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ALLOCATION OF GHG EMISSIONS IN A PAPER MILL, AN APPLICATION TOOL TO REDUCE EMISSIONS

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AN APPLICATION TOOL TO REDUCE EMISSIONS

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AN APPLICATION TOOL TO REDUCE EMISSIONS

A dissertation presented to the department of Enginyeria Química, Agrària i Tecnologia Agroalimentària - Universitat de Girona in partial fulfilment of the requirements for the degree of Doctor

by

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ABSTRACT

Paper industry sector is responsible for a considerable amount of GHG emissions, mainly derived from its intensive energy profile. Therefore, emissions related to heat and power demand through papermaking operations should be determined and analysed in detail, in order to set the appropriate targets and invest in successful emission reducing measures. A GHG emissions management system could assist with the achievement of the mentioned tasks, although such system is focusing on determining and quantifying emissions rather than allocating them through out the paper process; this allocation should bring in the most effective targeting.

This work aims to provide to paper mills a methodology to allocate emissions along their manufacturing process. For that purpose a method of gradual emission distribution –from production lines to particular unit levels– is performed. To achieve this end-result some other concepts are taken into consideration. Energy-related emission factors are evaluated, emphasising the configurations equipped with combined heat and power systems and stand-alone facilities. In this context, published allocation methodologies concerning CHP systems are analysed. Moreover, a method to calculate grid power emission factors of a grid power system is formulated an applied to Spanish electricity system.

The proposed allocation tool and the emission factor methodologies are put into practice within two paper mills (printing and writing paper manufacturers with different energy-generation configurations). Results are handled as indicators and validated within a benchmarking analysis procedure. The allocation method application underlines the first critical points, such as drying sections or the vacuum system. Thereby, general measures concerning a consolidation of zero-emissions scenario are discussed and exemplified in the two mills scope as well as in general terms. The selected measures comprise the reduction of emissions in origin and reduction of emissions in process, highlighting both management and energy efficiency potentials.

KEY WORDS

GHG Emissions, emissions management, emission factor, energy efficiency, paper industry

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GENERAL INDEX

ABBREVIATION

AAU: Assigned Amount Unit

AM: Allocation Method

BAT: Best Available Technology

CDM: Clean Development Mechanism

CEPI: Confederation of European Paper Industry

CER: Credit Emission Reduction

CL: Coated Line

CHP: Combined Heat and Power

DIP: Deinked Pulp

DCS: Distributed Control System

EEMS: Emissions and energy management system

EMS: Energy management system

ERU: Emission Reduction Unit

ET: Emissions Trading

EU: European Union

EU: TDS European Union Trading System

GHG: Green House Gas

GWP: Global Warming Potential

HHV: High Heat Value

HP: High Pressure

HUP: Hydrothermal Upgrading Process

HVAC: Heating, Ventilating and Air Cooling

HW: Hardwood Pulp

IEA: International Energy Agency

IPCC: International Panel on Climate Change

IPPC: Integrated Prevention Pollution Control

IR: Infrared Radiation

JI: Joint Implementation

LF: Long Fibre

LHV: Low Heat Value

LP: Low Pressure

LPG: Liquefied Petroleum Gas

LWC: Light Weight Coated

MIT: Massachusetts Institute Technology

MW: Molecular weight

NAP: National Allocation Plan

NG: Natural Gas

PM: Paper Machine

REE: Red Eléctrica Española

RFO: Residual Fuel Oil

RP: Recycled Pulp

SF: Short fibre

SHP: Single Heat and Power

SME: Small and Medium Enterprises

SW: Soft wood Pulp

TMP: Termomechanical Pulp

UL: Uncoated Line

UNFCC: United Nations Framework on Climate Change

VSD: Variable Speed Drive

WRI: World Resources Institute

WBSCD: World Business Council for Sustainable Development

NOMENCLATURE OF FORMULAS

B, methane captured and burned on site-specific basis

C, flow coefficient found from experiments

D, distance travelled

E, total emissions assigned to a general activity

f, frequency of the Karman vortex train

F, emission factor assigned to a general activity

H, heat output contained in particular stream

H, specific enthalpy of steam

h_{ope}, working hours

k, specific constant related to the flow meter

LHV, low heat calorific value of natural gas

n, number of steam stream outputs extracted from the plant

OC, Biological oxygen demand or Chemical oxygen demand, as input feed of the anaerobic system

OF, oxidation factor assigned to a particular emission factor

P, power consumption of a particular activity

Q, steam flow

S, specific entropy of a particular steam flow

T, temperature

u, relative uncertainty of particular activity

U, overall uncertainty of the reference activity

V, natural gas volume flow

$\frac{\partial f}{\partial y}$, sensitivity coefficient

$\dot{m}$, steam mass flow

Ψ, exergy of the specific stream

η, overall efficiency of producing heat or power in a specific facility

ρ, steam density

1 INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

Climate change has become an issue of great concern at all social levels. Although scientists have investigated and predicted its consequences for many years, it has been in lately decade when countries have taken it seriously, especially after the consequences that are already patent in our daily life.

Intergovernmental Panel on Climate Change (IPCC) is an organisation composed of experts on different subjects that are in charge of determining causes and consequences of the climate change. IPCC team is formed by 450 scientific authors, 800 adjacent authors, and 2.500 scientific revisers from 130 different states. IPCC published its first report in 1990, and later reports were published in 1995, 2001 and 2007 [1]. Summarising the problem at maximum levels, climate change is caused by the Green House effect of some atmospheric gases. The concentration of these gases in the atmosphere is increasing excessively. Human activities are directly related to the increase of green house gases (GHGs) emissions. The most common anthropogenic GHGs gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

Carbon dioxide is the most abundant of GHGs in the global computation of anthropogenic emissions as showed in Figure 1.1. Combustion of fossil fuels followed by deforestation lead to the outstanding role of carbon dioxide emissions. Basically, the main sectors responsible for the anthropogenic emissions are energy supply, industry and transport.

In terms of globalisation, climate change is an international problem. Human emissions are mostly produced in developed countries, although their effects are going to be spread around the planet. In this unbalanced world, the most affected are the ones with no blame.

As mentioned, transport, industry and energy sector activities are the main sources of GHGs emissions. According to the International Energy Agency (IEA) [2], industry has increased its final energy use by 61% between 1971 and 2004, with an average annual growth of 2%.

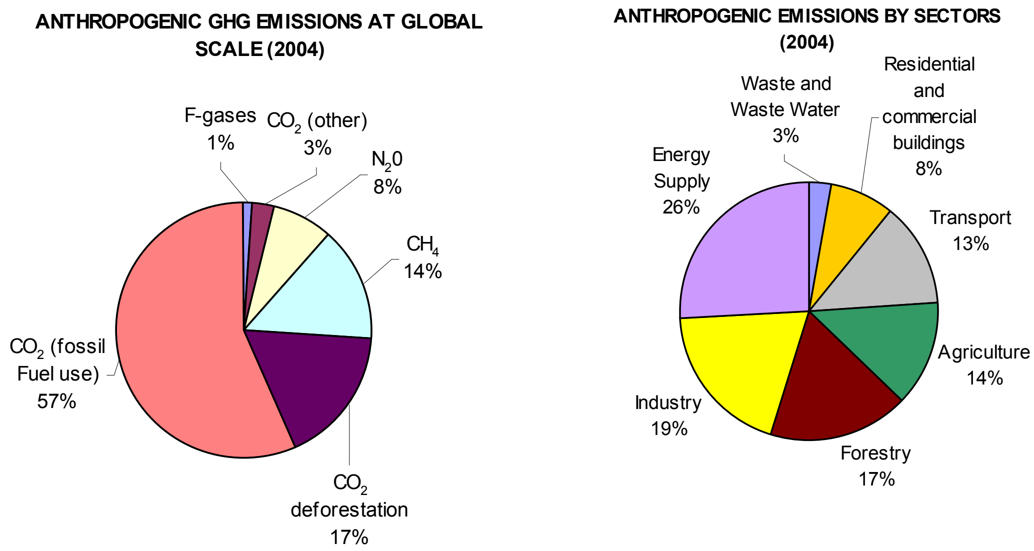

Figure 1.1 Share of anthropogenic emissions at global scale (2004). Source: IPPC [3] The share is expressed in terms of CO_2-eq.

One of the industries with an intensive energy profile is pulp and paper industry. According to the same IEA report, pulp, paper and printing activities consumed 6,45 EJ of final energy in 2004, this energy accounts for the 5,7% of the total industry energy use. Moreover, IEA declares that printing activities represent a small share compared to the pulp and paper sector. Furthermore –in a worldwide context– paper and pulp industry is a *capital intensive, high tech industry, which comprises large multinational players and many small companies.* [4].

To mitigate the effect of human activity at a global scale, United Nations framework promoted Kyoto Protocol [5]. The Protocol was signed in 1997 although it took legal effect in 2005. The Protocol commits developed countries to reduce emissions from a base level year (1990 or 1995, depending on the GHG).

European Union is determined to accomplish Kyoto Protocol and promotes legislation in order to ensure that all country members are taking the appropriated measures.

European Union has focused its restrictive emission legislation on the industry and energy sector. In the case of industry, legislation is centred on intensive energy sectors. Consequently, each affected industry has to report its annual GHGs emissions.

European State members are the responsible to assign to its affected industries a determined number of emission allowances. Therefore, industries affected by emission legislation must attain an equilibrium between production development and emissions allocation. Consequently, industries reach a stage with a double end: reducing emissions or paying for extra emissions emitted. Environmental and obviously economic interests force companies to review its primary energy consumptions, their manufacturing technologies and their daily production modes in order to reduce GHG emissions. In most cases, this is a matter of energy efficiency and energy sources.

Pulp and paper sector is included in the group of industries affected by emissions legislation due to its intensive energy profile.

According to Mensink (CEPI) [6], European pulp and paper industry has invested and sustained efforts to reduce CO_2 emissions. The sector achieved a reduction of emissions of more than 20% in the last decade.

However, there is still a long way to go. As European Union is requesting for more commitment to industries, an emission system management could become an interesting tool to help industries control and reduce emissions; the tool could also be integrated in the quality management system of the mill.

For this reason, World Resources Institute [7] considers different milestones to set an emission management system. The first step should accurately determine and analyse emissions. Various general protocols are already published to help industries account and report emissions. Most of them are included in the well known Green House Gas Protocol [8].

This protocol is over passing legislation minimum requirements to report and account emissions. The minimum reporting data process can become a simple process of fuel bills recompilation and conversion to CO_2 emissions with the corresponding factors detailed in the country legislation. Actually, GHG protocol proposes to account direct, indirect and lifecycle emissions, while government legislation is usually demanding for direct emissions.

Hakes [9] defines indirect emissions, as *the emissions from sources not owned or leased by a company but which occur wholly or in part as a result of the company's activities.* On the other hand, direct emissions are the emissions produced and justified by company production activity. Lifecycle emissions are directly or indirectly related to the lifecycle of the product, such as the mobility of employees to factories.

Different energy generation companies, such as British Petroleum [10] and Endesa [8], have already put the GHG protocol and other general protocols into practice. However, protocol implementation is not that frequent in small companies, where the amount of effort is still not justified.

Focusing the problem on paper industries, it already exists a specific tool to account and report emissions in this particular sector [11]. The tool is based on the GHG protocol. Nevertheless, this tool points out the particular methods to estimate all GHG emissions that can be produced in pulp and paper branches. This specific tool also deals with the aforementioned types of emissions (direct, indirect and lifecycle).

When approaching direct or indirect emissions, energy final use appears to be one of the main causes of emissions in the pulp and paper sector. Pulp and paper mills use great amounts of thermal and power energy in their manufacturing process. Therefore, mills have two possible ways to obtain the steam (thermal energy) and the power required. On one side, mills can obtain power and steam separately; power can be purchased from an external grid and steam can be generated in stand-alone boiler units. On the other side, mills can take advantage of combined heat and power plants (see Figure 1.2).

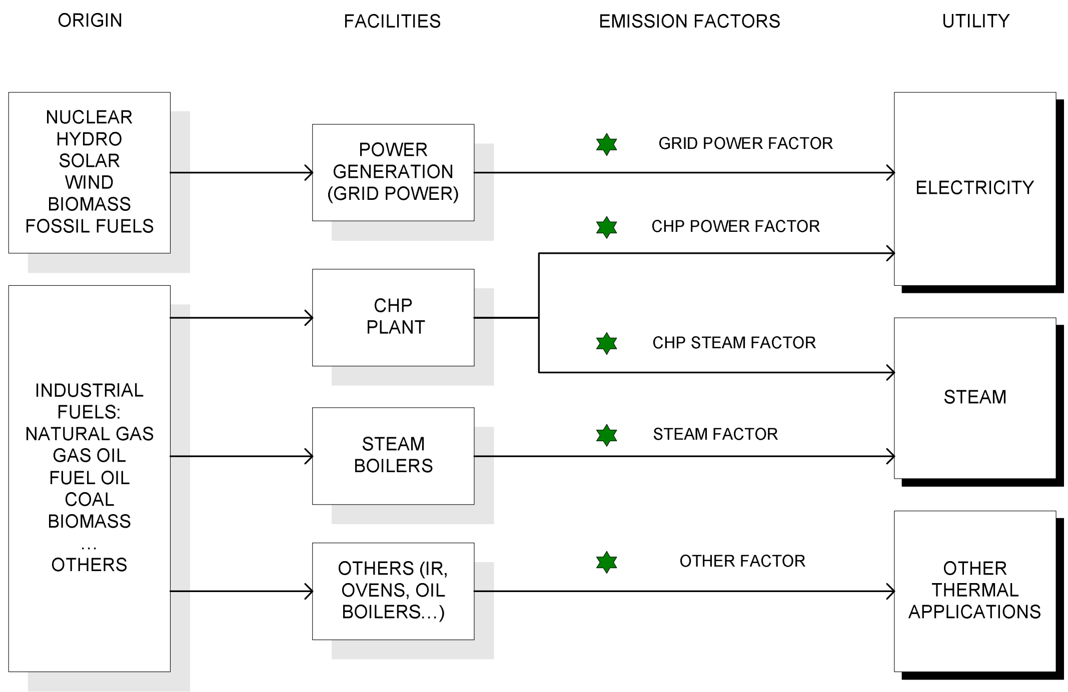

Figure 1.2 Covering energy demand in paper mills: possible scenarios and emission factors associated with each energy facility.

Emissions produced in steam and power generation will differ depending on their origin. Pulp and paper specific tool exposes these differences and offers various methodologies to allocate emissions into power or steam generation by means of the emission conversion factors. These allocation methods are going to be discussed and put into practice in this thesis, using real data.

Once the emissions are determined, protocols recommend analysing the results obtained in order to set reducing targets. However, this thesis considers that an intermediate gap needs to be filled: this is the distribution of emissions through out the process (see Figure 1.3). In addition, such emission allocation expects to contribute with energy efficiency and emissions indicators.

Emission and energy efficiency indicators are expected to be useful for internal use of the industry (energy and emissions system management) and for external benchmarking (to compare energy and emission ratios) between mills.

A deep knowledge of the process is necessary to proceed to the distribution of emissions, as each part of the process should be studied separately. It is a matter of approaching the problem gradually, from a general position to the basic operations of each part of the process.

Furthermore, International Energy Agency has developed some indicators to control the evolution of industrial emissions and energy consumption [4]. According to IEA, the key point is to establish indicators that satisfy the capture of energy use and CO_2 emission data in a sub-sector or process.

