Steam Boilers and the European Ecodesign process

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ABSTRACT

Ecodesign is an important instrument of European energy policy making, which drives technological development and leads to significant energy savings by improving the environmental performance of energy-related products. Minimum energy performance standards and voluntary agreements which have been introduced under the Ecodesign Directive and so far concern more than 50 different product groups. One of the product groups currently investigated for possible regulation includes industrial steam boilers. According to estimates, industrial steam generation systems account for about one third of the overall industrial energy demand. Consequently, increasing energy efficiency in steam generation is relevant for suppliers, users and policy makers.

In this paper, we will first give a short overview of the whole Ecodesign process. The first step of the Ecodesign process is the Preparatory Study and we consequently present basic elements of such study. Finally, we present findings from the Preparatory Study on industrial steam boilers and discuss them.

We find that design improving options for industrial steam boiler are state of the art and established in market. Nevertheless, policy measures under the Ecodesign framework might increase the speed of their diffusion on the market. The resulting overall energy savings for the period from 2016 to 2030 would be 71 TWh.

Thus the results of this paper provide policy makers with an understanding of potential energy savings in Europe that would result from equipping new steam boilers with economic energy efficiency options within the Ecodesign framework. Furthermore basic steps of an Ecodesign process are described illustrative.

Introduction

In addition to the Energy Labelling Directive (EUROPEAN PARLIAMENT 2010) the Ecodesign Directive (EUROPEAN PARLIAMENT 2009) is one of the major policy instruments fostering energy efficiency within the European Union (Ploetz et al. 2014). It establishes a framework for the setting of Ecodesign requirements for energy-related products with the aim of ensuring possible regulation of such products within the internal market. In order to investigate draft implementing measures for these products the European Commission carries out a series of analyses and assessments, which are called Preparatory Studies. One of the product groups recently investigated for possible regulation includes industrial steam boilers with a thermal capacity lower than 50 MW. The study was carried out under the supervision of DG Enterprise by PWC, NTUA and Fraunhofer ISI. This paper presents findings from the Preparatory Study on industrial steam boilers as part of the Ecodesign process with the aim to quantify the possible impact of the directive on the energy savings in Europe for up to 2030.

The paper is structured as follows: First, the Ecodesign Process is presented. Second, results from the steam boiler preparatory study are presented. Based on the Methodology for Ecodesign of Energy-related Products (MEErP) base cases for steam boilers are defined. Various efficiency options for these base cases relevant within the context of the MEErP are identified. An approach to quantify energy savings by prescribing the identified efficiency options within the framework of the Ecodesign directive is subsequently introduced. Finally the results are discussed.

The Ecodesign Process

General Process

The Ecodesign process is highly regulated and follows clearly defined procedures. The basic principles of the Ecodesign process are laid down in the Ecodesign Directive (2009/125/EC), which sets the framework for Ecodesign activities. The recast of the directive substituted the former Ecodesign directive (2005/32/EC). The main objectives of the directive are to ensure the free movement of energy-using products within the EU, to improve the overall environmental performance of these products and thereby protect the environment, to contribute to the security of energy supply and enhance the competitiveness of the EU economy, and to preserve the interests of industry, consumers, and other stakeholders. While the application of the Ecodesign directive has mainly focused on energy use until now, the scope of Ecodesign is beyond energy efficiency only. The assessments and the resulting regulation should consider all phases of the life cycle (manufacturing, transport, use, disposal) and thereby should not only take into account energy-related issues, but should consider the essential environmental aspects (consumption, material, emission, waste etc.) for each phase. Nevertheless, due to the characteristics of most of the products, energy efficiency or energy consumption levels in the use phase have been the major focus.

To determine potential products for regulation, the European Commission develops a working plan in which the market for energy-using and energy-related products is analyzed and potential candidates for regulation are identified (EC 2012). Based on this working plan, the Commission selects the specific products for which the Ecodesign process is initiated.

