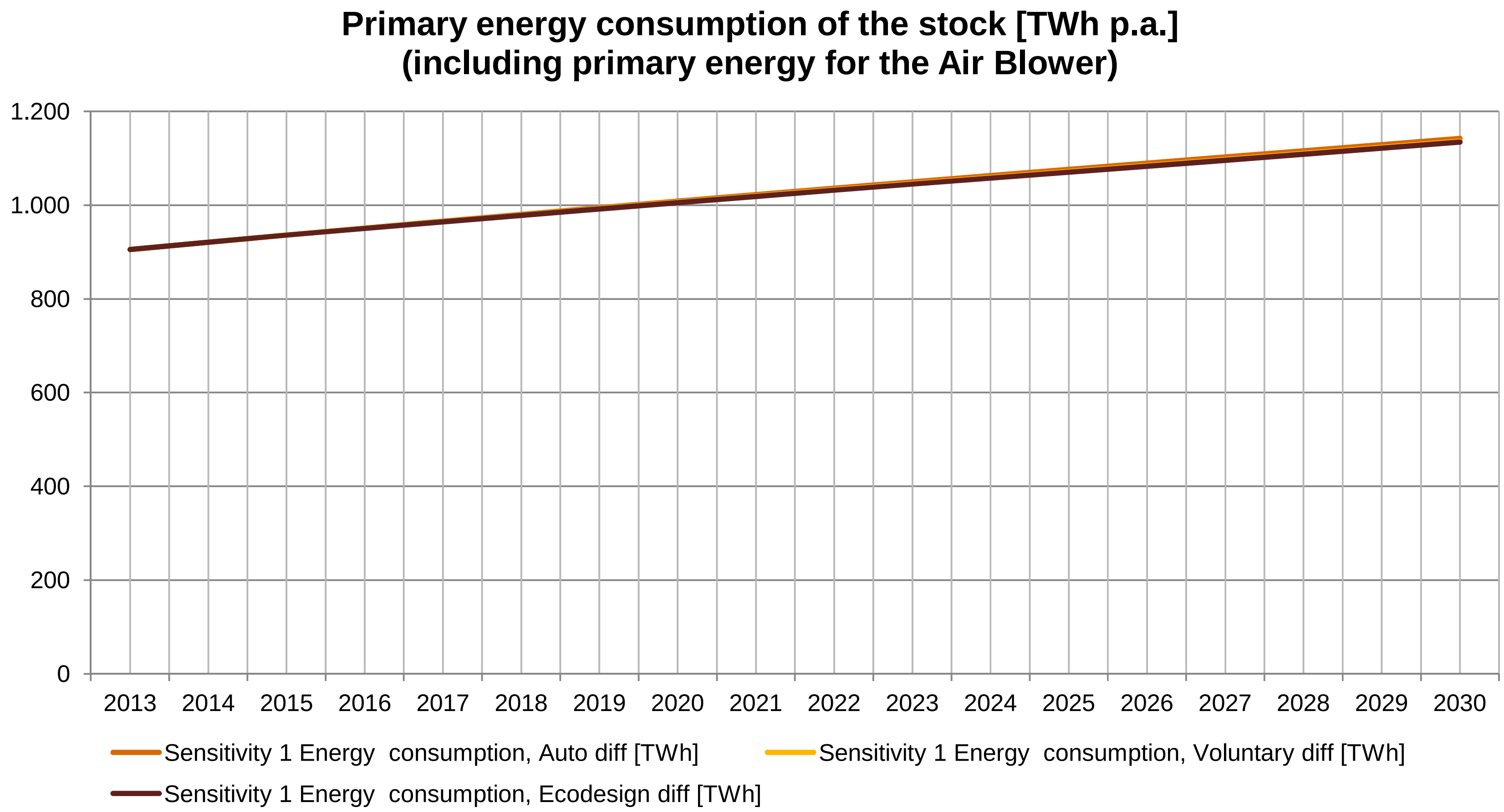


Figure 91 Energy savings at the burner