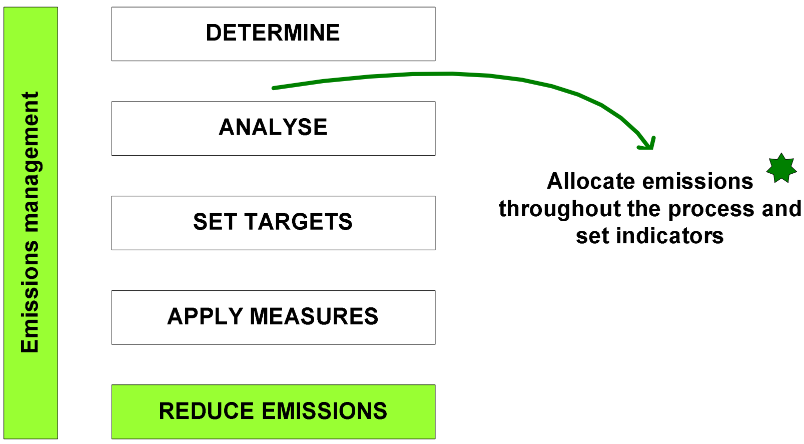

Figure 1.3 Allocating emissions through out the process. Covering the gap in an Emissions management system.

IEA considers that the "ideal" energy use and CO_2 indicators for the pulp and paper sector should take into account the type of pulp used, the grade of paper and the level of integrated paper and pulp mills. IEA recommends a detailed analysis (on a country-by-country level) before considering emission and energy use indicators as a base for target setting.

Moreover, according to Gullichsen and Paulapuro [12], the papermaking process is one of the biggest and most versatile in any industry and includes long and very complex processes. This fact has forced to set some boundaries to this thesis research. This thesis focuses on the papermaking process and does not consider the pulp sector because pulp sector is usually self-sufficient in energy terms and uses fuels with neutral emissions such as biomass and black liquor recovery. Therefore, this work just analyses non-integrated paper mills.

There is no pretension to produce a thesis for policy makers neither to base it in a theoretical case. The previous methodology proposed should be checked using existing cases. The emissions of two paper mills have been estimated and distributed through all their manufacturing process. The paper mills studied in this thesis are situated in Catalonia (Spain). One of them produces steam on-site and purchases power from an external supplier whether the other mill generates both energy streams in a CHP plant. This fact gives the opportunity to compare –in terms of emissions– the different methods of allocating emissions into steam and power generation. Moreover, it is expected to determine some emission/energy efficiency indicators of the two mills. The comparison is put into practice regarding both energy and emission focus.

Finally, this thesis reviews some related issues towards an ideal mill that manufactures paper with zero emissions.

To summarise, the aim of this work is to offer paper industries some clues to determine emissions and proceed towards indicators useful to set emissions-reducing targets. This thesis aims to improve or provide some remarks to the GHG pulp and paper protocol. The improvement is based on the distribution of emissions through out the manufacturing process and the settlement of some energy and emission indicators. The results are expected to facilitate the detection of the process red points and set emission targets as well as the basis for a complete emissions and energy management system.

1.2 OBJECTIVES

The main objective of this thesis is to develop and apply a new methodology of emissions allocation through the paper manufacturing process in order to detect the red points of the manufacturing process and point out the preferences of emission reduction in a paper mill.

In order to achieve this main objective, it is proposed to follow some other specific objectives:

- To estimate and evaluate different methodologies to determine emission factors derived from power and steam demand in paper mills:
  - Analysing different methodological views to achieve the already mentioned emission factors. In the case of CHP plants, evaluating different published methodologies by applying them to real data and analysing the results obtained. Finally, selecting the most appropriate methodology for the paper sector or proposing a new method in the case none of the analysed methods satisfies the expectations.
  - Building a proceeding to determine a grid power emission factor, using the Spanish peninsular grid as a sample case.
- To apply the new proposed allocation methodology to two Catalan paper mills by using the selected steam and electricity emission factors. To highlight which points of the mill are responsible for a higher amount of emissions. To compile emission and energy efficiency indicators and to use them as a benchmarking source.
- To propose some clues for an ideal mill regarding the already mentioned points and to analyse some possibilities to drive the mill towards a zero or neutral emission.

1.3 SUMMARY

In order to achieve these objectives, this work is structured in nine chapters, including this introductory chapter. Chapter 2 presents the climate change problematic (causes and consequences), the Kyoto Protocol and the EU legislation directives approved to accomplish it. It also summarises how it affects the Spanish pulp and paper sector.

Chapter 3 exposes different published methods to determine and manage emissions in the pulp and paper sector. Some of the methodologies are designed for general industrial activities and some others are specific for the pulp and paper sector.

Chapter 4 describes the papermaking process according to an energy point of view. The chapter includes some of the mill possible modes to cover its energy demand as well as additional published data on energy consumptions of different parts of the mill.

Chapter 5 proposes an allocation method to achieve the main objective of the thesis. The allocation method is designed within the basis of a similar structure of the paper process described in chapter 4.

Moreover, chapter 6 presents different methods to calculate emission factors. It includes an analysis of different allocation methods to attribute combined heat and power (CHP) emissions into power and steam generation and a methodology to determine Spanish grid power factor.

Furthermore, the results of the application of the allocation method proposed in chapter 5 and the emission factors evaluated in chapter 6 are applied to two Catalan paper mills in chapter 7. Results obtained are analysed and discussed. The chapter also includes a comparison of the energy efficiencies and emissions of the two paper mills.

Chapter 8 overviews some key points to achieve an ideal mill, including some notes for energy savings and an analysis of alternative energy sources to prepare the mill towards a zero or neutral emission operating mode.

Finally, chapter 9 expresses the final conclusions of this work taking into consideration the results achieved in previous chapters.

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2 CLIMATE CHANGE IN PULP AND PAPER FRAMEWORK

2.1 INTRODUCTION

The aim of this chapter is to present the climate change problematic and to describe how this affects the Spanish pulp and paper sector.

This chapter summarises the main points of the climate change phenomenon, its causes and its consequences.

It also includes an overview of the Kyoto Protocol and the reaction of the European Union towards the emissions-reducing commitment. It also summarises the EU carbon trading system and EU legislation directives approved to accomplish Kyoto protocol.

Several publications –both economical and with scientific basis– have appeared during last five years around climate change, its legal preventive commitments and the outcoming carbon markets. This chapter compiles a selection of a little part of these publications, with the aim of presenting to the reader a general vision of the mentioned subjects.

Finally, it exposes emissions situation in Spain and analyses how Kyoto protocol introduces legal commitment to the Spanish pulp and paper sector.

2.2 GREEN HOUSE GASES AND CLIMATE CHANGE

Environmental issues such as climate change and the destruction of the ozone layer have stimulated discussion on a regional, national and global scale. Due to an intense scientific research, it is now proved that our planet is living an age of climate change.

IPPC states that earth has been engaged to climate changes in several occasions. However, nowadays climate change presents a special feature: human activities are interfering and stressing it [1].

Climate change is defined as a gradual change in the planet global temperature caused by the increasing accumulation of greenhouse gases (GHGs) in the atmosphere. This phenomenon can be explained if it is considered the reaction of sun visible and infrared radiation towards our planet.

Sun visible radiation ranges from about 0,35 to about 0,75 μm in wavelength. Gases in the atmosphere absorb very little visible radiation. About 31% of incoming solar radiation is reflected and clouds and particulates in suspension can absorb about 19% of visible radiation. On the contrary, water vapour, carbon dioxide, methane, ozone, nitrous oxide, fluorocarbons, and other greenhouse gases absorb infrared radiation meanwhile is reflected from the surface of the earth. GHGs on the way to the atmosphere absorb over 90% of infrared radiation, which wavelengths ranges between 2 and 20 μm [2].

The effect is similar to having a blanket of gases around the earth. This blanket keeps the earth warm. An increase of GHG concentrations can decline to an increase of earth temperature while the atmosphere traps gradually more infrared radiation [1].

The International Panel for Climate Change (IPCC) considers six main –simple or groups– GHGs [1].

These gases are:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- hydro fluorocarbons (HFCs)
- perfluoro carbons (PFCs)
- sulphur hexafluoride (SF_6)

Moreover, IPCC states that the atmospheric concentration of GHG emissions due to human activities has increased by about 60% (in terms of CO_2 equivalents) over the years 1970 to 2004 (Figure 2.1) and keeps with annual increase of 0,4% [3]. IPCC alerts that if current trends in the use of fossil fuel continue, the atmospheric concentration of CO_2 would be more than double from the level of 300 years ago by the end of the next century. Figure 2.2 shows the exponential use of the energy generated by fossil fuel throughout three centuries.

As shown in Figure 1.1 and Figure 2.1, carbon dioxide gas is the most abundant of the GHGs; for this reason, carbon dioxide (CO_2) maintains the particular attention of policy managers and media. Therefore, the present work also focuses on this particular gas.

However, the rest of the non-CO_2 gases are more effective in absorbing infrared radiation and consequently they have a higher green house effect [4].

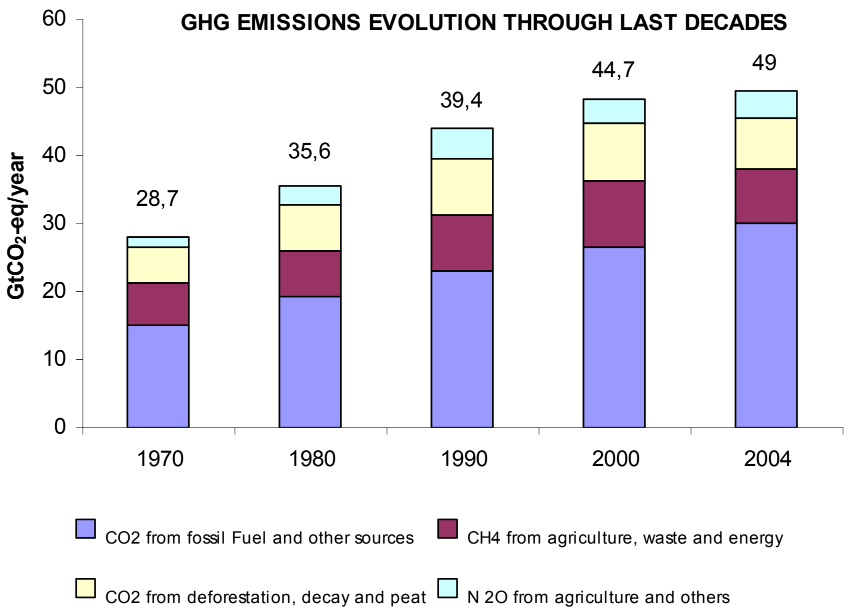

Figure 2.1 IPPC summary on GHG emissions evolution. Global annual emissions of anthropogenic GHGs from 1970 to 2004. Source: IPPC [5]

The following lines describe and present general information of the aforementioned GHGs.

Carbon dioxide

According to Houghton and Hackler [6], although carbon is naturally occurring and essential to life, the increase of emissions of carbon from fossil fuel combustion and deforestation unbalance the natural equilibrium of the earth. Thus, there is less carbon in the soil and vegetation and more in the atmosphere.

Because of CO_2 gas has a green house effect, increasing amounts of this gas unbalance the global climate. For this reason, the increase in fuel use in developed countries and rapidly growing usage rates in developing countries are both concerns.

According to the reasons exposed on previous lines, reducing CO_2 –and the rest of GHGs emissions– has become a clear preference at international scale. However, IPCC alerts that stabilization of CO_2 emissions at near-current levels will not lead to stabilization of CO_2 atmospheric concentration. In addition, stabilization of CO_2 concentrations requires eventual reduction of global CO_2 emissions to a minimum fraction of the current emission level.

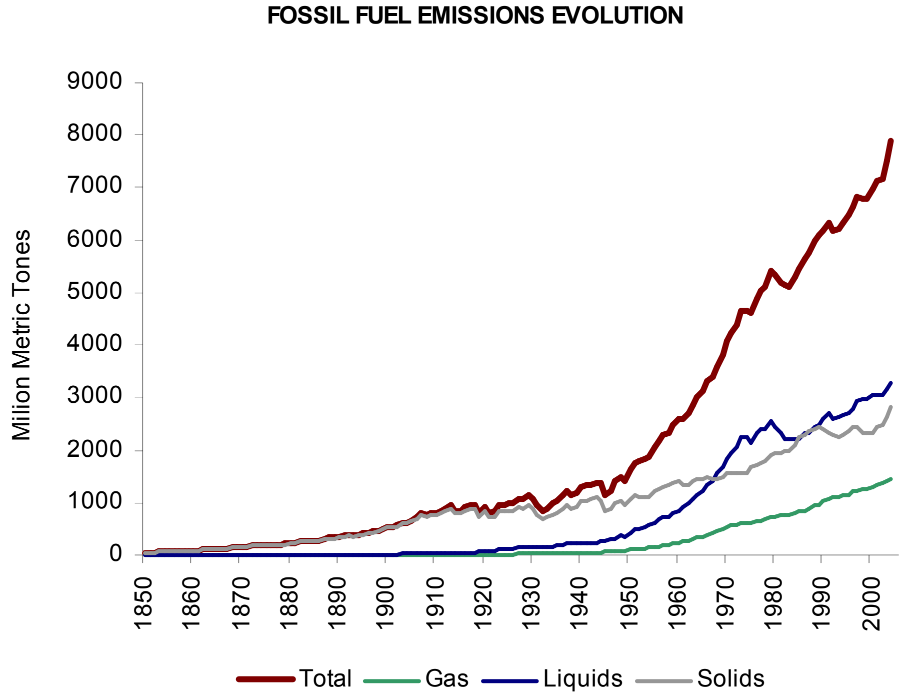

Figure 2.2 Evolution of fossil fuel emissions throughout three centuries. Source: Marland [7]

Despite this grey perspective, the lower the chosen level for stabilization, the sooner the decrease in global net CO_2 emissions has to start-up [3].

The rest of non-CO_2 gases

Massachusetts Institute Technology is carrying out a Program on the Science and Policy of Global Change. This is an organization for research, independent policy analysis and public education in global environmental change. Members of this team such as Reily, Sarofim, Paltsev and Prinn [8] have summarised the non-CO_2 gas sources (Table 2.1).

As mentioned previously, non-CO_2 gases are more effective in absorbing infrared radiation. In order of quantifying the warnings, IPCC [9] has assigned to each of these gases a global warming potential (GWPs). A GWP is an index for estimating relative global warming contribution due to atmospheric emission of one kg of a particular greenhouse gas compared to emissions of one kg of CO_2.

Table 2.1 Non CO_2 gases sources. Source: MIT [8]

GAS	EMISSION SOURCE
CH_4	Coal seams Petroleum production Transmission and distribution losses Landfill and wastewater gas Industrial sewage, paper and chemicals Industrial sewage, food processing Rice, enteric fermentation, manure management, agriculture waste, savannah and deforestation burning
N_2O	Adipic and nitric acid production Refined oil products combustion Coal combustion Agriculture soil, manure management, agriculture waste, savannah and deforestation burning
HFCs	Air conditioning, foam blowing
PFCs	Semi-conductor production, solvent use Aluminum smelting
SF_6	Electrical switchgear Magnesium production

Table 2.2 presents GWP of these gases previewed for the next 20 and 100 years [9]. This table shows that the famous GHG carbon dioxide (CO_2) is fixed with the lowest potential, although its importance remains in the highest concentration in the atmosphere (see Figure 1.1 and Figure 2.1)

Nitrous Oxide

N_2O is an unreactive gas, not soluble in water and with no absorption of visible radiation [10]. The atmospheric lifetime of N_2O is estimated to overpass the 100 years.

According to Bouwman, Van der Hoek and Olivier [11], the most important source of N_2O is found in the natural and agricultural cycling of the nitrogen that is necessary for the maintenance of living matter. Furthermore, Prather et al. affirm that up to 1/3 of CH_4 emissions and 2/3 of N_2O emissions composing the atmosphere come from soils [12].