The first step in considering whether and which Ecodesign requirements should be set for a particular product, is a Preparatory Study. Based on the Preparatory Study a working document is prepared by the European Commission to prepare the Consultation Forum. In this Forum, the stakeholders are able to express their views on the working document and the possible implementing measures presented in it. In the Consultation Forum there are seats for member state experts, industry groups and NGOs. Simultaneously an impact assessment of the proposed rules is prepared. The final version of the proposed legislation is sent to the Regulatory Committee on the Ecodesign of Energy-related Products (EEP) that consists of 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 European Parliament and the Council. After voting, the European Parliament and the Council have three months to apply scrutiny, in which they can review the final proposal and potentially still block its introduction. After further three months the World Trade Organization (WTO) is notified and the implementing measure is accepted after publication in the Official Journal of the European Union. An overview of the whole Ecodesign process is given in Figure 1.

Since the introduction of the Ecodesign directive, about 50 energy-related product groups covering lighting, electronics, white goods, motors and motor-powered aggregates, ventilation and air conditioning, heat production and other products have been subject to an analysis with regard to their environmental impact or are currently undergoing a survey (cf. Ploetz et al. 2013).

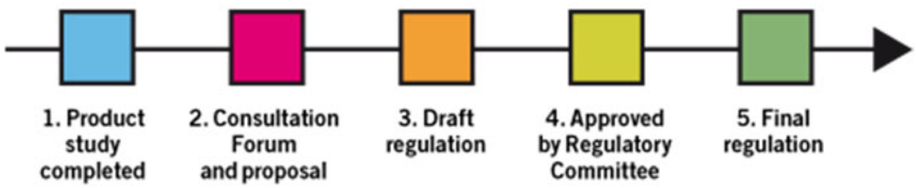

Figure 1 Ecodesign process steps (http://www.eceee.org/ecodesign/products)

Preparatory Study

The Preparatory Study is the first step in the Ecodesign Process and it results in recommendations for a potential improvement of the environmental performance of the product. The study provides the necessary information for the next phases in the policy process (to be carried out by the Commission).The overall task structure of an Ecodesign Preparatory Study is shown in Figure 2. It comprises a technical, ecological and economic life cycle analysis (LCA) of a product. The methodology of the preparatory study is described in the Methodology for Ecodesign of Energy-related Products (MEErP). The MEErP Methodology consists of 7 Tasks. Whereas Tasks 1 to 4 have a clear focus on data retrieval and initial product technical and market analysis, Tasks 5 to 7 have a clear focus on modelling. It is prescribed that Task 1 to 4 can be performed in parallel and Task 5 to 7 sequentially. The basic purpose of Task 1 is to define the product in the context of the Preparatory Study. Task 2 provides insight into the market status of the energy related product by gathering information on its production and trade data. Thus, within Task 2 the market volume and European stock of the product in scope is derived. Task 3 assesses the user behaviour. Within Task 4 the technical characteristics of the product in scope are introduced and efficiency improvement options or strategies are discussed. Based on the previous tasks so-called base cases are defined in Task 5 which represent a more or less "typical" product in the European stock and serve for further analysis. For these base cases different efficiency improvement options are assessed in Task 6. Finally, the effect of increasing the share of the assessed efficiency options in the market by means of the Ecodesign directive will be examined in Task 7 by drawing on specific policy scenarios.