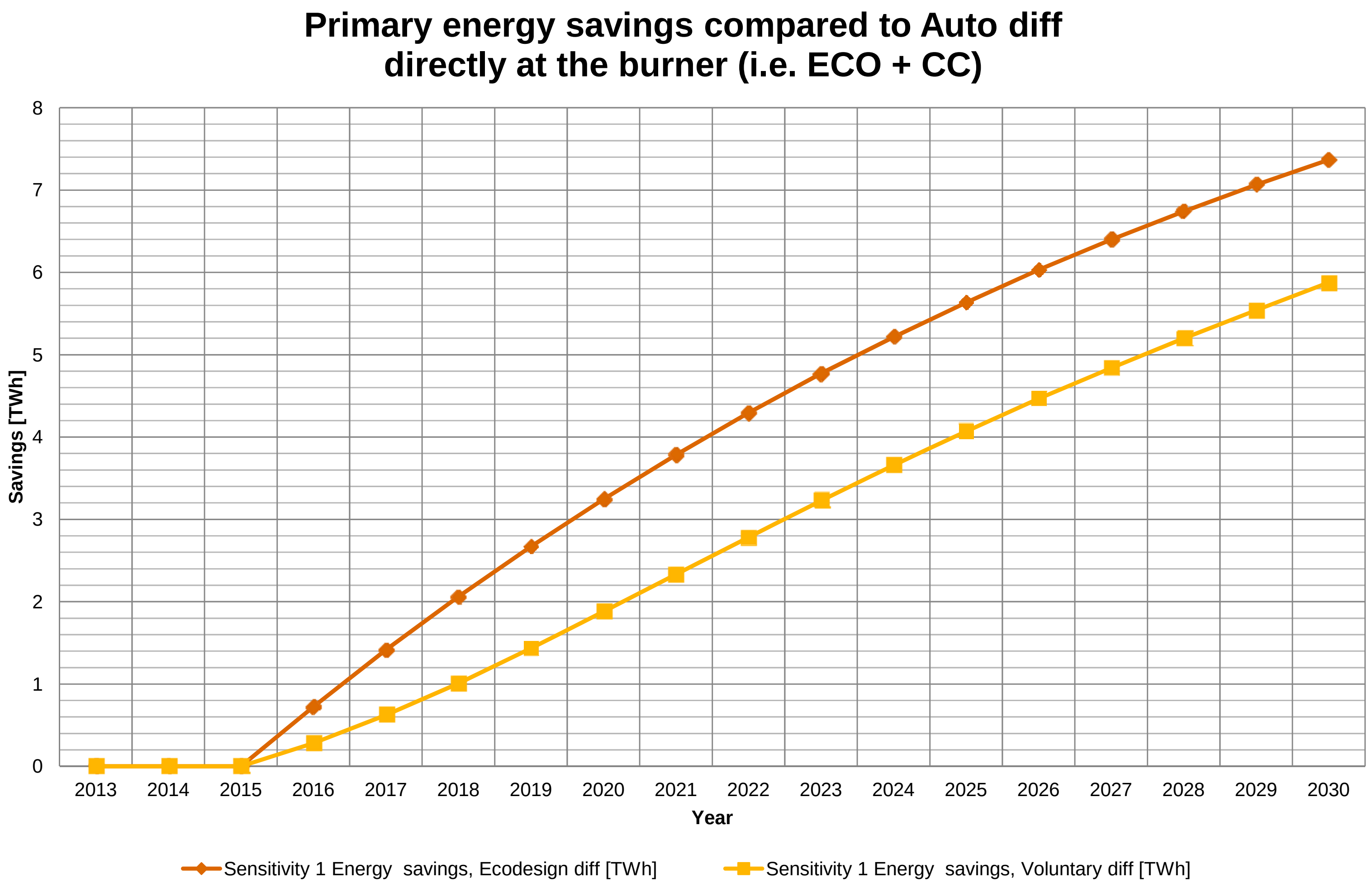


Figure 92 - Energy savings at the blower