Table 2.2 Global Warming Potential of GHGs. Source: IPCC [9]

GAS	TIME PERSISTENCE IN ATMOSPHERE	GWPs Kg CO_2 equivalent		
	years	20 years	100 years	500 years
CO_2		1	1	1
CH_4	12	62	23	7
N_2O	114	275	296	156
CHF_3	260	9.400	12.000	10.000
CH_2F_2	5	1.800	550	170
CH_3F	2,6	330	97	30
CHF_2CF_3	29	5.900	3.400	1.100
SF_6	3.200	15.100	22.200	32.400
CF_4	50.000	3.900	5.700	8.900
C_2F_6	10.000	8.000	11.900	18.000
CH_3OCH_3	0,015	1	1	<< 1
CF_3OCHF_2	150	12.900	14.900	9.200
CHF_2OCHF_2	26,2	10.500	6.100	2.000
CH_3OCF_3	4,4	2.500	750	230

Cycle of plants passes through a process of nitrification and denitrification. In both cases, N_2O and NO can be generated [13].

In the case of nitrification, ammonium NH_4^+ –which is used by a number of soil organisms as an energy source– is taken up by plants and incorporated into plant tissues as amino acids [14]; this is an aerobic system. However, if the supply of O_2 is limited by diffusion constraints the nitrifying bacteria is able to use nitrite as an electron acceptor and to reduce it to NO and N_2O.

$$\begin{array}{c} N_2O, NO\,(\text{emission}) \\ \Uparrow \\ NH_4^+ \Rightarrow NO \Rightarrow NO_2^- \Rightarrow NO_3^- \end{array} \tag{2.1}$$

On the other side, the organic material with fixed nitrogen can denitrify by the role of bacteria -producing N_2 or N_2O, which returns to the atmosphere. This process occurs under anaerobic conditions.

$$\begin{array}{c} N_2O\,(\text{emission}) \\ \Uparrow \\ NO_3^- \Rightarrow NO_2^- \Rightarrow NO \Rightarrow N_2O \Rightarrow N_2 \end{array} \quad (2.2)$$

European Union [15] contemplates some of the sources of N_2O already exposed on Table 2.1:

- Industry, especially in nitric acid and adipic acid industries
- Combustion: N_2O was identified as a relevant emission in fluidised bed combustion and particularly in circulating fluidised bed boilers, especially in coal firing. However, significant uncertainty may arise when quantifying N_2O emissions .
- Other sources, such as wastewater treatments and anaesthetics products or aerosols

Concluding, there is still work on legislation and research that needs to be coursed.

Methane

Methane (CH_4) is a colourless and odourless gas, which produces carbon dioxide and water in a complete oxidation process [11].

According to Prather et al [12], the concentration of methane in the atmosphere has more than doubled since the preindustrial era, from about $0{,}7\cdot10^{-6}$ mol/mol_{atm} to more than $1{,}7\cdot10^{-6}$ mol/mol_{atm} today.

Methane is formed naturally in soils by microbial breakdown of organic compounds in strictly anaerobic conditions, with a low redox potential [14]. In addition, methane is produced in anthropogenic action in a variety of cases: flaring of oil production, leakage in the gas distribution systems, as out-gassing coal mining, anaerobic decomposition of urban landfills, rice crops, and incomplete combustion of biomass [16].

HFCs, PFCs and SF_6

Hydro fluorocarbons (HFCs) have been developed to replace chlorofluorocarbons (CFCs) meanwhile hydro chlorofluorocarbons (HCFCs) are used primarily in refrigeration and air conditioning equipment. They do not have ozone-depletion potential [17].

Perfluorocarbons such as CF_4 or C_2F_6 have a role of intermediate products in aluminium melting process and in manufacturing of electrical semiconductor [1].

SF_6 has a high green house effect potential (Table 2.2). However, it has lower concentration ranges in the atmosphere. This gas is used as insulation in electrical equipment and becomes a waste product in magnesium manufacturing process [1].

Climate change consequences and prediction

To emphasise the gravity of the climate change consequences, IPCC predictions in climate change are pointed below [1]:

- Negative Economic Impacts
- Depletion of Natural Resources
- Flooding
- Disease
- Water Shortages
- Habitat Destruction
- Ecosystem Disruption
- Glacial Melting

This panorama should lead to a society great concern. Policy makers should also emphasize their efforts on energy reducing policies.

2.3 CLIMATE CHANGES POLICIES. KYOTO PROTOCOL

IPCC warning efforts claimed a quick answer to mitigate the mentioned predictions. At the 1992 Summit in Rio, UN Frame Convention Climate Change ultimate goal was *stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic human induced interference with the climate system. Such a level should be achieved within a period sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner* [18].

With just this information, one can imagine quickly which dilemma is appearing: How can society mitigate a climate change that has already started, maintaining its rhythm of development?

This question started to be in mind of policy makers in the 1960s. Nevertheless, the first milestone on the matter is considered *the Declaration of the United Nations Conference on the Human Environment* [19]. Other meetings, summits and development goals followed this conference.

KYOTO PROTOCOL

One of the most well known facts in environmental history took place in 1997 at the third Conference of the Parties of the UN Framework Convention on Climate Change (UNFCC).

Kyoto Protocol was defined as well as targets to cut the six main GHG emissions in developed industrialised countries (Annex I countries) [20]. The protocol sets an average GHG reduction target of 5,2% over the period 2008-2012 and uses 1990 as base year [21]. To avoid retaining development efforts, no target was set for emission levels in developing countries (non-Annex I). Kyoto protocol started to become applicable in February 16th of 2005 when it was ratified by Russia, as the condition of 55 nations accounting for at least 55% of CO_2 emissions was accomplished.

As mentioned, the target was the reduction of GHGs emissions. However, this reduction seemed impossible over the period 2008-2012 unless worldwide economy retrocedes. Consequently, three innovative flexible mechanisms were defined to reduce the totality of costs of achieving the emission targets. UNFCC justifies the mechanisms stating that they entail some economical and effective opportunities to reduce emissions as well as they enable a reduction of emissions in other countries. Over passing the country limits of emission reducing measures is justified by the cost of measures –the location of the project might be an influent parameter in overall costs– but the benefit is the same, wherever the action is executed, as the atmosphere is global [22]. The three flexible mechanisms are emissions trading, project mechanisms and absorption focus.

Flexible Mechanisms to accomplish Kyoto are described briefly in next paragraphs [23], [24].

A. Emissions Trading

Emissions Trading (ET), or Carbon Trading as it is alternatively known, settles the carbon emission trade of credits within nations.

Emissions Trading System has created the concept of allowances and fixed the concept of emissions as a commodity that can be traded between industries and countries. To quantify the terminology, one allowance is defined as a tonne of carbon dioxide equivalent.

Kyoto Protocol allows trading in emissions, but underlines not using trading systems as the main tool to bring in commitments. This mechanism aims to enhance markets of energy efficiency and innovation.

However, some controversy may arise due to emissions trading mechanism [25]. For the supporters, the best way to control carbon dioxide –and the rest of greenhouse gases– is not with voluntary measures but with a cap-and-trade system that enhances markets to promote energy-saving and pollution-reducing technologies [26].This fact should lead to the consolidation of management emission systems.

On the contrary, opponents of this flexible mechanism state that the priority should be commiting real reductions by reducing fossil fuel use rather than purchasing rights to pollute by paying for emission allowances [27].

Above all, this trading mechanism needs a market platform to develop itself. In the frame of Kyoto protocol, [28] three different types of market are already settled at current date:

- Markets of assigned amount unit (AAU); trading emissions between Kyoto countries allowances
- EUTDS European Trading System (explained in next paragraph)
- Future Markets; trading emissions of compatible markets of Kyoto with non-compatible markets

B. Project Mechanisms

Kyoto protocol considers two types of project mechanisms: Joint Implementation (JI) and Clean Development systems (CDM).

B.1 Joint Implementation

In Joint Implementation (JI) mechanism (also known as Activities Implemented Jointly), developed countries invest in emission-reducing projects in other industrialised countries; as a result they obtain reduction units. With such mechanism appears ERU terminology: Emissions Reduction Unit. An investor country obtains ERUs for reduction projects executed in a host country. The investor gets emission reduction credits when provides financial support to projects that are related to avoidance, reduction, or sequestration of GHGs.

B.2 Clean Development Mechanism

The Clean Development Mechanism (CDM) has a similar base compared to the joint implementation mechanism, although in CDM, developed countries invest in emission reducing activities in developing countries. The CDM seems to be a part of a program of sustainable development. This mechanism conceives CER terminology: Credit Emissions Reduction.

For some developing countries, CDM are attractive because of the possible financial income of foreign investment. According to Blanch F. [29], the CDMs can become a comfortable and economic way to accomplish Kyoto. Furthermore, policy reviewers [30] argue that developed countries might fall in further dependency instead of achieving important technology expertise. Additionally, understanding emissions as commodities can maintain the structural inequity between North and South.

C. Absorption Focus mechanism

This mechanism is also known as carbon sink mechanism. This mechanism considers that carbon emissions from burned fossil combustibles can be neutralised by trees. This fact implies that the mass forestry of a country outcomes as an alternative of allowances reduction of carbon dioxide emissions to atmosphere. Technical reviewers point out absorption focus mechanism doubtful points. FERN (Forest European Resource Network) questions whether a non-existing rigorous and scientific vegetable carbon performance can guarantee the amount of carbon that a forest can remove or absorb [30].

Reflections around Kyoto

Kyoto protocol is requiring to Annex I countries emission-reducing targets. As the climate change is a global problem, emissions should be also a global responsibility. From Figure 2.3 it is deduced that Non-Annex I emitters plus U.S.A are responsible for more than the 50% of the planet emissions. Great efforts have been done to force USA to ratify the Kyoto protocol. China, India and the rest of emerging countries are expected to raise emissions in the following years (Figure 2.4) although repairing measures are also in mind of policy makers.

Nevertheless, although there is no right to pollute, it should be taken into account that Chinese emissions rate per capita is five times less the rate of USA. (Figure 2.4)

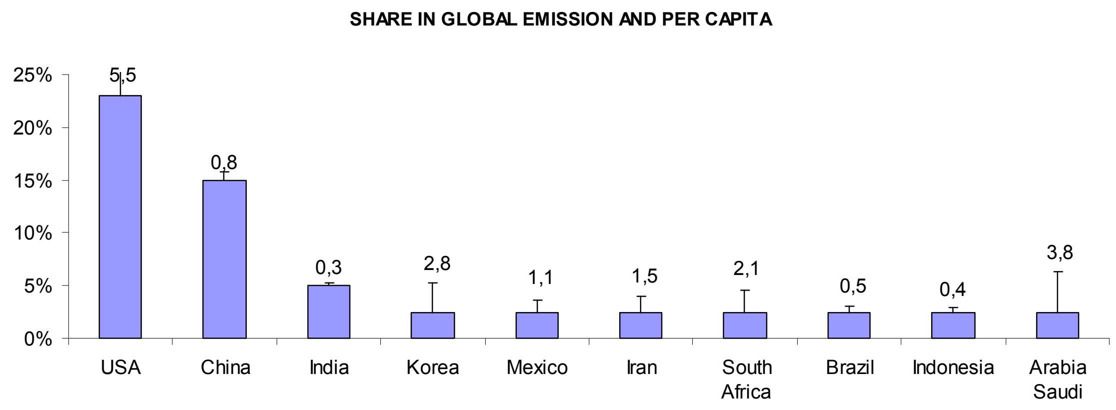

Figure 2.3 Large CO_2 non Annex I emitters, 2003. Source: Müller [31]. The figure includes the global responsibility on GHG emissions for each country and its rate per capita.

Figure 2.3 also denotes that some countries like Korea, South Africa or Saudi Arabia are responsible for a huge quantity of emissions per capita, although its absolute amount of emissions remains low.

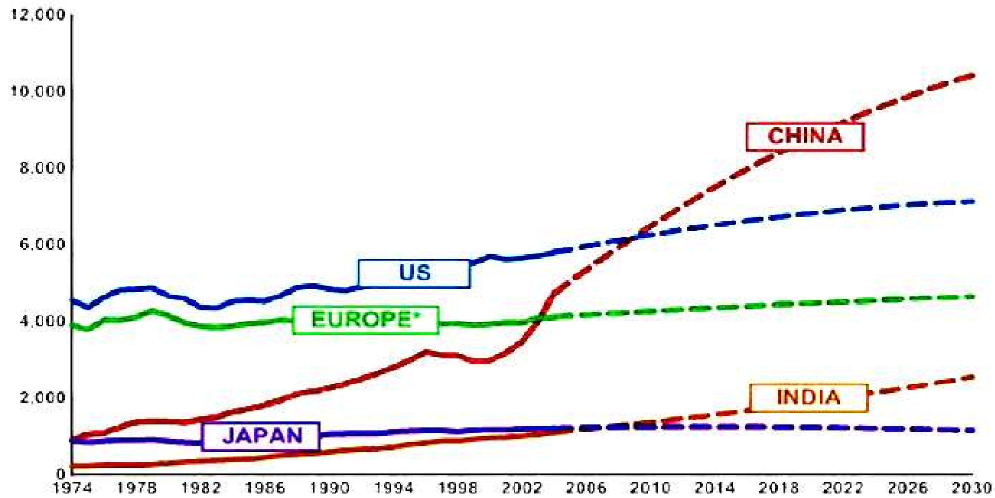

Figure 2.4 Annual CO_2 emissions in million tons of carbon dioxide Source: IEA [32]

Kyoto protocol has implicitly a monetary dimension. Therefore, the continuation of its dimension might be ensured in order to maintain the credibility of investors. Stephane Dion, the president of COP11 (11th Conference of parties) admitted his pleasure to have transmitted the correct message to Montreal audience: *the carbon market is here to stay* [31].

2.4 EUROPE SITUATION

2.4.1 Europe and the Kyoto Protocol

At current date, Kyoto protocol is legislated by 2003/87/EC directive and its amendments 2004/101/EC and the latest 2007/589/EC and 2008/994/EC. The directive enables the Community and the Member States to meet the commitments to reduce greenhouse gas emissions involved in Kyoto Protocol framework.

With this directive, European Union is establishing a greenhouse gas emission-trading scheme for the cost-effective reduction of emissions in the Community; this strategy is known as the EU ETS (European Union Emission Trading System).

Different trading units coexist in EU ETS markets; these are [28]:

- AAU: Allowance Amount Unit (related to Emissions Trading)
- ERU: Emission Reduction Unit (related to Joint Implementation)
- CER: Credit Emission Reduction (related to Clean Development Mechanism)

The EU ETS is applicable since 1rst January 2005, for 25 EU countries. EUTDS objectives have been scheduled in three periods:

- 2005-2007: start up period; characterized by a well-performed electronic register system with insufficient ambitiously levels for emission reductions.
- 2008-2012: first commitment period of Kyoto Protocol; the non-accomplishment can represent a fine of 40 to 100€ per tone of emission.
- After 2012: EU aims to reduce a 20% of emissions and limit the global climate change to 2 ºC temperature increase.

Each Member State must monitor and quantify GHGs emissions and develop a national allocation plan (NAP). The plan forces the State to report the total amount of assigned allowances for that period and the method proposed to distribute them [33].

However, not all CO_2 focus activities are included in the directive. The directive just delimits two types of activities (Table 2.3):

- Energy generators
- Intensive energy industrial consumers, such as intensive energy iron, steel production and processing, mineral industry and pulp, paper and board.

More deeply, directive 2003/87/EC applies to activities listed in Table 2 [34] from the directive, leaving free of charge the rest of them (transport, residential, services and agriculture activities).