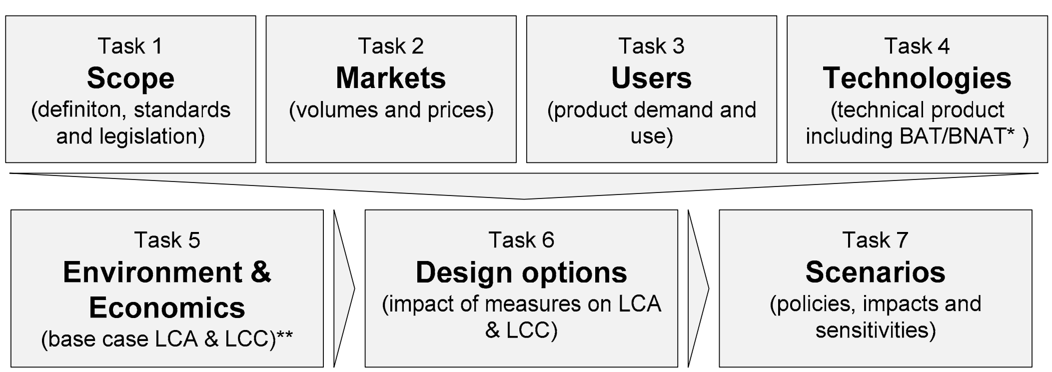

Figure 2 Overview of tasks of a Ecodesign preparatory study (based on Kemna et al. 2011).

The Preparatory Study for Steam Boilers

An industrial steam boiler generates steam by burning fossil fuel and is usually embedded in a steam system within a facility. A steam system is basically categorized in a generation, distribution, end use and recovery system in practice (U.S. Department of Energy 2012). The industrial steam boiler is part of the generation system. The system boundary between the generation and distribution or recovery system might vary depending on the viewpoint. Nevertheless, engineering standards for industrial steam boilers indicate the system boundary applied in practice. Thus we define our system boundary based on the standards EN 12952 for water tube boilers and on EN 12953 for shell boilers[1]. The main components within the system boundary selected are illustrated in Figure 3. As can be seen, the components of the industrial steam boiler that are included in the scope of the Preparatory Study are the combustion system (air blower, burner) and the basic heat transfer equipment (evaporator, and optional economizer and/or air pre-heater).

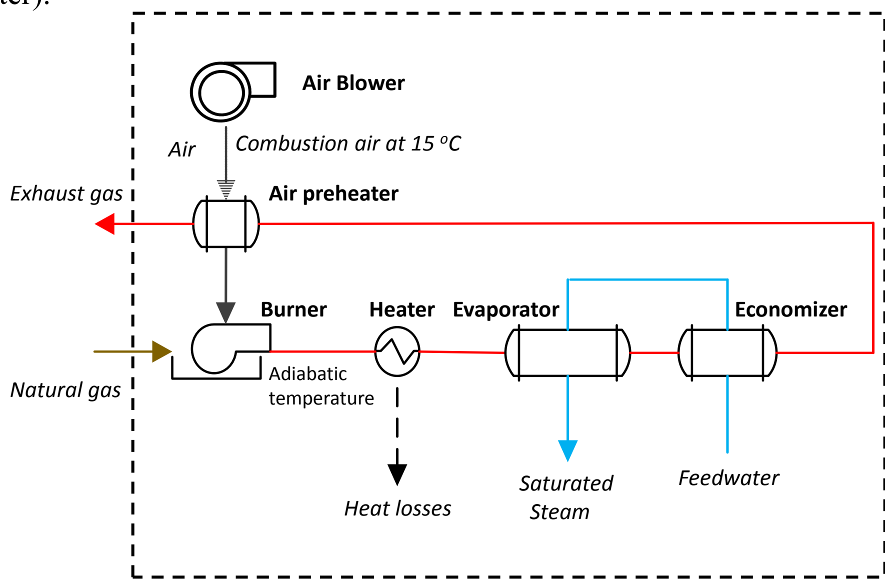

Figure 3 Main components within the system boundary

Definition of base cases

The MEErP prescribes to define a set of so-called base cases. The basic idea is to quantify the environmental impact and especially the energy consumption of the product group in scope based on these base cases. As stated previously, these base cases are representative of typical products being used in the market of the European Union. The number of base cases should in general not be higher than ten. Consequently, the first step of the base case definition is to set a system boundary in order to sufficiently limit the scope of the product.