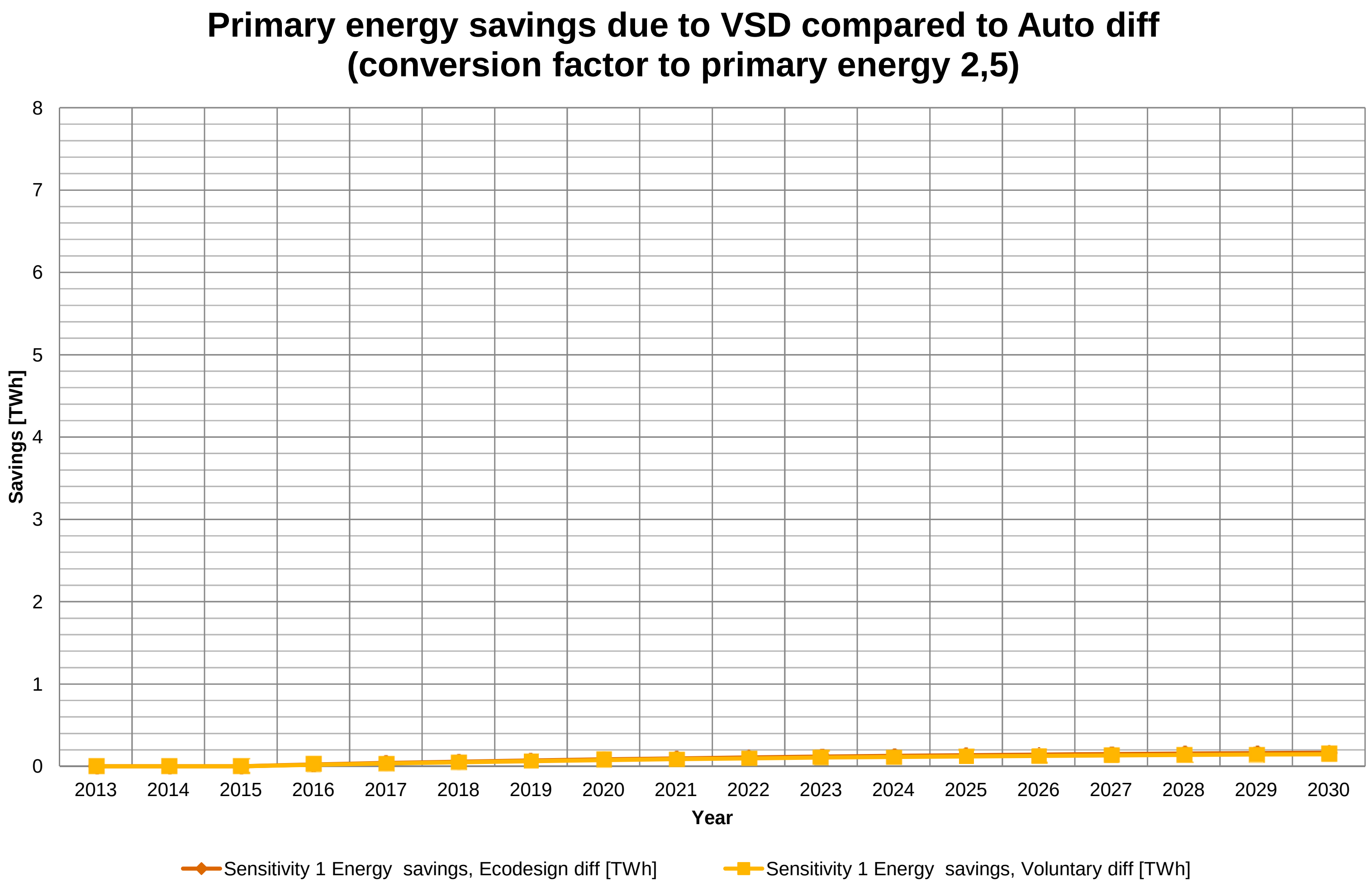
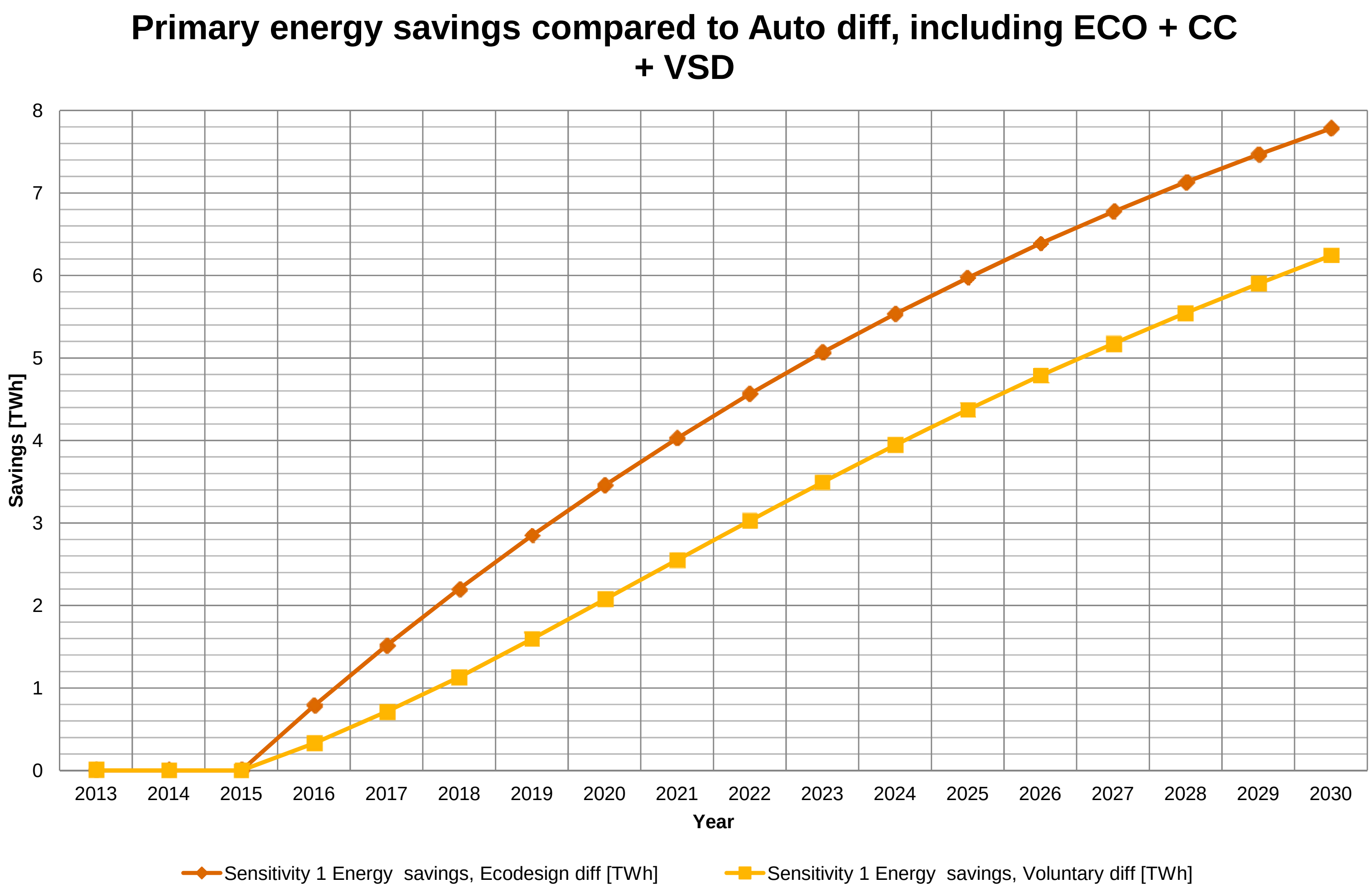