Table 2.3 Activities included in 2003/87/EC directive. Source: 2003/87/EC [33]

ENERGY ACTIVITIES
▪ Combustion installations with a rated thermal input exceeding 20 MW (except hazardous or municipal waste installations) ▪ Mineral oil refineries ▪ Coke ovens
Production and processing of ferrous metals
▪ Metal ore (including sulphide ore) roasting or sintetering installations ▪ Installations for the production of pig iron or steel (primary or secondary fusion) including continuous casting, with a capacity exceeding 2,5 tonnes per hour ▪ Installations for the production of cement clinker in rotary kilns
Mineral industry
▪ Installations of cement clinker with a production capacity exceeding 500 tonnes per day or lime in rotary kilns with a production capacity exceeding 50 tonnes per day or in other furnaces with a production capacity exceeding 50 tonnes per day ▪ Installations for the manufacture of glass including glass fibre with a melting capacity exceeding 20 tonnes per day ▪ Installations for the manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain, with a production capacity exceeding 75 tonnes per day, and/or with a kiln capacity exceeding 4 m^3 and with a setting density per kiln exceeding 300 kg/m^3
Other activities
▪ Industrial plants for the production of pulp from timber or other fibrous materials. Paper and board with a production capacity exceeding 20 tonnes per day

As expressed on Table 2.3, this directive subjects pulp plants and paper and board plants exceeding a daily production of 20 tones. Moreover, pulp and paper plants owning a CHP plant that is fired with fossil fuels and over passes 20 MW of capacity are also subjected to GHG emission legislation. At current date, EU is focusing on carbon dioxide emissions, leaving the rest of non-CO_2 gases aside.

EU ETS has stimulated the creation of a carbon market. For the moment, some specific participants are dominating this market. Figure 2.5 shows the type and quantity of companies participating in the EU ETS versus the market product sophistication. It is understood that direct emissions trading is a simple market product meanwhile speculative emission reduction credit is a more sophisticated trading unit.

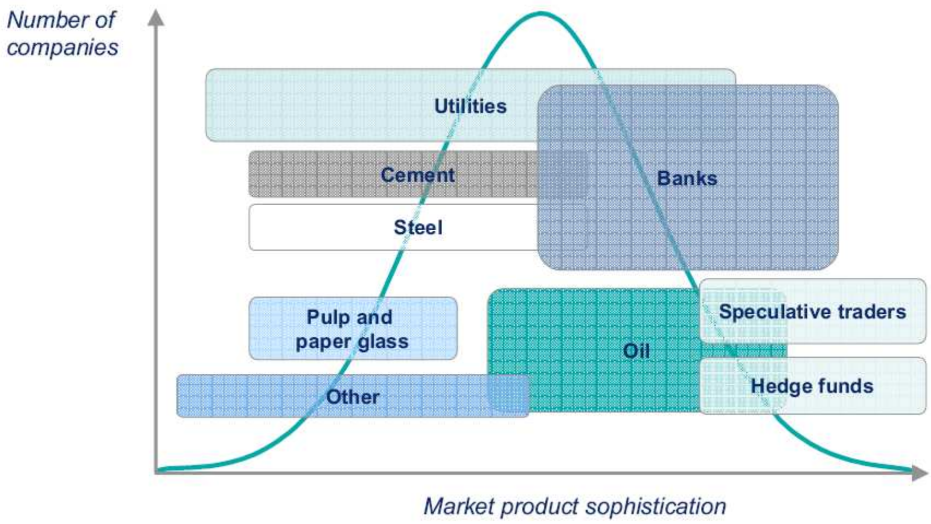

Figure 2.5 Agents involved in the carbon market. Source: European Climate Exchange [35] The sophistication of the product traded (such as ERUs or CERs) depends on the type of company activity.

The carbon market has lead to different emission trading platforms through out Europe. Most of them are operating electronically [36].

Figure 2.6 presents the most recognised carbon platforms with a visual representation of their range of activity located. Nord Pool platform assumes the carbon market of the northern European countries (Norway, Sweden and Finland). Powernext platform and New Values are settling their business in France and Netherlands, respectively. Sendeco and GME develop carbon platforms in Spain and Italy. EEX and EX Alpen Adria run the German and Austrian platforms.

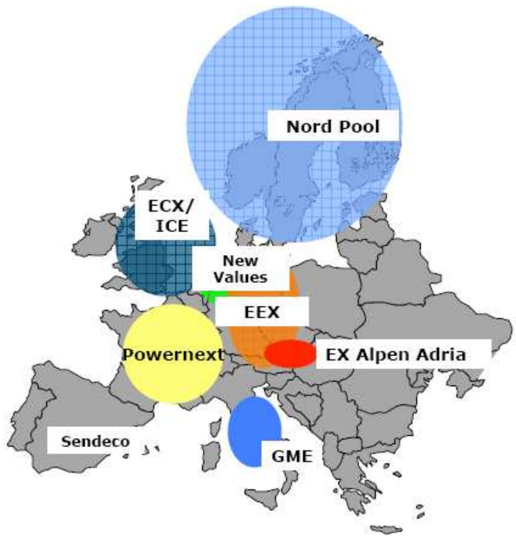

Figure 2.6 Exchanges in Europe with CO_2 product. Source: Nord Pool [37] . The figure shows the operational network of each of the CO_2 trading platforms.

Finally, the biggest trading system is British ECX (Emission carbon exchange) platform, which was getting in 2006 the 77% volume of the emissions market [38]

2.5 SPAIN SITUATION

2.5.1 Spain and the Kyoto Protocol

When Kyoto protocol was formulated, Spain was given an average GHGs reduction target of +23% over the period 2008-2012 compared with 1990. That meant Spain could raise its emissions until that target limit was reached. However, due to a non-existent or non-efficient energy policy, Spain is at current date over-passing the target with a +53% value [39]. Spain lack of reaction has been used as an example of non-efficient policy makers [22].

Nevertheless, Spain has started to put some efforts on its energy policy [36].

Legislative steps based on 2003/87/EC and its amendments are listed below:

- Law 1/2005 of regulation of the trading regime of GHG emissions
- Real Decreto 1866/2004 National Allocation Plan (NAP) of emission allowances, 2005-2007.
- Real Decreto 60/2005 which modifies Real Decreto 1866/2004.
- Real Decreto 1264/2005 organizes and regulates RENADE [40], an institution that coordinates and registers emission allowances of all the affected activities
- Real Decreto 1315/2005 that establishes bases to follow and verify emission gases of the activities included in Law 1/2005
- Real Decreto 202/2006 sets dialogue tables from syndicates and business sectors in order to analyse and follow the effect of the national allocation plan in the competitiveness and stability of activities.

The NAP in Spain is addressed to two main types of industries: small and medium enterprises (SMEs), and large companies. Three quarters of the installations affected by the NAP are SMEs although their volumes of allowances represent the 30% of the totality of allowances. Actually, just a quarter of large companies are dealing with the 70% of the allowances [41].

Figure 2.7 presents the volume of allowances of each type of company affected by NAP legislation.

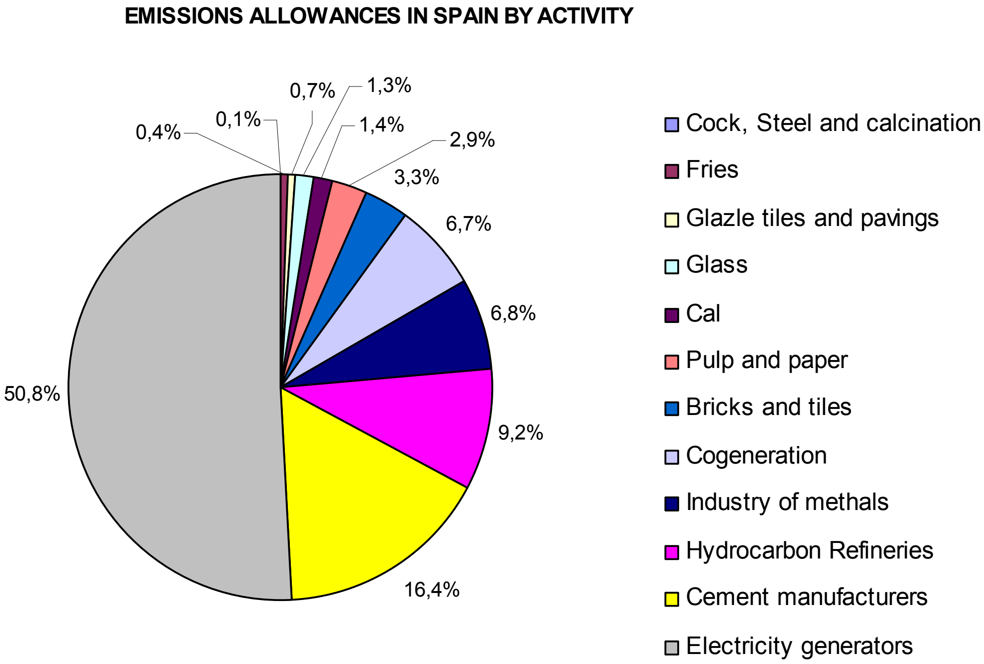

Figure 2.7 Emission allowances in Spain by activity sector. Period 2005-2007. Source: Energy Carbon Finance [41]

As exposed on Figure 2.7, electricity generators are the most affected by emission legislation. At today's date, Spanish government has already established emission allowances for the period 2008-2012.

Table 2.4 shows the quantity of allowances by sector. Pulp and paper sector experiments a bit of relief in emissions allowances. This is not the case of energy generators and cogeneration facilities.

Spain began to optimise the efficiency of the non-legislated sectors after its NAP. On July 2005 was approved E4 Spain energy strategy for the period 2004-2012. In addition, to reinforce E4 strategy, on July 2005 Spanish Parliament approved "Plan de Acción 2005-2007 de la Estrategia de Ahorro y Eficiencia Energética para España" [42]. Afterwards it approved the same plan for the period 2008-2012. In the first plan, Spanish government included 22 primary measures to improve the energy efficiency of the main energy consumer sectors. Moreover, on March 17th 2006 it was presented the "Código técnico de edificación", which contemplates energy efficiency in new buildings with the objective of obtaining constructions with a sustainability criteria [43]. Later, Spanish government approved RD/661/2007 in order to promote green power energy.

Table 2.4 Evolution of Spanish Allowances by sector and period

SECTOR	**ALLOWANCES AVERAGE 2005-2007** Mt CO_2	**ALLOWANCES AVERAGE 2008-2012** Mt CO_2	**VARIABILITY 2005-2007 2008-2012** %
Electricity	85.400	54.053	-36,7
Cogeneration	13.001	11.800	-9,2
Hydrocarbon refineries	15.250	16.133	5,8
Cock, Steel and calcination	11.230	12.194	8,6
Cement manufacturers	27.535	29.015	5,4
Cal	2.456	2.276	-7,3
Glass	2.244	2.209	-1,6
Fryes	0,68	0,62	-8,8
Bricks and tiles	4.773	4.297	-10
Glazle tiles and pavings	0,88	1,42	62,2
Pulp, paper and board	5.298	5.470	3,2
Total	182.175	152.673	-16,2

2.5.2 Pulp and paper policy in Spain concerning GHG emissions

After this description of Spanish energy policies, it might be necessary to focus again on the industrial sector, and more deeply on the pulp and paper industry.

As mentioned, Spanish pulp and paper sector does not escape from emission legislation (Table 2.3). Spanish government sets annually to each mill a fixed quantity of allowances [44]. Paper and board mills with a production capacity under 20 tonnes per day are exempt.

Frequently, a pulp and paper manufacturer owns or has operational control of a CHP plant for its production process. It should be taken into account that 2003/87/EC Directive and its aforementioned amendments legislate CO_2 emissions of:

- Combustion installations with a rated thermal input exceeding 20 MW
- Residual Incinerators

Implicitly and explicitly, the first mentioned point forces pulp and paper sector to assume following objectives:

- Report CO_2 emissions
- Establish and consolidate systems to control emissions
- Adopt measures to reduce emissions

2.5.3 Pulp and Paper Spanish profile

Pulp and Paper sector in Spain has historically been a sector of medium and small-scale production. Statistic report of Spanish pulp and paper association (Aspapel) 2006 [45] describes the profile of Spanish pulp and paper mills. Table.2.5 and Table 2.6 present the existing pulp and paper mills and their productivity during the period 2002-2006. These tables denote Spanish pulp and paper sector is major composed of non-integrated paper factories of small capacity.

Table.2.5 Spanish pulp sector. Evolution of number and productivity of mills. Source: ASPAPEL [45]

NUMBER OF PULP MILLS AND PRODUCTIVITY					
Annual tones	2002	2003	2004	2005	2006
Capacity < 10.000	2	2	2	2	2
10.001 to 25.000	2	2	2	2	2
25.001 to 50.000	0	0	0	0	0
50.001 to 100.000	4	4	3	3	3
100.001 to 250.000	4	4	5	4	4
> 250.000	3	3	3	4	4
Total	15	15	15	15	15

Table 2.6 Spanish pulp sector. Evolution of number and productivity of mills. Source: ASPAPEL [45]

NUMBER OF PAPER MILLS AND PRODUCTIVITY					
Annual tones	2002	2003	2004	2005	2006
Capacity < 10.000	57	57	43	43	37
10.001 to 25.000	20	20	18	18	16
25.001 to 50.000	30	30	21	22	21
50.001 to 100.000	6	6	14	14	15
100.001 to 250.000	17	17	17	16	17
> 250.000	2	2	3	3	3
Total	132	132	116	116	109

Moreover, Aspapel has compiled the productivity profile of Spanish paper mills according to manufactured paper grades. Table 2.7 shows that the main type of paper production is focused on newsprint, paper and writing paper and case materials. The same table shows how the production capacity of these grades is increasing annually.

Table 2.7 Spanish paper mills. Evolution of production per type of paper produced. Source: ASPAPEL [45]

PAPER PRODUCTION Mt/y					
	2002	2003	2004	2005	2006
Newsprint and printing and Writing	1.474	1.491	1.582	1.719	1.973
Santitary and Tissue	486	494	511	540	607
Case Materials	2.252	2.329	2.360	2.357	2.712
Corrugating medium	1.131	1.162	1.194	1.175	1.363
Testliner and Kraftliner	628	684	700	734	877
Biclass and leather	493	483	466	448	472
Kraft Sack	160	170	161	158	148
Folding Boxboard	508	455	407	407	357
Others	485	495	506	516	557
Total	7.617	7.763	7.886	8.054	9.065

Regarding emissions allowances, up to 58% of Spanish mills have assigned less than 30.000 tonnes of CO_2 annual allowances. The sector not only differs on mill size but also does not undertake the same pattern throughout Spanish regions [46].

For example, Catalonia is the autonomous region with the major number of mills -30%-, although the 62% of them undertakes less than 30.000 annual tones of allowances. On the other hand, Aragon plants represent the 7% of the total Spanish pulp and paper plants, although the 75% of those plants over-pass the 30.000 tones of CO_2 annual allowances.

Furthermore, it should be denoted that emissions allowances are subjected to the energy self-supplying capacity of the mill. Indeed, mills owning a CHP plant are committed to report its related emissions. On the contrary, mills with single heat and power systems do not respond for their indirect emissions related to electricity purchase.

2.5.4 Combined heat and power plants in Spain

According to Business Europe [47], Spanish pulp and paper sector is a European leader in CHP plants. Moreover, Aspapel adds that the Spanish pulp and paper sector has installed nearly 60 CHP plants since 1990, and has transformed the sector from a large electricity consumer into an integrated energy business operation that produces electricity efficiently [48].

Figure 2.8 presents the capacity of CHP plants installed in the pulp and paper sector. Catalonia is the region with higher installed power and with a major number of CHP plants, followed by Andalusia and Aragon.

According to Figure 2.9, Spanish pulp and paper sector has increased its CHP power installed in more than 70% along the last decade. Moreover, during the period 2008-2012, ASPAPEL estimates and additional installation of 250 MWe [49]. Therefore, the important effort of pulp and paper sector as an electrical generator has started to be relevant. In year 2003, the 2,5% of electricity produced in Spain was supplied by pulp and paper CHP plants. In addition, pulp and paper sector produces more electricity than it consumes (see Figure 2.9) [50].