[1] 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. Fire-tube boilers are covered by the standard for shell boilers.

The second step is to define the technical and operational key characteristics for the base cases. Together with the key characteristics the base cases should depict "average products" used in Europe as accurately as possible. Within this context it has to be stressed that the industries and thus the processes where steam boilers are applied differ from one another. For example, the processes range from applications where only heat is transferred to applications where heat- and mass is transferred such as in thermal separation processes. This heterogeneity makes the definition and setting of "typical" key characteristics difficult. Furthermore there is no comprehensive data or study available on the population of industrial steam boilers in the European Market. Given these boundary conditions the approach followed was to contact stakeholders representing steam boiler manufacturers. Thus we also discussed the purpose of the study during stakeholder meetings with the Association of the European Heating Industry (EHI), the representative European body of steam boiler manufacturers in Europe. The outcome of this discussion was the definition of key technical characteristics for each one of the base cases, such as the thermal capacity, operating pressure and thermal efficiency. The key characteristics for the base cases are summarized in Table 1.

Table 1 Definition of base cases

Base case No.	Design	$\dot{Q}_{Steam.BC}$ [MWth]	η_{th} [%]*	Operational pressure [bar]	Steam production [t/h]
1	FT	2,5	87	15	3,2
2	FT	2,5	86	25	3,2
3	FT	7	87	15	9,0
4	FT	7	86	25	9,0
5	FT	20	87	15	25,8
6	FT	20	86	25	25,7
7	FT	35	87	15	45,1
8	FT	35	86	25	44,9
9	WT	35	85	15	45,1
10	WT	35	84	25	44,9
*: Without any efficiency improving design options; FT: Fire-tube; WT: Water-tube					

Energy efficiency options for industrial steam boilers

Identification of energy efficiency options for industrial steam boilers

Planning manuals, industry guidelines and scientific literature list various efficiency options for steam systems (U.S. Department of Energy 2012;United States Environment Protection Agency 2010;Therkelsen and McKane 2013;Einstein et al. 2001;Schult and Meyer 2013;Carbon Trust 2012). Within the context of the MEErP relevant options have to be filtered and selected. This is based on the fact that only certain measures can be fostered by any means of the Ecodesign directive as the directive clearly focuses on the product definition set in the Preparatory Study. Thus several measures which can hardly be modelled within these system boundaries had to be excluded from the study. An example is the blowdown heat recovery from blowdown water (Carbon Trust 2012). Additional measures that were excluded where those for which the effect of the efficiency improvement largely depends on the boundary conditions of the user application, as the Ecodesign directive sets requirements for manufacturer of steam boilers and not the end-users or customers. Such an example includes the automatic blowdown systems. These systems usually reduce the frequency of the blowdown heat recovery operation and thus the amount of the blowdown water, resulting in lower heat losses and thus lower annual fuel consumption (Carbon Trust 2012). Nevertheless the blowdown ratio necessary is determined by the feed water quality, which is within the scope of the customer. Thus the potential energy savings through this measure are strongly dependent on the operating conditions chosen by the customer leading to its exclusion from the Ecodesign directive. Finally efficiency measures having negative environmental side-effects were not examined in the study. This is because within the Ecodesign directive such measures and/or conflict of interests between different legislations should be prevented. This is for example the case by applying an air pre-heater in order to pre heat the combustion air by cooling the exhaust gas. Although the increase of the combustion air temperature is beneficial for the energy efficiency of the steam boiler, it can be detrimental in terms of pollutants (and especially NOx) emissions. This is because the thermal NOx formation is strongly dependent on the temperature of the combustion air (Schult and Meyer 2013). In fact, industrial stakeholders participating at the stakeholder meetings in Brussels indicated that the application of an air pre-heater might lead to a trespassing of national NOx emission limits. We consequently excluded the air-pre-heater from further analysis. So finally, only efficiency options were chosen for the Preparatory Study which lie within the system boundaries set by the product definition and do not cause any direct negative environmental side-effects. The options chosen for further analysis are the following:

- Economiser (ECO): An economiser preheats the feed water by cooling down flue gases via a heat exchanger. Thus it increases the overall thermal boiler efficiency by reducing heat losses and subsequently the fuel consumption. For the analysis we assume that by equipping each base case with an ECO the thermal efficiency increases by 5.5 percentage points.
- Combustion Control (CC): This measure refers to the implementation of an automatic control system for determining the flowrate of the combustion air. In the case of complete, i.e. perfect combustion gas or oil would burn stoichiometrically so that no oxygen would be existent after combustion. This is in practical applications not the case as some of the oxygen is left over in the flue gas. One reason is that since the condition of air isn't always the same, burners without O2 correction have to be set to cover most unfavourable weather conditions – ensuring that every molecule of fuel is completely burned off. An automatic control system uses the measured O2 and CO content in the exhaust gas as input. The aim is to adjusts the volume of the combustion air in the way that excess air in the flue gas is being minimized (O2 correction, addressing real life burner configurations). It furthermore guarantees that CO-thresholds are not trespassed (CO-measuring). Thus it minimizes heat losses through excess air in the flue gas and increases the thermal efficiency of the steam boiler (Schult and Meyer 2013). For the

analysis we assume that by equipping each base case with CC the thermal efficiency increases by 1.75 percentage points.

- Variable Speed Drives (VSD): Operating a steam boiler at part load requires less combustion air and thus a lower speed of the fan compared to full load operation. When the electric drive is not equipped with a frequency converter the volume of sucked-in air is regulated by air dampers. When the drive for the air blower is equipped with a frequency converter the speed of the drive can be adjusted to the needs of the load of the steam boiler. Thus, a frequency converter saves electrical energy compared to regulating with air dampers (Schult and Meyer 2013). For the analysis we assume an average load of 75% and calculate the appropriate electrical energy savings for each base case.

Long-term impact and scenarios

Modelling of stock and technology diffusion

According to Hirzel et al., "Stock models can serve as means to describe and analyse the structure of energy demand. They are mathematical descriptions of how objects or sales build a stock of objects or products over time. As a general rule of stock modelling, the size of a stock of objects within a system is characterised by four parameters: the number of objects entering and leaving the system and the number of generated and destroyed objects within the system"(Hirzel et al. 2012). We utilize an approach presented in Hirzel et al. (2012) to develop a stock model for steam boiler based on historical sales data. As only estimations on historical sales data exist for the last few years, we employ a back casting approach to estimate data for further years. This approach is based on the historical development of the gross domestic product in Europe. The approach and the results are described in Aydemir et al. (2015).

In order to evaluate how much energy can be saved by means of the Ecodesign directive it has to be estimated how the chosen energy efficiency options could be adopted by customers in the future (i.e. future sales) omitting any fostering by means of the Ecodesign directive (i.e. policy mechanisms). Thus, a model to anticipate the diffusion of the design options is necessary. Within the literature on new technology diffusion there are several models which describe the adoption of new technologies among users. The so-called epidemic and probit models are the most common (Geroski 2000). The probit model follows "the premise that different firms, with different goals and abilities, are likely to want to adopt the new technology at different times". The epidemic model "builds on the premise that what limits the speed of usage is the lack of information available about the new technology, how to use it and what it does" (both quotes from Geroski 2000). No data on the different goals and abilities of firms which buy industrial steam boilers has been available for our study. As a consequence we model the diffusion of the design options based on ideas from epidemic models. Within epidemic models two main approaches of describing the diffusion of new technology are present. One common approach leads to the central source model, where the knowledge about the existence of a new technology among potential users drives the adoption of the technology. The other common approach is based on so-called word of mouth communication. In this model the underlying idea is that when new hardware is adopted so-called software[2] knowledge is built by using the technology. This

[2] Within the context described above software knowledge is knowledge about a new product which is being mainly built up by using the product. For industrial goods this can for example be operational experience.

approach 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)" (Geroski 2000). This function is a logistic function which has a characteristic S-shape. Our premise is that the technology diffusion for the chosen design options follows the word of mouth approach. We consequently assume that the percentage of sales that is equipped with the appropriate design options can be described by a logistic function with a characteristic S-shape.