Figure 93 - Combined energy savings



8.4 Subtask 7.3: Impact analysis industry and consumers

For each of the policy options described in the previous paragraph, the costs and benefits should be assessed. This will be performed in more detail in an Impact Assessment by the European Commission at a later stage in the policy-making process but, as a preliminary step of the analysis, basic impacts that are likely to occur as a consequence of introducing Ecodesign measures are identified.

In particular, this preliminary assessment deals with impacts on manufacturers of steam boilers, markets and consumers.

There are only a limited number of steam boilers in the European market and only a few manufacturers.

Steam boilers are mostly custom-designed to meet very specific requirements, all of which have particular requirements, limitations and constraints. Therefore, the maximum energy efficiency that is achievable is very varied.

These large differences are difficult to capture by the methodology used for eco-design preparatory studies, based on representative base cases, as there is so much variation in the designs available or implemented. As a result, the additional costs and potential energy savings values used for policy and impact analysis may be reasonable estimates of "average" values, but the particular costs and energy reductions achievable for some process designs will be very different to others.

In the following paragraphs, some key issues to be taken into account for further impact assessment are described. In particular, the key issues are related to the potential impacts of the designed scenarios on manufacturers and market competitiveness and on users of steam boilers.

8.4.1 Impact on manufacturers

As fully described in Task 6 and in Task 7, subtask 7.2, the technology improvements in the steam boilers market are already available on the market. Thus, the implementation of the policy options would be technically achievable by all manufacturers.

As technology already exists, no additional R&D should be needed to achieve the eco-design options.

The effect of ecodesign on the volume of investment in new design would depend on the extent (if any) to which steam boilers prices increase and the extent (if any) to which that has a chilling effect on investment. According to our analysis on costs provided in Task 5 and 6, the investment cost for a boiler equipped with ECO, APH and CC (all options) could almost double. Nevertheless to equip boilers with Economizers and improved Combustion Control seems to be already common in market as they have estimated market shares of 80 and 60% for new sold boiler. Thus it is questionable whether a pure boiler price is a reference to consider when evaluating possible impacts on market value. As the boiler prices only accounts to a small fraction of customer LCCs due to the high life time and corresponding fuel costs a review on LCCs results in additional indications. Thus in the following section "**Impact on users**" considerations on customers LCC will be discussed.