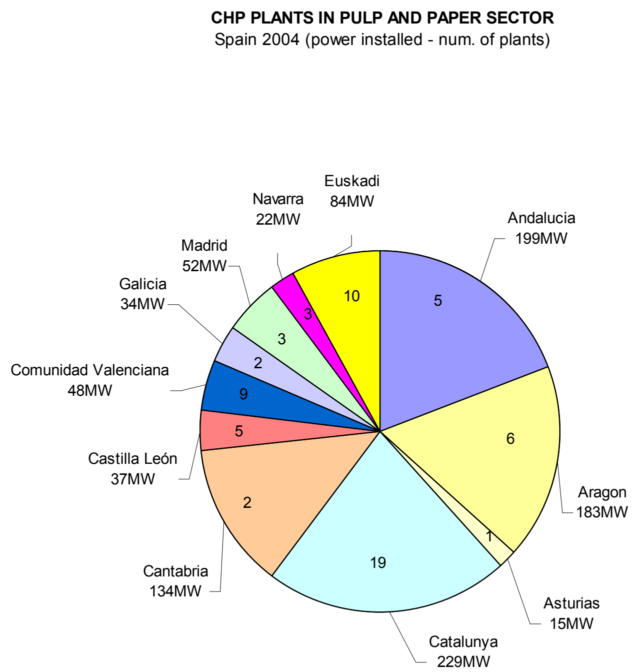

Figure 2.8 CHP plants in pulp and paper sector. Based on Aspapel data [48]. – Each portion indicates the number of plants of each autonomous region. The total power capacity installed is indicated outside.

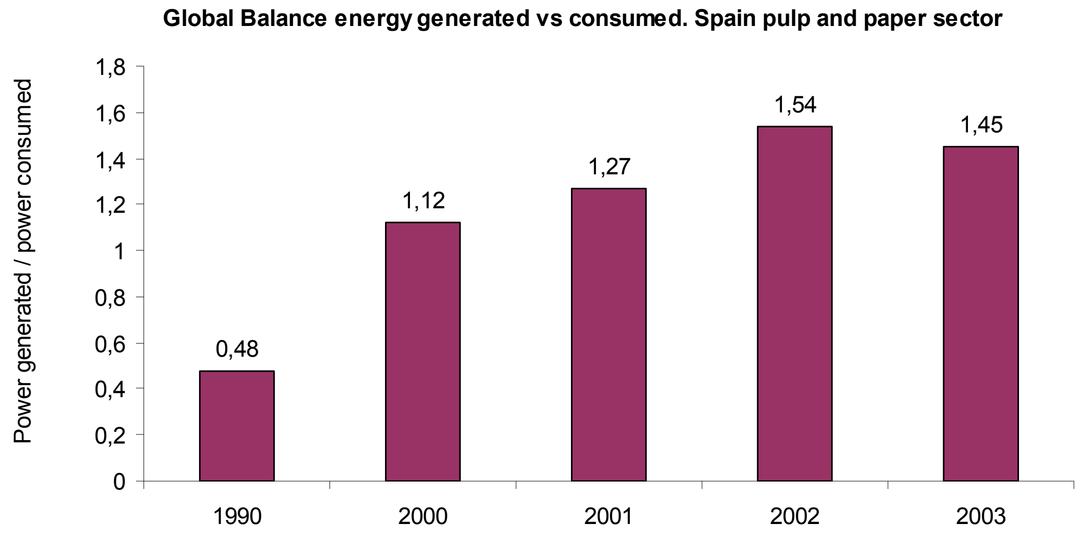

Figure 2.9 Evolution of CHP energy production versus consumption in pulp and paper sector. Source: ASPAPEL. The figure exposes the ratio of energy generated/energy consumed for the totality of pulp and paper sector and denotes that pulp and paper sector is self-sufficient, in terms of power energy [51].

CHP plant provides great benefits to pulp and paper industry, such as:

- Constant power quality and reliability
- Energy efficiency, due to simultaneous generation of steam
- Economic profit by selling electricity to the market pool

However, Aspapel outstands that CHP emission allowances have become a critical point in terms of economical survival. The key-issue is that Spanish sector has to be as competitive as the European one. If allowances of emissions are more restrictive than the European ones, the sector might outcome in disadvantage.

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3 MANAGING AND QUANTIFYING EMISSIONS

3.1 INTRODUCTION

The aim of this chapter is to present the main published methods regarding calculations and management of emissions in the pulp and paper sector. Some of the methodologies are designed for general industrial activities and some others are specific for the pulp and paper sector.

Different articles and papers on how to account and report GHG emissions have been published. The most cited are listed in the following bibliography:

- *Global Reporting Initiative, Sustainability Reporting Guidelines* [1]
- *Measuring Eco-efficiency: A Guide to Reporting Company Performance* [2]
- *Environmental Performance: Group Reporting Guidelines (BP)* [3],
- *The Challenge of GHG Emissions: the "why" and "how" of accounting and reporting for GHG emissions: An Industry Guide* [4]
- *An overview of greenhouse gas emission inventory issues* [5]
- *Green House Gas Protocol: the GHG protocol for project accounting* [6]
- *Green House Gas Protocol: A corporate accounting an reporting standard* [7]
- *IPPC Guidelines for pulp and paper industries* [8]

All these documents contain useful information to establish rules for an efficient report of emissions of industrial activities. However, the Green House Gas protocol guide synthesises most of them. The guide is destined to all types of companies and does not provide specific methods for emission calculation, although it indicates the most used methods as well as reference documents to find them. Basically, the GHG protocol is written in general terms.

Furthermore, this chapter presents a specific document for pulp and paper sector and debates specific tools for calculating emission factors.

Finally, it summarises the Integrated Prevention Pollution Control (IPPC) Guidance for the pulp and paper sector. IPPC is a regulatory system that uses an integrated method to control the environmental impacts of industrial activities. The system helps to determine the appropriate controls for industry to protect the environment through a single permitting process. The mentioned guidance gives some indications on how to treat different type of pollution –such as carbon dioxide emissions– and energy waste.

3.2 GREEN HOUSE GAS PROTOCOL

One of the most complete methods in the field of emissions report is the Green House Gas Protocol [6]. The aim of such protocol is to guide companies to settle the basis and structure to produce a GHG emission inventory. The development of an emission inventory corresponds to the first step “determine” of the emissions management system (see Figure 1.3).

The Green House Gas Protocol provides a step-by-step guide for companies to use in quantifying and reporting their GHG emissions. Nowadays, large companies and multinational players, such as British Petroleum, Endesa or Repsol have already applied GHG protocols. However, samples of emission protocol applications are difficult to encounter in pulp and paper sectors and particularly in medium enterprises.

3.2.1 Protocol Guidelines

Figure 3.1 pictures the structure of the protocol guidelines. New Zealand Report [4] summarises the steps of GHG protocol in three main actions: plan, calculate and report.

The following lines proceed to describe briefly the main structure of the GHG protocol.

3.2.2 Plan

Plan is the first action recommended as a starting point of GHG protocol appliance. Most of the documents from the mentioned bibliography [1-7] accord that plan action is basic for a good computation and report development results. Plan steps are the basis of the protocol.

Following paragraphs detail different steps included in Plan action –as described in Figure 3.1.

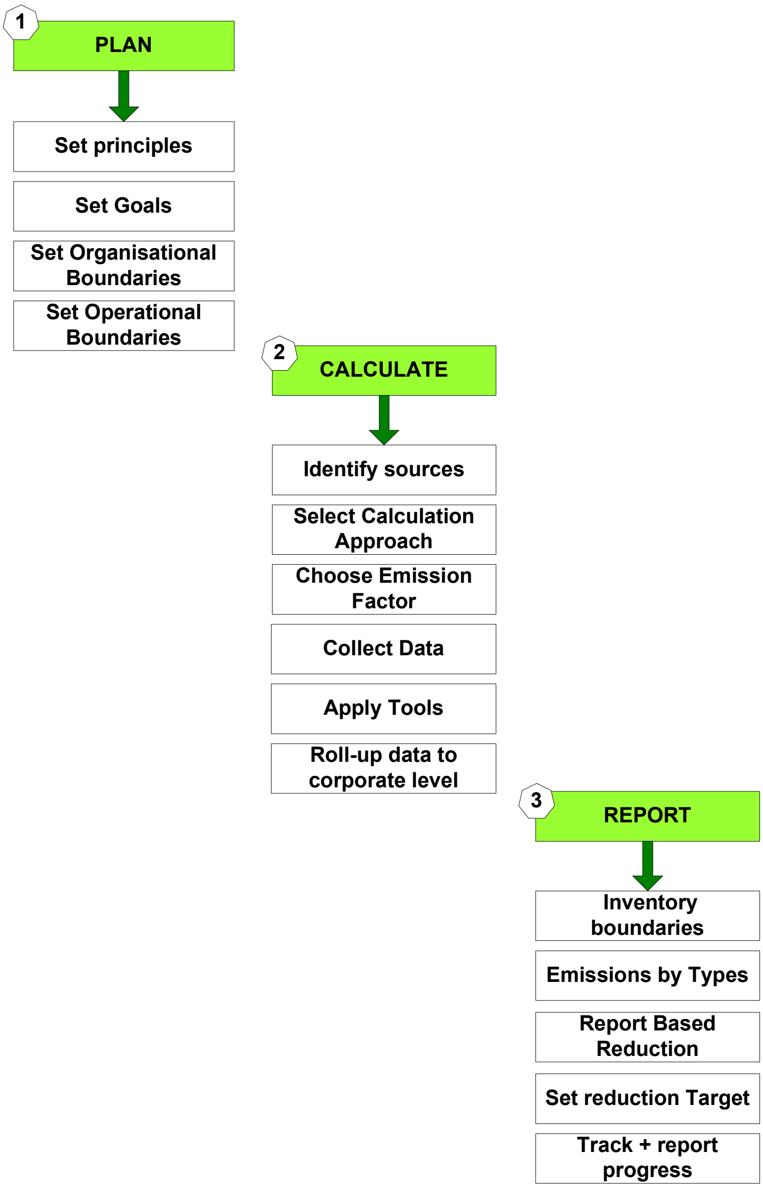

Figure 3.1 Structure of a GHG protocol. Plan, calculate and report are the basic steps to settle the basis for a GHG emission management system.

3.2.2.1 Adopt and apply principles

Even in an implicit way, the team in charge of GHG protocol has to adopt some basic principles, especially if taking into consideration that their results might lead to an economical and environmental decision-making and further investment policy [4]. The principles to achieve are relevance, completeness, consistency, transparency and accuracy.

- Relevance: working on the tasks seriously, taking into account that the results might lead to great benefits.

- Completeness: determining, accounting and reporting all the GHG emissions included in the inventory design boundaries. Emission exclusions need a justification.
- Consistency: achieving consistent concepts in order to process empirical comparisons of emissions over an historical period.
- Transparency at all levels: defining clearly how have been processed the tasks of collecting results and documentation, deciding hypothesis and estimations and assuming limitations of the GHG inventory.
- Accuracy: taking into account the same policy of precision in all report levels: data transferring, data treatment and data report.

3.2.2.2 Set Goals

According to GHG protocol, companies usually set the following business goals to encourage the project of a GHG inventory:

- Managing the risks of GHG emissions and discerning reduction opportunities
- Producing public reports of GHG emissions and participating in voluntary GHG programmes
- Being part and contributing in mandatory reporting programmes
- Playing a role in GHG markets
- Distinguishing in a primary state emission reduction projects

An additional goal could be included:

- Adopting a management system of emissions

These goals might be summarised in reducing energy and emission costs, accomplishing legal aspects and marketing the company with an eco-label or carbon foot print label.

3.2.2.3 Set Organizational Boundaries

A compendium of different relationships between companies, filial companies, state participations, etc. can puzzle with the business operations. GHG emissions need an organisational boundary to fix where their limits in the multi-relational company framework are.

The total of emissions produced in specific processes must be assigned to a specific organisation. Managers in charge of the protocol implementation in each project should define the bounds of the emissions produced in each focus. The GHG Protocol [6,7] especially defines equity share approach, financial control approach and operational approach of the emissions of an operation (Figure 3.2).

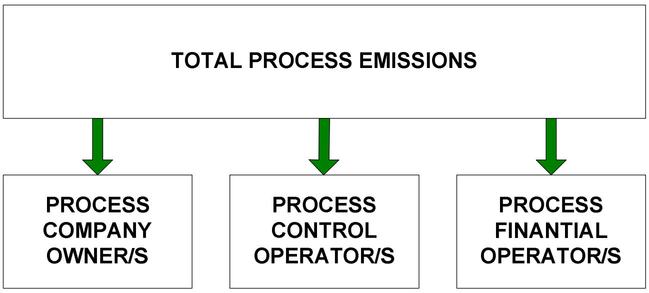

Figure 3.2 Organisational Boundaries of GHG emissions processes. The GHG report must delimit and coordinate the multirelational activities subjected to emission releases.

- Equity share approach: if a company owns part of an operation of another company, GHG emissions reflect the share of ownership of the operation.
- Financial control approach: emissions reflect the share of economic or operational direction of an operation (the percentage of economic or operation policy right).
- Operational control approach. If a company has complete rights to take part in the operational policy of a unit operation, the emissions of that operation are assigned to this company.

3.2.2.4 Set operational boundaries

The GHG protocol recommends identifying each type of emissions associated with each operation, to classify them as direct, indirect emissions or lifecycle emissions.

Setting operational boundaries also includes a base year decision. While starting an inventory and recompilation data, companies fix a single year as their base year. However, Protocol allows selecting an average of annual emissions over several consecutive years. Protocol recommends choosing a base year the earliest year where data can be considered reliable.

If a company has historically used a conversion factor to report emissions, and later to this period, the company has corrected it, historic data needs a recalculation process, to maintain data consistency.

Scope concept

The previous step of setting organisational boundaries could lead to a double-counting problem between companies. With the aim of avoiding the double counting between factories, the GHG Protocols define the concept of Scope. These guidelines define three emission scopes: Scopes 1, 2 and 3.

Figure 3.3 pictures the mentioned scopes. It visualises different facilities associated with the emission scopes.

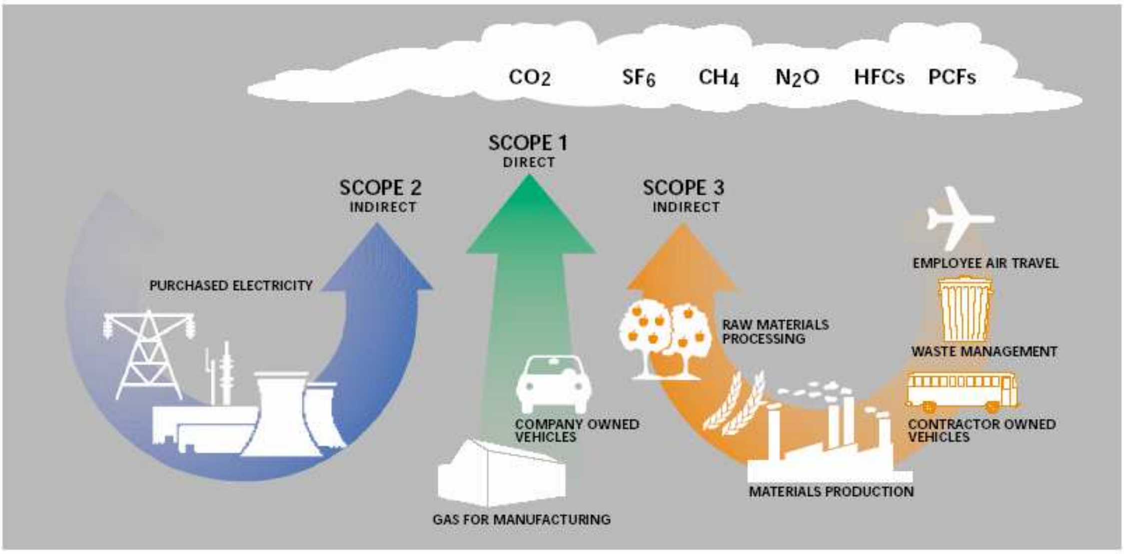

Figure 3.3 Emission classification: Scopes. Source: NZBCSD [4]. Scope 1 is related to direct emissions, Scope 2 is associated with indirect emissions meanwhile Scope 3 has a lifecycle approach.