The EHI provided estimations on the share of sales which are equipped with ECO and CC for the years 1993 and 2013. We furthermore made own estimations on the share of sales equipped with VSDs. With these values we derive characteristic S-curves for the design options representing the share of sales equipped with the options over time. These curves represent the autonomous (business as usual, i.e. Auto Diff) market diffusion scenario (cf.Figure 4).

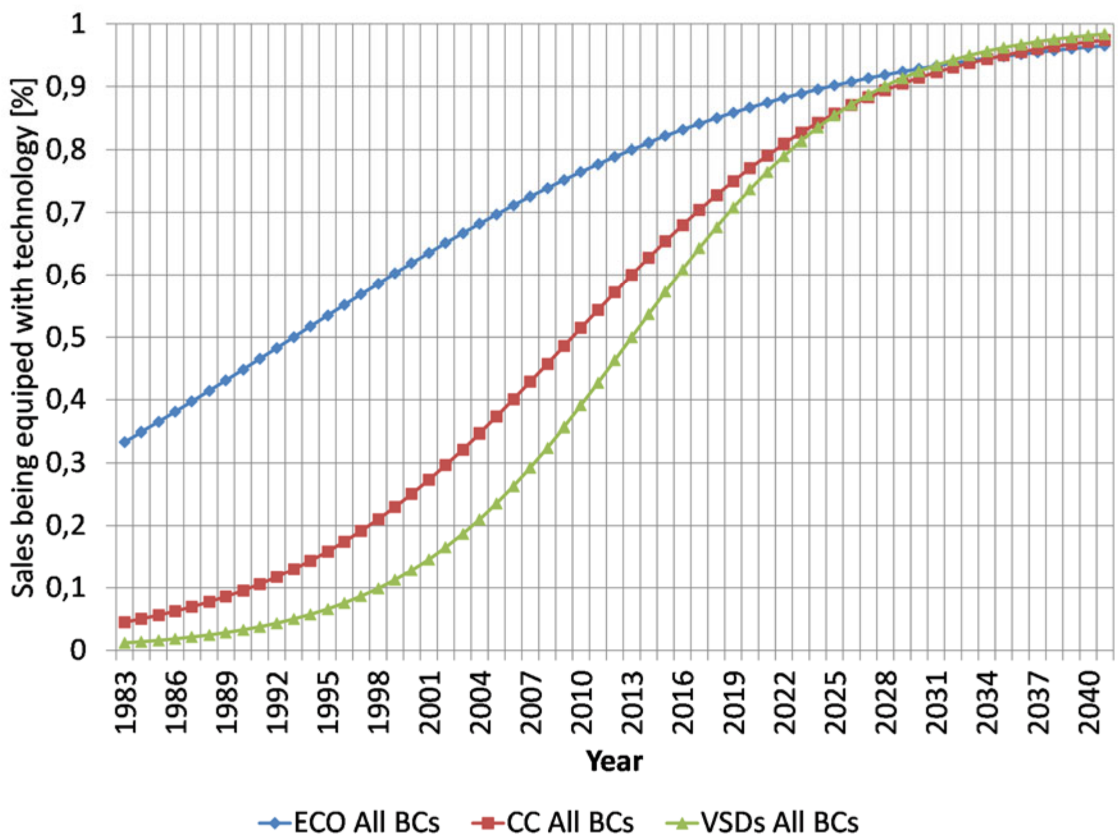

Figure 4 Assumed S-curves for chosen design options

Scenario analysis

The goal of the scenario analysis is to estimate which energy savings can be achieved by means of the intervention through the Ecodesign directive up to 2030 compared to an autonomous development of the steam boiler market. There are basically two mechanisms in the Ecodesign directive which intend to foster the diffusion of energy-efficient technology among energy-related products. Within the framework certain implementing measures can be prescribed. An exemplary measure is to set so-called Minimum Energy Performance Standards