8.4.2 Impact on users

As already mentioned in the foregoing, the purchasing prices for Steam boilers increase when prescribing mandatory design features. Nevertheless it has been shown in Task 6 that the efficiency options dealing with the increase of the thermal efficiency are all cost effective. Thus one proxy to evaluate how relevant the increase in purchasing prices would is to evaluate the quotient of investment necessary for a Steam boiler and fuel costs during life time, as fuel costs are the major factor driving customer LCCs. Thus the investments with the different design options are being set into relation to the fuel costs in Table 87 assuming a lifetime of 25 years, 1250 operation hours per year and a constant gas price of 10,57 EUR/GJ for the next 25 years. It can be seen for the share of investment on fuel cost during the entire life that:

- the share is **below 2%** for Base Cases 5 to 10 in any configuration, and
- the share is **below 4,5%** for Base Cases 1 to 5 in any configuration.

As a consequence impact on users may be referred to the energy costs. In a "Voluntary Agreement" Scenario and as well an "Ecodesign" Scenario users would benefit from reduced energy costs.

The timeline on which Eco-design measures are implemented (mandatory measures for every new sold steam boiler from 2016 onwards) takes into account the time necessary to adapt products and production lines; however additional tiers may be suggested with options in 2018, 2020.

Table 87 - Share of investment on fuel cost

	Fuel Cost				Investment				Share of investment on fuel costs			
Values in [k€]	w/o options	with ECO	with ECO + CC	with ECO + CC + APH	w/o options	with ECO	with ECO + CC	with ECO + CC + APH	w/o options	with ECO	with ECO + CC	with ECO + CC + APH
Base Case 1	3.417	3.214	3.154	3.121	59	74	104	125	1,7%	2,3%	3,3%	4,0%
Base Case 2	3.457	3.249	3.188	3.154	59	73	103	133	1,7%	2,2%	3,2%	4,2%
Base Case 3	9.568	8.999	8.832	8.739	97	120	150	212	1,0%	1,3%	1,7%	2,4%
Base Case 4	9.679	9.097	8.926	8.832	97	118	148	207	1,0%	1,3%	1,7%	2,3%
Base Case 5	27.336	25.711	25.233	24.968	136	184	214	342	0,5%	0,7%	0,8%	1,4%
Base Case 6	27.654	25.992	25.504	25.233	136	178	208	377	0,5%	0,7%	0,8%	1,5%
Base Case 7	47.838	44.994	44.158	43.695	156	231	261	385	0,3%	0,5%	0,6%	0,9%
Base Case 8	48.395	45.486	44.632	44.158	156	222	252	358	0,3%	0,5%	0,6%	0,8%
Base Case 9	48.964	45.988	45.116	44.632	156	236	266	467	0,3%	0,5%	0,6%	1,0%
Base Case 10	49.547	46.502	45.610	45.116	156	221	251	506	0,3%	0,5%	0,6%	1,1%

Assumed lifetime: 25 years, assumed operation hours p.a.:1250, assumed gas price for 25 years: 10,57 EUR/GJ

8.5 Subtask 7.4: Sensitivity analysis of the main parameters

Within our approach we apply static S-curves for the technology diffusion resulting in energy savings which are proportional to the assumed efficiency increase (or saving potential) per design option. As a consequence these are main parameters driving the energy consumption and thus the potential energy savings. We therefore vary the efficiency improvement within technical reasonable boundaries and analyse the effect on the potential energy savings. For the VSD the energy savings are dependent on the average load set for the Base Cases. The cases for the sensitivities are presented in Table 88.

Table 88 - Cases for sensitivity analysis

Sensitivity Case	ECO [-]	CC [-]	APL [%]	Comment
No. 1	5,50	1,75	75	Reference case
No. 2	3,00	1,75	75	Low ECO savings
No. 3	7,00	1,75	75	High ECO savings
No. 4	5,50	0,50	75	Low CC savings
No. 5	5,50	2,50	75	High CC savings
No. 6	5,50	1,75	50	High VSD savings
No. 7	5,50	1,75	90	Low VSD savings
No. 8	3,00	0,50	90	Lowest savings
No. 9	7,00	2,50	50	Highest savings

Efficiency increase [%pt.]