According to these protocols, emissions from Scope 1 and 2 should be compulsory reported meanwhile the report of Scope 3 emissions is optional.

- **Scope 1**:

Involves all direct emissions produced or controlled into unit operations of the company while generating electricity, heat or steam. For example, emission from combustion of boilers, dryers, owned or controlled by the company.

Emissions associated with the sale of own-generated electricity to another company are included in Scope 1.

Scope 1 also includes emissions produced in chemical processes and emissions produced by transport from vehicles owned or controlled by the company.

Emissions associated with the combustion of biomass need a separate report.

- **Scope 2**:

Comprises emissions associated with purchased electricity used in the company operations. Although some National o State Allocation programmes just request companies for Scope 1 emission report (this is the case of Spain), protocol strongly recommends reporting this type of emissions. Usually, electricity represents a great share of the energy use of the company. Accounting for Scope 2 emissions allows companies to assess the risks and benefits associated with changing electricity and GHG emissions costs. Protocol suggests companies considering the acquisition of a CHP plant.

Moreover, the protocol highlights that purchased electricity factor does not include trade and distribution electricity losses. Therefore, while using emission factor for purchased electricity, it should be defined if this factor includes or not distribution losses. Chapter 6 accurately describes a method to calculate emissions related to purchased electricity.

- **Scope 3:**

Includes emissions associated with indirect activities of the lifecycle of the companies product. In this case, responsibilities of Scope 3 are not owned or controlled by the company. Scope 3 involves different activities; for example, transport of raw material, waste treatment, or employees mobility. According to the GHG Protocol, Scope 3 report might conduct to innovative ideas to emissions reductions associated with the product itself.

Double Counting when dealing with scopes

As mentioned, the organisational approach of emissions might be a problem when different companies include the same emissions in their inventories. Figure 3.4 exemplifies this case.

The protocol does not place much importance to double counting problem because above all an inventory is useful for own reductions costs and environmental impact. Moreover, a national allocation plan is in charge of arranging the double counting problem.

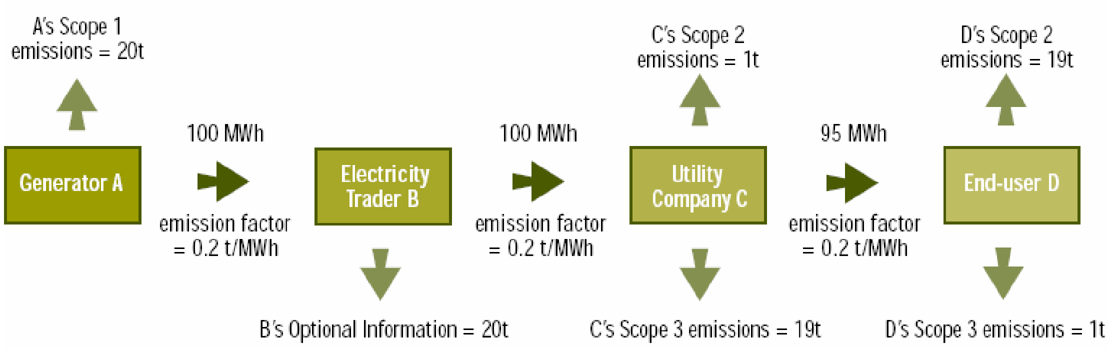

Figure 3.4 GHG accounting from the sale and purchase of electricity. Source: GHG protocol [6] Company A is a power generator that produces direct emissions. The utility company C purchases power from company A by means of an electricity trader B. As a trader company, B is not producing any emissions neither using power. Company C transforms power and supplies it to company D. The transmission process has some losses. The emissions associated with inefficiencies are considered Scope 2 emissions – not generated in situ.

3.2.3 Calculate

As presented in Figure 3.1, the GHG emissions protocol defines six steps to identify and quantify the sources or emission focus. These are identifying sources, selecting calculation approach, choosing emission factors, collecting data, applying calculation tools and finally rolling-up data to corporate level.

3.2.3.1 Identify Sources

Although the GHG protocol is a general protocol, its Annex D [6] defines the possible emission focus of pulp and paper industries. Table 3.1 depicts typical emission sources of a pulp and paper company classified in accordance to the three different scopes.

3.2.3.2 Select Calculation Approach

GHG protocol poses two processes for determining emissions: directly or by a calculation approach. The direct calculation requires monitoring of gas concentration and flow rate registering. This type of measurement is excessively expensive even unavailable in most of the cases.

Table 3.1 Pulp and Paper emission sources categorised by Scopes. Source: GHG Protocol [6]

TYPE OF SCOPE	SOURCE
Scope 1	**Stationary combustion** Production of steam and electricity, fossil fuel-derived emissions from calcinations of calcium carbonate in lime kilns, drying products with infrared dryers fired with fossil fuels **Mobile combustion** Raw materials, products, wastes, operation of harvesting equipment transports **Fugitive emissions** CH_4 and CO_2 accidental emissions
Scope 2	**Consumption of purchased energy uses** Electricity, heat or steam
Scope 3	**Stationary combustion** Production of purchased materials or waste combustion **Process emissions** Production of purchased materials **Mobile combustion** Transportation of raw materials, products, waste, employee business travel, employee commuting **Fugitive emissions** Landfill CH_4 and CO_2 from waste

On the other hand, the common process for accounting emissions derives to different calculation approaches:

- Calculation based on a mass balance or stochiometric basis related to a facility or process.
- Calculation based on documented emission factors. Emission factors are ratios used to relate GHG emissions to a measure of activity at an emission source.

For example, if a company has access to the amount of fuel used and the carbon content of it, the company is able to report the emissions from a stationary combustion source, such as a boiler unit.

The carbon content of a fuel or substance is either estimated by default carbon content coefficients or with and accurate and periodic fuel sampling [5]. In both cases, protocol recommends companies using the most accurate calculation approach available to them in their reporting framework.

3.2.3.3 Collect activity data and choose emission factors

Calculation methods concerning direct emissions are based on the amount of commercial fuels (natural gas and heating oil) and the published emission factors.

On the other hand, calculation of indirect emissions require the amount of electricity purchased and the additional published emission factor, either related to an specific supplier, local grid or alternative system.

Finally, Scope 3 emission approach is usually based on activity data such as fuel consumed, passenger distance travelled (kms) and published emission factors.

GHG protocol recommends using specific emission factors or other particular emission methods rather than general emission factors or methods.

3.2.3.4 Collect data

The potential data source [2] for a company to calculate its emissions is listed below:

- Cost reports: periodic financial data related to electricity or fuel costs
- Fuel invoices: quantity and carbon content data provided by supplier
- Plant survey: collected data from internal meters and periodical reports
- Environmental, Health and Safety reports

3.2.3.5 Apply calculation tools

In order to calculate emissions, protocol defines two main categories of calculation tools, cross-sector tools and sector-specific tools.

Tools from both categories are available in the web page of the GHG protocol. The tools are reviewed and updated periodically.

Table 3.2 presents different types of cross-methods that pulp and paper companies apply. In addition, the specific tools for pulp and paper sector are presented in Table 3.3.

Table 3.2 Cross-sector Tools for calculating GHG emissions. Source: Pulp and paper Tools [8]

CALCULATION TOOLS	MAIN FEATURES
Stationary Combustion	Calculates direct and indirect CO_2 emissions from fuel combustion in stationary equipment
	Provides three options for allocating GHG emissions from a cogeneration facility (*)
	Provides default fuel and national average electricity emission factors
Mobile Combustion	Calculates direct and indirect CO_2 emissions from fuel combustion in mobile sources
	Provides calculations and emission factors for road, air, water, and rail transport
HFC from Air Conditioning and Refrigeration Use	Calculates direct HFC emissions during manufacture, use and disposal of refrigeration and air-conditioning equipment in commercial applications
	Provides three calculation methodologies: a sales-based approach, a life cycle stage based approach, and an emission factor based approach
Measurement and Estimation Uncertainty for GHG Emissions	Introduces the fundamentals of uncertainty analysis and quantification
	Calculates statistical parameter uncertainties due to random errors related to calculation of GHG emissions
	Automates the aggregation steps involved in developing a basic uncertainty assessment for GHG inventory data

(*) Options are detailed in Chapter 6

Table 3.3 Specific tools for pulp and paper sector

CALCULATION TOOL	MAIN FEATURE
Pulp and paper	Calculates direct CO_2, CH_4 and N_2O emissions from production of pulp and paper. This includes calculation of direct and indirect CO_2 emissions from combustion of fossil fuels, bio-fuels and waste products in stationary equipment.

Nevertheless, companies can use their own calculation methods if they consider convenient and ensure consistency with the GHG Protocol Corporate Standards proposed.

3.2.3.6 Roll up data to corporate level

According to the protocol, two basic approaches can assist with transmission of GHG emissions from the company facilities to the managers in charge of the emissions management (the corporate level):

- Centralised: each level in charge from an individual facilities reports activity, quantity of fuel or electricity consumption to the corporate level. The corporate level applies tools to convert activity data into GHG emissions.
- Decentralised: each level in charge from an individual facility directly calculates its GHG emissions using verified methods and afterwards reported to the corporate level.

Both methods have advantages and disadvantages. On one hand, if emissions are standardised in many facilities, the centralized approach can be useful, especially in the case of an office-based organisation. On the other hand, if GHG emission calculations require a deep knowledge of the facility, decentralised roll up data is more suitable. However, some errors can be transmitted to the corporate level.

In any case, the two approaches can be combined together –some facilities with one approach and the others with the other one–, or even duplicated. In that case, corporation level needs to contrast reporting consistency.

3.2.4 Report

A public GHG emissions report that is in accordance with the *GHG Protocol Corporate Standard* [8] shall include the following information:

- Description of the company and the inventory boundary
- Information of the different type of emissions
- Reports containing project based reductions
- Definition and commitment of a reduction target
- Track and report progress and carry out different performance checks

3.2.4.1 Description of the company and inventory boundary

The introduction of the report should include a general introduction of the company and highlight the organizational and the operational boundaries. If scope 3 is included, the report should list the types of activities covered. It is also important to denote the reporting period covered.

3.2.4.2 Information on the different type of emissions

There is a large piece of information that should be given in order to assist the analysis of the emissions results. The strength concerns the following data:

- List of methodologies enabling the calculation or measuring of emissions, giving a reference or link to any calculation tool used.
- Total emissions from scope 1 and 2; data must be independent of any GHG trades i.e, purchases, sales or commercial transferes.
- Emissions data classified into each scope
- Emissions classified in six GHGs separately (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6)
- Total emissions with a neutral CO_2 origin, such as emissions from biomass or bio fuels combustion
- Indication of base year, including the justification of base year emissions recalculation due to modification of organizational boundaries, corrections or changes to calculation methods
- Exclusions of sources, operations or facilities, including justified reasons

3.2.4.3 Reporting project based reductions

The resulting reductions of an energy efficiency approach are usually included in their protocol inventory boundaries. However, in some cases companies target or consider reductions of emissions that are not contained in their protocol inventory scope or that are not assuming emissions changes over time. For example:

- A company installs an on-site CHP plant that supplies electricity to the company and an extra amount to other companies. Its direct emissions increase considerably while there is a displacement on purchased power from grid. In this case, any resulting emissions reductions at the plants where the grid electricity is generated will not be included in the inventory of the company (this is the case of Mill B, described in Chapter 7).

- A company substitutes a fossil fuel with a residual fuel that was formerly sent to landfill or to incineration without energy recovery. This change of fuel might not pose a direct effect on the company direct emissions. However, the change could result in emissions reductions in other activities.

3.2.4.4 Deciding target levels of reduction

Once the emissions are accounted and reported, the company can analyse results deeply. A target level of emission reduction can be defined after an accurate analysis of the data reported. To control the reduction targets, it is necessary to establish some indicators, such as the relationship between GHG emissions and other business variables such as shippable production.

3.2.4.5 Track and report progress and carry out regular performance checks

Obtaining an emissions account protocol involves economical and organizational efforts. Therefore, some report progress and periodical performance checks should be maintained in order to keep the credibility of the report and the reliability of the results. Additionally, to keep towards reducing measures, it should be formalised a relationship between the target and the annual GHG inventory. The corresponding checks of emissions in accordance with the target have to be reviewed.

3.3 SPECIFIC TOOLS FOR PULP AND PAPER INDUSTRY

3.3.1 Introduction

Table 3.3 presented the specific tool of pulp and paper sector recommended by the GHG general protocol. This tool and other particular information are also captured into the *Calculation Tools for Estimating Green House Gas emissions for pulp and Paper Mills* [8] from now on, pulp and paper tools. The pulp and paper tools gives technical support to technicians on emission calculation methods whereas the GHG protocol is much more addressed to corporate levels.

Figure 3.5 pictures the inventory strategy of direct and indirect emissions related to a pulp or paper mill. The authors of pulp and paper tools do not use the terminology of Scopes explicitly, although they distinguish between direct and indirect emissions, as detailed below.

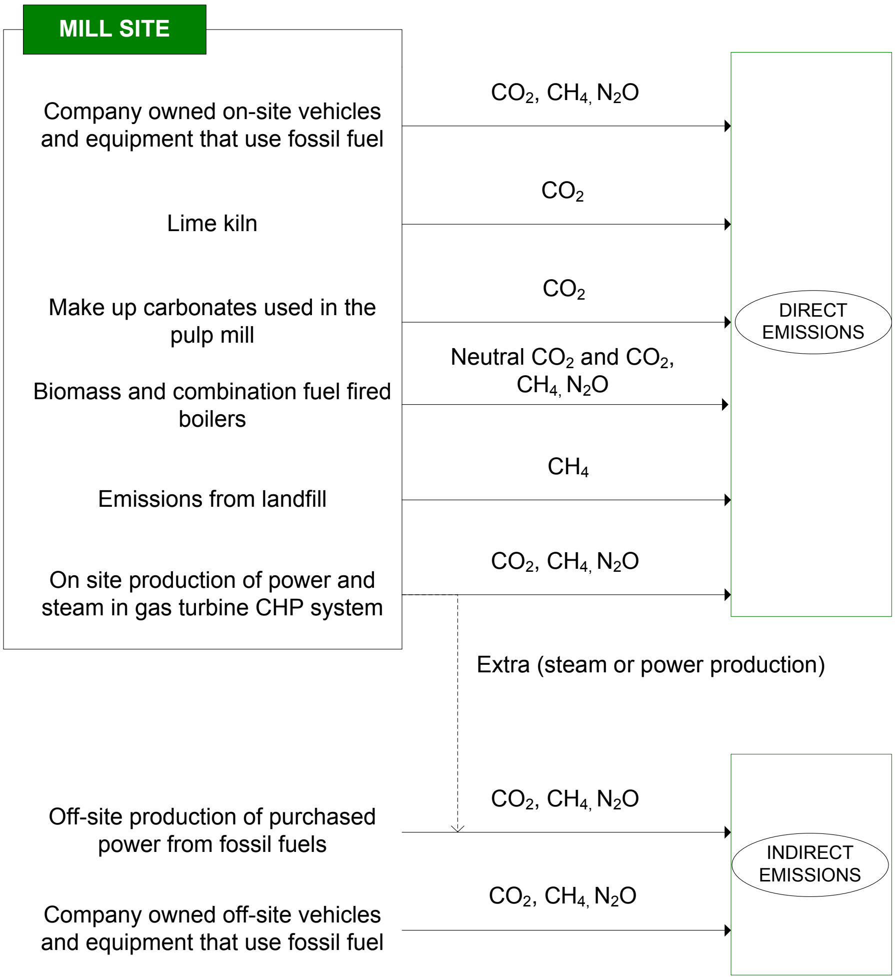

Figure 3.5 Inventory Strategy for Pulp and Paper Mills, GHG Emissions. Based on Pulp and paper tools Guide [8]

In a pulp or paper mill, GHG direct emissions are either associated with fossil fuel combustion in on-site operations –such as boilers and CHP plants– or with carbonate ($CaCO_3$ or Na_2CO_3) production process. In addition, methane is also a potential focus in mill landfills by decomposition of organic materials. The authors of this particular guide are also considering some emissions related to external transport of owned vehicles.