(MEPS) for products in scope. For an industrial steam boiler such measure could result in minimum energy efficiency standards for products sold. Furthermore, the directive provides the possibility for voluntary agreements or other self-regulation measures. Within this framework industry associations or comparable bodies might proceed to self-regulatory actions with the goal of increasing the energy efficiency of new manufactured products. However, these initiatives have to fulfil certain criteria presented in Annex VIII of the Ecodesign directive. Criterion 3 on representativeness requires that the "Industry and their associations taking part in a self-regulatory action must represent a large majority of the relevant economic sector, with as few exceptions as possible" (EUROPEAN PARLIAMENT 2009, Article 15). As only a few manufacturers responded to the surveys carried out within the Preparatory Study and only two manufacturers participated at the open held stakeholders meetings in Brussels a self regulatory initiative might be unrealistic. Thus self-regulatory initiatives for further analysis in the context of this paper are omitted.

As already mentioned, one possibility for an implementing measure might be to apply an MEPS for industrial steam boilers. However, this would have to at least need to address the pressure level and type of applied fuel in a proper way. This is based on the fact that these factors determine the maximum efficiency possible for industrial steam boilers by using state of the art technology. Bearing in mind that customers operate industrial steam boilers differently at various part loads during a year, the part load behaviour should also be subject of an MEPS for industrial steam boilers. Due to the lack of data (operation hours) and the heterogeneity of the design configurations (i.e. the application of different fuels and pressure levels) the setting of an MEPS requires an in-depth technical analysis of the many different cases to set adequate thresholds for each one. As a result, another approach within the possibilities of the Ecodesign directive is followed. An implementing measure prescribing mandatory design features for industrial steam boilers is assumed. From the presented design options we consider equipping industrial steam boilers with an Economiser (ECO), Combustion Control (CC) and Variable speed drives (VSD) to be mandatory. This is based on the fact that from the techno-economic analysis for the chosen design options we conclude the options to be cost effective in terms of customers' Life-Cycle-Cost[3], not to be technically restricted in any case and not causing any negative environmental side effects. As a consequence we model two scenarios where we forecast the energy consumption of industrial steam boilers based on the assumptions listed in the following:

- **Autonomous diffusion (Auto Diff):** it assumes the increase of the percentage of new sales equipped with the design features ECO, CC and VSD to follow fitted S-curves (as in Figure 4).
- **Ecodesign diffusion (Ecodesign Diff):** it assumes the design features ECO, CC and VSD to be mandatory for every new steam boiler sold from 2016 onwards.

We then derive the energy consumption per scenario, per year by first forecasting the market share of the design options per technology, per year for each scenario. For the Auto Diff scenario the market share follows the fitted S-curves as presented in the foregoing section. For the Ecodesign Diff the market share is simply 100% for the chosen design options from 2016

[3] This analysis has been made in the Preparatory Study. Please refer to the report on Task 6 published at www.eco-steamboilers.org for further information.

onwards representing the mandatory implementing measure. The scheme to calculate the energy savings based on the scenarios above for each year is described in Aydemir et al.(2015).

The results are as follows. The energy consumption (including fossil fuel at the burner and converted primary energy for the blower) rises from 908 TWh in 2013 up to 1146 TWh in 2030 for the Auto Diff, and up to 1138 TWh in 2030 for the Ecodesign Diff (-0,7%).