Furthermore the assumed sales per Base Case for 2013 is the second set of input parameters driving the energy consumption and thus potential energy savings as

- it is an input factor for modelling the stock in past, and
- an input factor for estimating sales and thus influencing future stock modelling too.

The sales are varied by increasing and decreasing the values for 2013 by 20%. The values (rounded figures) for each Base Case are listed in Table 89.

Table 89 - Sensitivity for Case No.10 and No.11

Base Case No.	Case No.10, -20%	Ass. sales 2013	Case No.11, +20%
BC 1	674	842	1010
BC 2	337	421	505
BC 3	64	80	96
BC 4	32	40	48
BC 5	254	317	380
BC 6	127	159	191
BC 7	75	94	113
BC 8	38	47	56
BC 9	426	533	640
BC 10	214	267	320

We sum up the energy savings for the cases from 2013 up to 2030 and compare them with the reference scenario (No.1). The results are listed in Table 90. It can be observed that:

- Within the pessimistic case No.8, (setting only low efficiency improvements) savings might be approx 51-52% lower for the scenarios (cf. Sensitivity Case No 8).
- Within the optimistic case No.9 (setting only high efficiency improvements) savings might be approx. 29% higher for the scenarios (cf. Sensitivity Case No 9).
- When the energy improvements for the economizer are overestimated (and all else stays equal) the savings might be approx. 25% lower (cf. Sensitivity Case No. 2), when they are underestimated and all else stays equal savings might be approx. 14% higher (cf. Sensitivity Case No.3).
- In case of overestimating the improvement potential of the combustion control savings might 21-22% lower for the scenarios (cf. Sensitivity Case No.4). In case of underestimating savings might be 12-13% higher for the scenarios (cf. Sensitivity Case No.5).
- In case of overestimating the average part load the resulting savings are approx 3-4% higher (cf. Sensitivity Case No.6). In case of underestimating the average part load the resulting savings are approx. 3-4% lower (cf. Sensitivity Case No.7).
- In case of overestimating the sales for 2013 by 20% the resulting savings are 20% lower (cf. Sensitivity Case No.10). In case of underestimating the sales for 2013 by 20% the resulting savings are 20% higher (cf. Sensitivity Case No.11).

We finally note that we do not vary any fuel prices as they have no effect on the savings estimated which is based in the methodology. They only would affect customer LCC (cf. Task 6). In Task 6 fuel prices has been set constant for the next 25 years resulting in the outcome that the in Task 7 evaluated design options are cost effective. Thus no fuel price dependency has been incorporated in Task 7, which is reasonable behind the background that fuel prices are predicted to increase in the future (HIS CERA[104]).

104 January 2014 IHS CERA European Power Macro, Wholesale Price, and Spreads Outlook to 2035.

Table 90 - Results from variation of technical parameters

Sensitivity Case	Energy Savings for the period from 2013-2030 [TWh]				Energy Savings for the year 2020 [TWh]				Energy Savings for the year 2030 [TWh]			
	VD	ED	R.VD	R.ED	VD	ED	R.VD	R.ED	VD	ED	R.VD	R.ED
No. 1	50,9	71,5	0%	0%	2,1	3,5	0%	0%	6,2	7,8	0%	0%
No. 2	38,2	53,8	-25%	-25%	1,5	2,6	-28%	-24%	4,8	5,8	-23%	-25%
No. 3	58,0	81,3	14%	14%	2,4	3,9	15%	14%	7,0	8,9	13%	14%
No. 4	40,2	55,5	-21%	-22%	1,7	2,6	-16%	-24%	4,7	6,1	-24%	-21%
No. 5	57,1	80,8	12%	13%	2,3	3,9	10%	14%	7,1	8,7	14%	12%
No. 6	52,7	73,6	4%	3%	2,2	3,6	5%	3%	6,4	8,0	3%	3%
No. 7	48,9	69,3	-4%	-3%	2,0	3,3	-5%	-3%	6,0	7,6	-3%	-3%
No. 8	24,8	34,5	-51%	-52%	1,0	1,6	-50%	-52%	3,0	3,8	-52%	-51%
No. 9	65,8	92,4	29%	29%	2,7	4,5	29%	30%	8,1	10,0	29%	28%
No. 10	40,6	57,2	-20%	-20%	1,7	2,8	-20%	-20%	5,0	6,2	-20%	-20%
No. 11	61,2	86,0	20%	20%	2,5	4,2	21%	21%	7,5	9,3	20%	20%

VD: Voluntary diff; R.VD: Relative change towards Case No. 1 in VD.
ED: Ecodesign diff; E.VD: Relative change towards Case No. 1 in ED.