On the other hand, indirect emissions mainly derive from purchased electricity. If the mill has a CHP plant, which sells an extra amount of electricity to outside grid, this guide considers the share of exported electricity as indirect emissions.

Furthermore, as it can be checked in Figure 3.5 the authors of pulp and paper tools are not accounting for HFCs, PFCs, SF_6. They state that this kind of emissions is not found in pulp and paper mills.

At the same time, they consider CO_2 from biomass combustion as a different matter, since its neutral at effects of climate change.

Moving to a practical point of view, pulp and paper tools recommend and describe some methodologies to account for the emissions exposed on Figure 3.5. These methodologies include some of the mentioned crossed-tools of the GHG general protocol (common with other industrial sectors) and the specific for the sector.

- CO_2 emissions from fossil fuel combustion of stationary facilities
- GHG emissions associated with power and steam that is imported and consumed
- GHG emissions attributable to power and steam exports
- CH_4 and N_2O emissions from facilities firing fossil fuel, such as recovery boilers, biomass boilers, and lime kilns
- CO_2, CH_4, and N_2O emissions related to transport and mobile sources
- CH_4 emissions assigned to mill waste in landfills and anaerobic waste treatment systems
- CO_2 emissions from production of carbonates used in the pulp mill
- Fossil fuel-derived CO_2 exported to other precipitated calcium carbonate plants

The previous list takes into consideration methane and nitrous oxide emissions from landfills or fossil fuel combustion. Particularly in this last case, there is the possibility to ignore emissions because the quantity of them is too low. Thus, the concept of materiality appears. *Materiality refers to the significance of the difference between reported data and actual results obtained by a verifier or auditor* [5].

Pulp and Paper tools compile in Table 3.4 ranges of emission factors that might help to identify significant and insignificant sources of GHGs.

Furthermore, it has to be noted that emission factors bring in a certain grade of uncertainty. According to ISO 3534-1[9], uncertainty can be defined as the estimation added to a result of a measure that features the range of values wherein the correct value is included.

Table 3.5 presents the uncertainties related to direct emission factors defined by IPCC. Methane and nitrous oxide factors entail a high grade of uncertainty. The lowest uncertainty grade corresponds to energy emission factors related to CO_2 emissions.

Table 3.4 Emission Factor Ranges. Useful in Identifying Significant and Insignificant Sources of GHGs. Source: Pulp and Paper Tools [8]

EMISSION FACTORS				
FUEL	**FOSSIL CO_2**	**CH_4 (CO_2 equiv.)***	**N_2O (CO_2 equiv.)***	**UNITS**
Natural gas used in boilers	56.100 - 57.000	13 - 357	31 - 620	kg CO_2-equiv/TJ
Residual oil used in boilers	76.200 - 78.000	13 - 63	93 - 1.550	kg CO_2-equiv/TJ
Coal used in boilers	92.900 - 126.000	15 - 294	155 - 29.800 (1)	kg CO_2-equiv/TJ
Bark and wood waste fuel	0	< 21 - 860	< 310 - 8.060	kg CO_2-equiv/TJ
Blak liquor	0	42 - 630	1.550	kg CO_2-equiv/TJ
Lime liquor	depends on fuel	21 - 57	0 (2)	kg CO_2-equiv/TJ
Lime calciners	depends on fuel	22 - 57	1550 (3)	kg CO_2-equiv/TJ
Pulp mill make-up $CaCO_3$	440	0	0	kg CO_2 / $CaCO_3$
Pulp mill make-up Na_2CO_3	415	0	0	kg CO_2 / Na_2CO_3
Diesel fuel used in vehicles	74.000 - 75.300	82 - 231	620 - 9.770	kg CO_2-equiv/TJ
Gasoline in non-rad mobile sources and machinery -- 4-stroke engines	69.300 - 75.300	84 - 30.900	93 - 2.580	kg CO_2-equiv/TJ
Gasoline in non-rad mobile sources and machinery -- 2-stroke engines	69.300 - 75.300	9.860 - 162.000	124 - 861	kg CO_2-equiv/TJ
Anaerobic wastewater treatment	0	5,25 (4)	0	kg CO_2-equiv / kg COD treated
Mill solid waste landfills	0	3.500 (5)	0	kg CO_2-equiv / dry ton solid waste

* CO_2-equivalents are calculated from IPCC Global Warming Potentials (CH_4 = 21, N_2O = 310).
(1) Reported N_2O emission factors greater than 1500 kgCO_2-equiv./TJ are generally limited to fluidized bed boilers.
(2) IPCC information suggests N_2O is not likely to be formed in lime kilns in significant amounts.
(3) Amounts of N_2O, if any, formed in calciners are not known, so the largest factor for fuels normally used in kilns is shown in this table.
(4) Assumes no capture of gas from the treatment plant.
(5) Assumes that 50% of landfilled waste is degradable organic carbon, 50% of the degradable organic carbon degrades to gas, 50% of the carbon in the gas is contained in methane, none of the methane is oxidized in the landfill cover or captured, and all is released in the same year that the waste is landfilled.

Table 3.5 Related Uncertainties of Direct emission factors. Source: IPCC [10]

GAS	SOURCE CATEGORY	UNCERTAINTY DUE TO EMISSION FACTOR
CO_2	Energy	7%
	Industrial Processes	7%
	Land Use Change and Forrestry	33%
CH_4	Biomass Burning	50%
	Oil and Nat. Gas Activities	55%
	Rice cultivation	>60%
	Waste	>60%
	Animals	25%
	Animal waste	20%
N_20	Industrial Processes	35%
	Agricultural Soils	-
	Biomass Burning	-

Having analysed materiality and emission factor uncertainties, this work will basically focus on the tools related to CO_2 emissions from stationary and mobile fossil fuel combustion as well as CO_2 emissions of imported and exported heat and power generation.

3.3.2 GHG emissions from stationary fossil fuel combustion

According to specific pulp and paper tools, carbon dioxide emissions from stationary fossil fuel combustion are the main focus of GHG emissions for most pulp and paper mills. The estimation of this type of emissions is usually based on the carbon content or emission factors for all fossil fuels being burned.

Calculating emissions with the carbon content of the fuel and an oxidation factor –which indicates how complete the reaction is– becomes a common option. Another common alternative is to use an emission factor that converts the energy content of the fuel into emissions.

The usual data source for carbon content or emission factors for most of the mills is listed below:

- information concerning particular fuels used at the mill-site

- the most convenient data supplied by national authorities reports
- the most appropriate information from other scientific sources, such as the IPCC [11]

When calculating methane or nitrous oxide emissions, protocol recommends converting these emissions into tones of carbon dioxide equivalents. The conversion non-CO_2 gas to $CO_{2\text{-equi}}$ is done by means of the GWP (Global Warming Potential). Therefore, a tone of methane or nitrous oxide is equivalent to 21 tones and 310 tones of carbon dioxide, respectively.

3.4 CALCULATING EMISSIONS FROM FOSSIL FUEL COMBUSTION

A fossil fuel can be defined as a mix of hydrocarbons (some of them saturated) which contain some impurities related to elements such as sulphur (S), oxygen (O) or nitrogen (N). In an approaching situation, the empirical formula of a fossil fuel could be the following:

$$C_nH_mS_sN_xO_y \tag{3.1}$$

In a complete combustion of a fossil fuel, it takes place the following reaction:

$$C_nH_mS_sN_xO_y + kO_2 \rightarrow nCO_2 + \frac{m}{2}H_2O + sSO_2 + \frac{x}{2}N_2O_4 \tag{3.2}$$

Where k is defined as:

$$k = n + \frac{m}{4} + s + x - \frac{y}{2} \tag{3.3}$$

k represents the minimum amount of oxygen that should be provided to achieve a complete combustion.

As main reactants are carbon and hydrogen, the gases of the combustion process are carbon dioxide and water (usually water vapour). If the combustion agent is air, flue gases will have a substantial part of nitrogen and some argon.

Combustion of fossil fuel produces different type of pollutants and gases as well as some release of ash particles into the environment. Table 3.6 summarises some of the main pollutants that can appear in combustion of natural gas, fuel oil or coal. Not all pollutants are GHGs.

Table 3.6 Pollutants of fossil fuel combustion of natural gas, fuel oil and coal. Based on data supplied by IEA [12]

FUEL COMBUSTED POLLUTANT	**NATURAL GAS** $kgCO_2/MWh$	**FUEL OIL** $kgCO_2/MWh$	**COAL** $kgCO_2/MWh$
Carbon Dioxide	180,97	253,67	322,96
Carbon Monoxide	0,06	0,05	0,32
Nitrogen Oxides	0,14	0,69	0,71
Sulphur Dioxide	1,55E-03	1,74E+00	4,01
Particulates	1,08E-02	1,30E-01	4,24
Formaldehide	1,16E-03	3,40E-04	3,42E-04
Mercury	0,00	1,08E-05	2,47E-05

* No post combustion removal of pollutants. Bituminous coal burned in a spreader stoker is compared with fuel oil (Num.6) burned in an oil-fired utility boiler and natural gas burned in uncontrolled residential gas burners. Data supplied in HHV.

According to Table 3.6, coal and fuel oil are composed of much more complex molecules than natural gas. Both fuels have higher carbon ratio and higher nitrogen and sulphur contents. For this reason, coal and oil combustion release higher levels of carbon emissions, nitrogen oxides (NOx), and sulphur dioxide (SO_2). In addition, coal and fuel oil also release a relevant amount of ash particles into the environment.

Furthermore, NOx formation occurs by three main mechanisms. The first one derives from the thermal dissociation of N_2 and O_2. The second mechanism forms NOx from the primary reactions of N_2 molecules during the combustion of air and hydrocarbon radicals supplied by fuel. Finally yet importantly, principle mechanism that produces NOx is the combustion of slightly fuel-lean mixture that requires an excess of oxygen in the reaction chamber.

Besides reaction 3.2, other emissions can be released from prime-mover engines in the case the reaction is incomplete. For example, CO or volatile organic compounds (VOC) emissions are formed in incomplete combustion. CO arises when the residence time is too low at high temperature or when there is an incomplete mixing in the final stage of fuel oxidation. VOCs also result when some fuel remains unburned or partially burned.

However, not all these pollutants are GHGs. The main GHGs on fossil fuel combustion are CO_2, N_2O or CH_4. Methane is released in unburned fuel if the fuel is natural gas; meanwhile formation of N_2O during the combustion process is enhanced by a complex serial of reactions and depends on many factors. However, N_2O is minimised when the temperature of combustion is higher than 800 ºC.

3.4.1 Estimation of carbon dioxide emissions due to fossil fuel combustion

As introduced in paragraph 3.2.3.2, emissions can be determined directly or by calculation approach. By legislation, plants submitted to directive 1999/30/EC and directive 2000/69/EC must monitor air pollutants such as CO, NOx, SO_2, benzene and releasing ashes. However, CO_2 and the rest of GHGs are not included in this directive. As mentioned, as direct approach calculation can become extremely expensive, industries usually use a calculation approach method to determine its emissions.

For that reason, the most common calculations are based on energy units and conversion factors.

CO_2 emissions (E_{CO_2}) calculation approach is expressed with the following formula:

$$E_{CO_2} = \text{Activity Data} \cdot F_{CO_2} \cdot OF \tag{3.4}$$

Where

F_{CO_2} is the emission factor $[tCO_2/MWh]$. The emission factor can include the oxidation factor (OF), indicating this fact when needed.

Activity Data is the net energy content of fuel consumed [MWh], and it is defined as:

$$\text{Activity Data} = \text{Fuel Consumed} \cdot LHV \tag{3.5}$$

Where

Fuel consumed is expressed in terms of mass (m) or volume (V) [t or m^3]

LHV is the specific Low heat value of the fuel burned in [MWh/t] or [MWh/m^3]

Table 3.6 shows how for the same energy content, natural gas emits less carbon dioxide than fuel oil or coal.

To contrast fuel oil and natural gas emission factors presented in Table 3.6, it has been used some punctual analysis samples. A natural gas sample and a fuel oil sample have been used to calculate the emission factors according to stochiometric reactions and considering a complete combustion. Table 3.7 shows results of a punctual analysis of a Spanish natural gas sample, supplied on January 2007. In the same table, it is expressed the stochiometric relation of each of the natural gas compounds, as well as the amount of carbon dioxide per mol of natural gas, its specific low heat value and its molecular weigh (MW) according to the sample composition.

Table 3.7 Natural gas sample. Analysis and physical features. Spanish natural gas. January 2007

NATURAL GAS COMPOSITION (NG)			STOCHIOMETRY	MASS BALANCE
Compound		% (molar)	kmol comp./kmol CO_2	$kgCO_2/kmol_{NG}$
C_6H_{14}	Hexane and higher	0,0136	6	0,036
C_3H_8	Propane	1,2545	3	1,656
C_4H_{10}	Isobutane	0,0903	4	0,159
C_4H_{10}	Butane	0,1434	4	0,252
C_5H_{10}	Isopentane	0,0251	5	0,055
C_5H_{10}	Pentane	0,0184	5	0,040
N_2	Nitrogen	1,1388	-	-
CH_4	Metane	87,5557	1	38,525
CO_2	Carbon dioxide	1,4438	-	0,635
C_2H_6	Etane	8,3164	2	7,318
NG	Total	100	$kgCO_2/kmol_{NG}$	48,677
Specific low heat value [kWh/Nm^3]		10,636		

* NG abbreviates natural gas

According to data compiled in Table 3.7, Table 3.8 presents the natural gas emission factor of the above sample.

Table 3.8 Emission factor of a punctual sample of natural gas.

NATURAL GAS EMISSION FACTOR	
Molecular weight NG [kg/kmol]	18,189
Specific heat value [kWh/Nm^3]	10,636
Mass relation [$kgCO_2$/kgNG]	2,676
Specific density [$kgCO_2/m^3$]	2,173
NG emission factor [$kgCO_2$/kWh]	0,204

*NG abbreviates natural gas

The punctual emission factor is closer to the factor provided by IPCC [13] (0,202 $kgCO_2$/kWh), as the difference approaches 1,2%.

Following lines present similar calculations of the emission factor regarding a residual fuel oil used in a boiler house of a paper mill.

Fuel oil is a fraction obtained from petroleum distillation, made of long hydrocarbon chains, particularly alkanes, cycloalkanes and aromatics. The term fuel oil usually refers to the heaviest commercial fuel that can be obtained from crude oil, heavier than gasoline and naphtha. Table 3.9 shows results of a punctual sample of a residual fuel oil (RFO).