The sensitivity of the approach towards changes of assumed sales in 2013 and assumed energy savings per design option is tested. Thus the energy savings per design option are varied within technical meaningful thresholds (Case No. 1-9). A sensitivity analysis is also carried out in respect to the sales corresponding to the year 2013 since they constitute a major input for the building of the stock in 2013 (Case No. 10-11). Finally another variable examined is the GDP increase assumed for the future (Case No. 12-13). The variations and the resulting energy savings for the period from 2013 up to 2030 are listed in Table 2 for the differing cases.

Table 2 Sensitivity variation

Case	ECO [-]	CC [-]	APL [%]	Cumulated energy savings [TWh]*	Relative Change towards No.1	Comment
No. 1	5,50	1,75	75	71,5	0%	Reference case
No. 2	3,00	1,75	75	53,8	-25%	Low ECO savings
No. 3	7,00	1,75	75	81,3	14%	High ECO savings
No. 4	5,50	0,50	75	55,5	-22%	LOW CC savings
No. 5	5,50	2,50	75	80,8	13%	High CC savings
No. 6	5,50	1,75	90	73,6	3%	Low VSD savings
No. 7	5,50	1,75	50	69,3	-3%	High VSD savings
No. 8	3,00	0,50	90	34,5	-52%	Lowest savings
No. 9	7,00	2,50	50	92,4	29%	Highest savings
No. 10	5,50	1,75	75	57,8	-19%	Sales 2013: -20%
No. 11	5,50	1,75	75	86,3	21%	Sales 2013: +20%
No.12	5,50	1,75	75	68,8	-4%	GDP growth = 1,0%
No.13	5,50	1,75	75	74,1	4%	GDP growth = 2.0%
* : for the period from 2016 to 2030.						

Discussion of results

Under the given assumptions an application of the Ecodesign directive as proposed would reduce the energy demand caused by industrial steam boilers in future. Thus, an up to 0.7% lower energy demand can be achieved compared to the Auto Diff in 2030 (within the set system boundaries). The overall energy savings for the period from 2016 up to 2030 amount to 72 TWh for the reference case. Varying the energy savings per design option within technical meaningful ranges the resulting overall savings decrease by 50% or increase by 30% (cases 1 to 9). Increasing and decreasing the sales in 2013 by 20% the energy savings are also increased or decreased by 20%. This means that total energy savings are crucially influenced by assumptions on energy savings per option and stock building. Varying the assumed GDP growth for the future differences in energy savings are not so high compared to those previously. An increase and decrease of the GDP growth in future by one third of the original value only increases or decreases the overall savings by 4%.

Conclusions and outlook

The goal of this paper was to introduce the Ecodesign process and major steps of the so called Preparatory Study which is the first step in the process. This was done by presenting major steps from the Preparatory Study on industrial steam boiler serving as illustrative case. Within that study the possible impact of the Ecodesign directive on the energy savings for industrial steam boilers in Europe for up to 2030 was quantified.

Due to lack of data on the European stock of industrial steam boilers, the number of machines was quantified by employing a back casting approach. Furthermore, an autonomous market diffusion of efficiency options in the future for the steam boiler stock in Europe was assumed by fitting S-curves based on historical best guess market share values from industrial stakeholders. Finally, the potential energy savings for the assumed Ecodesign implementing measures were quantified. It was found that the energy savings that can be achieved by means of the Ecodesign directive are small compared to the overall consumption (based in the slow exchange within the stock). As already mentioned above, several efficiency options were omitted within this paper and the Preparatory Study as the Ecodesign framework clearly focuses on products and not systems. Although the question how to separate products from systems is not trivial in the case of industrial steam boilers, a categorization in generation, distribution, end-use and recovery system is prevalent in science and practice (U.S. Department of Energy 2012). As several studies indicate, large untapped energy savings also lie within the distribution and recovery system (Therkelsen and McKane 2013, Einstein et al. 2001). Thus a study on energy saving potentials of European steam systems is worth considering.

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