8.6 Subtask 7.5: Conclusions and recommendations

This section provides a summary of the main outcomes of the previous analyses, looking at suitable policy options (defined in Task 5) in order to achieve the environmental improvements and in the light of the lifecycle cost of the technologies carried out in Tasks 6.

Studies for steam generation systems and databases on industrial efficiency indicate that there are large potentials to increase energy efficiency in steam generation systems which are not located within the generation system itself i.e. the system boundary set within this study. Nevertheless industrial guidelines present various measures to increase the efficiency of the steam boiler itself. Many of these measures seem to be well known by manufactures and plant engineering companies and had been identified and presented in this study (Task 6) with the outcome that the common measures are beneficial in terms of Life Cycle Cost.

Different scenarios have been drawn up to illustrate quantitatively the improvements that can be achieved at EU level by 2030 with suitable Ecodesign policy actions against the Business-as-Usual scenario. The main technical improvement options considered in the analysis include:

- **Economiser (ECO):** Preheats feedwater and cools down flue gases. Increases overall boiler efficiency reducing flue gas losses.
- **Combustion Control (CC):** digital control systems, temperature sensors, oxygen monitors, CO monitor, oxygen trim controls: reduces excess air of combustion.
- **Variable Speed Drives (VSD):** Electricity consumption can be reduced. Useful if the boiler load is below maximum.

The energy saving potential of Steam boilers was assessed for the following three scenarios:

- **Autonomous diffusion (Auto diff):** it assumes the increase of the percentage of new sales to be equipped with the design features Economiser (ECO), Combustion Control (CC) and Variable Speed Drives (VSD, evaluated separately) to follow fitted S-curves.
- **Ecodesign diffusion (Ecodesign diff**): it assumes the design features Economiser (ECO), Combustion Control (CC) and Variable Speed Drives (VSD, evaluated separately) to be mandatory for every new sold steam boiler from 2016 onwards.
- **Voluntary agreement diffusion (Voluntary diff):** it assumes the increase of the percentage of new sales to be equipped with the design features as above to be faster than in the Auto diff.

Based on the analysis and on the outcome of the stakeholders consultation carried out within the scope of this study, a list of recommendations to be taken into account for further policy developments are then provided in the following paragraph.

8.6.1 Ecodesign measures in form of mandatory design features for Steam Boilers

As fully described in the previous tasks, one of the main barriers is related to the "not-standardized" configuration of steam boilers since they are mainly produced in conjunction with the customer to meet very specific requirements. Moreover, according to the stakeholders consulted (see Task 2), it has been observed that there are only a limited number of steam boilers in the European market and only a few manufacturers.

The main consequence is reflected in a not homogeneous market which is the base for energy savings calculation and for the impact assessment to be delivered by European Commission.

Thus, in case of ecodesign measures to be applied to steam boilers market, the following may be recommended:

1) Building a solid internal database at European level.

Apart from market data – relevant to estimate the impacts - ecodesign measures require stakeholders to provide technical data on the environmental performance of steam boilers covered by the measure. The purpose of this provision is to facilitate enforcement activities by national market surveillance authorities and to enable European Commission to properly assess the level of ambition and impact of the proposed self-regulation measures.

The market and technical data collection exercise can be coordinated and financed by EC, with the cooperation of the main Associations, such as:

- European Heating Association;
- Conformity Assessment Bodies Forum Pressure CABF PED/SPV;
- European Standards Organisations:
- National Associations of Boilers;
- National Energy Agencies.

Such new database would allow European Commission, in case Ecodesign process will go ahead with an Impact Assessment and monitoring implementing measures, to gather market information on specific size of steam boilers installed in Europe and in third countries.

The new database, available to European Commission and Associations, can be built in full compliance with confidential and competition rules in place in the different member States.

2) Working closely with current standardization planning processes.

The steam boilers producers present standardized size classes and configuration possibilities to design an industrial steam boiler according to customer needs (cf. Task 1).

3) Considering a bottom- up approach

to take into account and structure the key elements for a successful eco-product improving the performance of steam boiler. As arose from the analysis carried out before, the use of "product case studies" allowed a better focused assessment of technical, economic and using needs. Such case studies would include information on technology, power and steam output, product costs, installation costs, O&M costs, main consumables, industry served. The bottom-up approach would thus rely on a database of realistic product-types built on Stakeholders' feedback.

8.6.2 Voluntary agreement

During the stakeholder consultation the response rate from industry was rather low and only a minor share of the industrial actors played an active role in the discussions. No official position on the industry's position on a voluntary agreement is known. Due to the low number of affected producers in the EU, a self regulatory regime might be a reasonable alternative to an EU regulation.

Applying a voluntary program - coordinated by an industry association through minimum thresholds – would allow steam boilers producers to keep the technological diversity and produce according to client's technical requirements.

According to the "Guidelines on the self-regulation measures concluded by industry under the Ecodesign Directive 2009/125/EC"[105], self-regulation measures concluded under the Directive play an important role in the ecodesign area.

Self-regulation initiatives, as an alternative to an implementing measure, have to:

- respond to the policy objective of the Directive and to be consistent with the economic and social dimension of sustainable development;
- comply basically with all provisions of the internal market and competition rules;
- be agreed by the majority industry, and associations, of the relevant economic sector.

For the appropriate use (and success) of self-regulation some specific recommendations are provided below:

1) **Openness of participation**. Self-regulatory initiatives should be open to the participation of third country operators, not only in the preparatory phase but also in the implementation phases. At any time, other companies active on the steam boilers market must be able to join the self-regulation initiative and to participate in its operational costs.
2) **Representativeness** of industry players and **compliance with competition rules**. As foreseen by Ecodesign methodology, the key stakeholders (Industry and Association) have been involved. The voluntary agreement should, thus, at least 70% of the total sales of the steam boilers placed on the market should be covered by the self-regulation initiative.
3) **Compliance to competition rules and protection of confidential data. C**are must be taken to ensure respect for competition rules confidentiality and market relevance.
4) **Set up quantified and clear objectives and staged targets (**benefit associated to earlier stages**.** We recommend adopting well defined objectives starting from a clear baseline. The objectives should be in line with the objectives of the Directive to contribute to sustainable development by increasing energy efficiency and the level of protection of the environment, while at the same time increasing the security of the energy supply.
5) **Monitoring of results,** as well as the publication of the agreement and of the results obtained Moreover, it is relevant to ensure a monitoring exercise aiming at evaluate and measure the achievements made through clear and reliable indicators. In particular, a clear share of responsibilities and a monitoring plan should be identified. While self-regulation does not involve the adoption of a legislative instrument, the Commission can nevertheless consider to introducing an evaluation system. Setting up the objectives for self-regulation measures, no administrative burdens should be guaranteed.

Under specific circumstances, in particular considering the nature of the appropriate target market, **self-regulation** can be more effective than legislation in reaching the proposed goals (by means it can deliver the objectives set at a political level faster and in a more cost-effective way than legislative means). Self-regulation initiatives aim to achieve a comparable overall improvement by combining the requirement to achieve strict objectives at well-defined intervals (such as the elimination of a low performing product category); moreover, this initiatives allow for flexible and adjusted adaptation to technological options and market sensitivities, in the view to achieve the general goal of increasing the market share of the better performing products to a set target level over the life-time of the commitment.

105http://www.eceee.org/ecodesign/Horizontal-matters/7__Guidelines_on_Ecodesign_VA_-_220113_sent.pdf

Self-regulation may be a feasible option, in particular in sectors where the market is not fragmented, which is the case under consideration. Recital 18 of the Ecodesign Directive 2009/125/EC encourages the Commission to give priority to the self-regulation measure over the mandatory measure, if the former is likely to deliver the policy objectives faster or in a less costly manner then the latter. As explained in Recital 19 of the Directive, self-regulation measures can enable quick progress due to rapid and cost-effective implementation, and can allow for flexible and appropriate adaptations to technological options and market sensitivities.

8.6.3 Actions to support eco design measures and the exploitation of energy efficiency full potential

More important results may be achieved by putting in place actions to support ecodesign measures aimed at market transformation driving consumers (end-users of steam-systems) choice towards **more efficient products** or **early replacement**. Such actions co-ordinated at EU level could contribute to the raise of a higher level of energy savings.

Despite Ecodesign process focuses on newly sold products, it has been underlined that the mayor savings can be achieved by improving the current stock and not the newly sold products. Actions should be aimed at accelerating the process of replacement of inefficient (or less energy efficiency levels) products.