Table 3.9 Chemical and physical features and emission factor. Fuel Oil sample. Spain 2007

FUEL OIL CHEMICAL AND PHYSICAL FEATURES	
Compound	Composition % (mass)
Carbon	86,25
Hydrogen	11,03
Sulfur	2,2
Nytrogen	0,41
Ashes	0,08
Heavy metals [ppm]	0,76
Low Heat Value [kWh/kg]	11,15
Molecular Weight [kg/kmol]	190
FUEL OIL EMISSION FACTOR	
Stochiometry relation C/RFO	13,656
Mas relation $kgCO_2/kg_{RFO}$	3,163
Emission factor $kgCO_2/kWh$	0,281

Comparing this punctual RFO emission factor with the factor provided by IPCC (0,278 $kgCO_2/kWh$) [13], it can be seen both differ around 0,83%. Although it should be taken into account that RFO composition is more variable than natural gas.
In both cases, results seem to differ considerably from Table 3.6. However, it has to be taken into account that results are expressed in HHV.

3.4.2 Estimating GHG non-CO_2 emissions due to fossil combustion

European Union still has some uncertainties around the effect and the legal control of non-CO_2 gases [14].

EU states that the main potential reduction of N_2O emissions involves the nitric acid and adipic acid industries. However, emissions of N_2O in fossil combustion are still not clear and not yet legislated. The grade of uncertainty related to energy processes might also be a relevant decision factor.

In the case of methane, at current date there is no EU regulation regarding oil and gas production, transmission, distribution or use.

However, emissions of these non-CO_2 gases can be calculated using the same basis of formulas 3.4 and 3.5 as well as the emission factors and GWP supplied by IPCC.

For example, the annual emissions of the non-CO_2 gases produced in a gas fired turbine which burns 47.063.481 Nm^3 of natural gas are presented in formulas 3.6 and 3.7.

$$E_{CH_4} = V \cdot LHV \cdot F_{CH_4} = 1{,}1\,t\,CH_4 = 24\,tCO_{2\text{-eq}} \quad (3.6)$$

$$E_{N_2O} = V \cdot LHV \cdot F_{N_2O} = 0{,}18\,t\,N_2O = 57\,tCO_{2\text{-eq}} \quad (3.7)$$

This calculation is based on the following points:

- Natural gas LHV of 10,84 kWh/Nm^3
- IPCC estimates that natural gas combusted in a turbine has a methane emission factor of 0,6 $kgCH_4/TJ$ (0,00216 $kgCH_4/kWh$) and emission factor for nitrous oxide of 0,1 kgN_2O/TJ (0,0036 kgN_2O/kWh)
- GWP (CH_4) = 21 and GWP (N_2O) = 310

According to IPCC, data on nitrous oxide is very limited. As controlled and uncontrolled emissions are expected to have little effect on total GHG emissions, companies might use IPCC emission factors (assuming uncertainties) unless they research for other factors more suitable for their particular case.

3.4.3 Emissions associated with imported power

Most of the paper mills that purchase electricity, import it from the national grid. In this case, emissions (E_{CO_2}) are calculated using the following formula [8].

$$E_{CO_2} = P \cdot F_{CO_2} \tag{3.8}$$

Where P is the power purchased and F_{CO_2} is the power emission factor.

The government or the authorised organism should define grid power emission factor.

However, if the mill decides to calculate the factor itself, in chapter 6 is proposed a method to determine Grid Power Factor for a national grid or an alternative or independent grid system.

3.4.4 Emissions associated with steam and power generated in a CHP plant

Combined Heat and Power systems (CHP) are one of the most efficient forms of distributed generation [15]. CHP plants produce simultaneously useful thermal and power energy. Paragraph 4.2 (Energy generation in a paper mill) exemplifies and highlights some details of the main components of these cogeneration systems.

The allocation of emissions in cogeneration systems has concerned either researchers, companies or policy makers.

Some methods on emissions allocations have been published during the last few years. Rosen M. A. [16] has published a selection of most of them. In a CHP plant, the power generation process has not the same efficiency as the one involved in steam production. At the same time, the energy content of steam and power generation can be analysed by thermodynamic criteria or even with economical criteria. Rosen M. A. selects the following methods:

- *Allocation based on energy content of products*
- *Allocation based on exergy content of products*
- *Allocation based on economic value of products*
- *Allocation based on increase of fuel consumption towards electrical production*
- *Allocation based on increase of fuel consumption towards thermal energy generation*
- *Allocations based on shared emissions savings between electrical and thermal energy*
- *Allocation by agreement or other factors*

Although there are several methods for allocating greenhouse gas emissions in CHP plants, World Resources Institute WRI/WBCSD [17] highlights three methods:

- *Efficiency method*
- *Energy Content Method* (this is the equivalent to Allocation based on energy content of products)
- *Work Potential Method* (this is the equivalent to Allocation based on exergy content of products)

The authors of *Calculation Tools for Estimating Greenhouse Gas emissions from pulp and paper mills* [8], also outstand these three methodologies, although they feature the efficiency method in two different modalities:

- Simplified efficiency method
- Complete efficiency method

This work classifies the mentioned methods in two groups: a first group is based on efficiency concepts to separate emissions; meanwhile the second group uses thermodynamic criteria for the same purpose. Paragraph 6.2 describes the methodologies recommended by WRI/WBCSD and Rosen and applies them into a real case, discussing and comparing the obtained results.

3.4.5 Emissions from mobile sources

Both, pulp and paper specific tools and GHG tool for Calculating CO_2 emissions from mobile source [18] describe a method to calculate emissions related to different type of transports: road, rail, air or water transport.

Both tools present two potential methods based on the available data regarding to transport and fuel:

- Fuel-based Method: Calculations Based on Aggregated Fuel Consumption data. This method is essentially the same as the method to estimate GHG emissions from stationary combustion sources.

$$E_{CO_2} = V \cdot LHV \cdot F_{CO_2} \tag{3.9}$$

- Distance-based Method: Calculations Based on Distance Travelled and Distance-based Emission Factors

$$E_{CO_2} = D \cdot Ft_{CO_2} \tag{3.10}$$

Where D is the distance travelled and Ft_{CO_2} is the emission factor related to transport.

EPA [19] and IPPC [11] have published some tables of emission factors for a variety of mobile sources.

3.4.6 Landfills-related emissions

Landfills can release CH_4, CO_2 and N_2O. However, according to Pulp and paper tools, just CH_4 emissions from landfills should be taken into consideration; CO_2 from landfills has been formed from biomass –which is climate carbon neutral– and N_2O emissions are not appreciated, due to its low concentration.

Landfills can be equipped with gas collectors. If methane is usually combusted, the resulting carbon dioxide is considered neutral. In the case methane is not collected, USEPA [20] supplies an approximate methodology to calculate such emission focus.

3.4.7 Emissions from anaerobic regarding waste water treatment

As in the case of landfills, pulp and paper specific tools assume that methane needs to be accounted for emissions report. Moreover, this tools state that if methane is collected and burned afterwards, the carbon dioxide emitted –as a complete oxidation reaction– is carbon climate neutral.

In the case methane is released to the atmosphere, IPCC [21] presents a formula to estimate the methane emissions (E_{CH_4}) of systems that are not completely anaerobic.

$$E_{CH_4} = OC \cdot F_{CH_4} - B \qquad (3.11)$$

Where,

OC is BOD or COD of the input feed of the anaerobic system

F_{CH_4} is the emission factor. Default values are 0,25 kg CH_4/kg COD in the input feed or 0,6 kgCH_4/kg BOD in the same place.

B is the methane captured and burned determined on a site-specific basis. B term releases when the water treatment basis is prepared to retain part of the methane, [kg CH_4/year]

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4 PAPERMAKING PROCESS

4.1 INTRODUCTION

GHG Protocol described in paragraph 3.2, extensively details how to produce an emissions inventory and how to set the boundaries and the calculation basis to approach accurate reduction targets. As mentioned in Chapter 1, one of the objectives of this thesis is to propose a methodology to distribute emissions through out the paper process.

It is because of this intention, detailed knowledge of the paper mill process has to be acquired. This chapter overviews some basic information of how energy is obtained in paper mills and a general description of paper manufacturing processes, focused on an energy consumption point of view.

Paper mills manufacture different types of products. These products can be classified as:

- Newsprint
- Uncoated printing and writing papers
- Coated printing papers
- Packaging paper
- Packaging paper cardboards
- Liner and fluting
- Tissue
- Speciality Papers

As the practical cases of chapter 7 are printing and writing paper mills, this chapter explains the papermaking process with an approach to these paper grades, although most of the operations described are also applied to other types of paper production.

Finally, it summarises an additional general data on energy consumption in paper mills. This information can be a reference point when considering partial or a global consumption of a paper process. The energy data included in this chapter is published by International Energy Agency (IEA) [1], Centre Technique du Papier [2] and IPPC BREF [3], specific summary of BATs for pulp and paper sector [3].

To conclude, this chapter compiles its reference data on energy consumptions.

4.2 COVERING ENERGY DEMAND IN A PAPER MILL

Papermaking process has a high thermal and power demand profile. Paper mills have different options to ensure its energy requirements.

On one hand, paper mills can cover its energy requirements with single heat and power systems (SHP). This implies purchasing electricity from an external grid and producing steam in different stand-alone boiler units. Boilers are fired with different type of fuels, such as coal, biomass (black liquor or other type), fuel oil, gas-oil, LPG or natural gas. Thereby, fossil fuels or biomass are responsible for CO_2 emissions.

On the other hand, paper mills can also acquire electricity from a combined heat and power plant (CHP) –usually installed next to the mill. In addition, some mills can cover its energy demand using a combination of both systems.

Figure 4.1 depicts the advantage of CHP plant efficiency compared with single heat and power (SHP) system [4]. As shown in Figure 4.1, CHP system requires 100 units of primary energy to generate 30 units of electricity and 45 units of heat, while the same units of heat and electricity require 154 units of primary energy in a SHP system. With a reduction in primary energy consumption, CHP also includes environmental benefits [5]. For the same energy output, fewer emissions are produced.

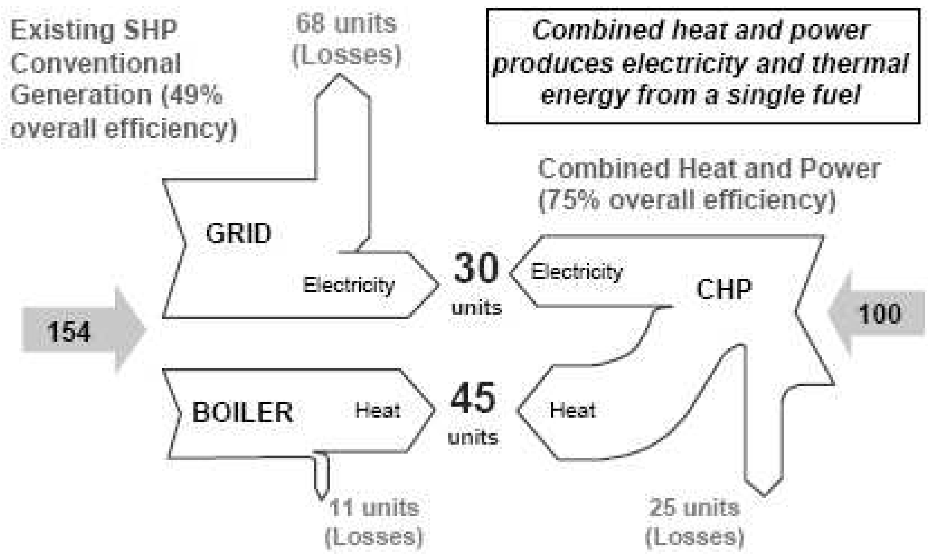

Figure 4.1 CHP versus Heat and Power Production. Source: Kaarsberg [4]

A range of technologies can be used for cogeneration. However, CHP systems consist of a number of standard facilities integrated together:

- prime mover (heat engine)
- generator
- heat recovery
- electrical interconnection

The most common prime movers are [6] reciprocating engines, gas-fired turbines and steam turbines.

- Reciprocating engines

  Reciprocating engines are internal combustion engines that have similarities with automobile engines. These systems have a high capacity of producing electrical energy (33% to 53%). However, it is difficult to recover the thermal output from them because it comes from two sources, the exhaust gas and the engine cooling system. On one hand, the exhaust gases can leave the engine at 400 ºC; on the other hand, the cooling system of the engine recovers heat with a low quality, often in form of hot water (below 90 ºC).

- Gas-fired turbines

  Gas combustion takes place in a combustion chamber at high-pressure conditions and with an excess of compressed air. The combusted gases expand through the gas turbine producing mechanical work; a generator converts this shaft work into electricity. The turbine exhaust gases have a high thermal energy potential (temperature ranges 450-550 ºC) and are often driven to a Heat Recovery Steam Generator (HRSG) which produces steam at high, medium or low-pressure conditions. Gas turbines have a power yield from around 24 to over 42%.

- Steam turbines: back pressure and condensing steam turbines

  A high pressure steam flow expands through a turbine to produce shaft work, which is recovered with an electric generator. Energy technology sector has developed two types of steam turbines: backpressure and condensing steam turbines. The first ones deliver a low or medium pressure steam stream used in different thermal applications. On the other hand, the condensing turbine exhausts steam at pressures lower than atmosphere. The exhausted steam is returned to the condensing line through a condenser. Condensing turbines can have intermediate processes of steam extractions. Condensing turbines have higher power efficiency than backpressure turbines.

In the specific case of pulp and paper sector, backpressure steam turbines are dimensioned according to the steam demand of the paper plant. Condensing turbines are more suitable for processes without thermal applications and with higher requirements on electricity production.

In addition, the energy market has developed alternative prime movers, such as micro turbines and fuel cells, both not feasible for pulp and paper industries, due to its insignificant power capacity. Micro turbines are small versions of gas turbine systems. They have a power range from 20 kWe to 200 kWe. Fuel cells convert the chemical energy of hydrogen and oxygen into electrical energy using an electrochemical reaction. Fuel cell can lead to hot water or steam and to a little amount of electricity.

- Single Cycle plants

The most simple cogeneration system consists of a stand-alone boiler followed by a backpressure steam turbine.

- Combined cycle plants

According to IEA [1], in pulp and paper sector, one of the most common types of CHP is composed by a gas turbine and a HRSG combined with a steam turbine.

Feeding fuel is burned in a simple cycle gas turbine to generate electrical power. Exhaust gases from the turbine still have an energy potential use. Heat exhaust gases are conducted into a HRSG.

The HRSG converts the energy content of the turbine exhaust gases into high-pressure steam. It is also possible to produce a reheated steam or to increase the amount of steam by producing an extra combustion (auxiliary burner) with the primary source fuel.

Moreover, if HRSG generates high-pressure steam, there is a possibility to deliver additional power using a steam turbine. If the mill requires steam at intermediate pressure, the steam turbine might be designed with an intermediate extraction for this purpose.

According to Strickland and Nyober [7], three main factors define a cogeneration system: the heat-to-power ratio, overall efficiency and the qualities of the heat output, described in Table 4.1.

Table 4.1 Main energy keys of different types of cogeneration systems. Source: Nyober [7]

COGENERATION SYSTEM	ELECTRICAL ENERGY OUTPUT % of fuel input	OVERALL EFFICIENCY %	HEAT TO POWER RATIO	THERMAL QUALITIES
Back-pressure steam turbine	14 - 28	84 - 92	4,0 - 14,3	High
Condensing steam turbine	22 - 40	60 - 80	2,0 - 10,0	High
Gas turbines	24 - 42	70 - 85	1,3 - 2,0	High
Reciprocating engine	33 - 53	75 - 85	0,5 - 2,5	Low
Combined cycle gas turbine	34 - 55	69 - 83	1,0 - 1,7	Medium
Fuel Cells	40 - 70	75 - 85	0,33 - 1	Full range
Microturbines	15 - 33	60 - 75	1,3 - 2,0	High

Aside from CHP efficiency advantages, supporters of CHP systems also conclude [6]:

- CHP can replace older, high emitting emission sources that would otherwise not be upgraded or retired.
- CHP plant can use as feeding energy several types of fuels, such as:
  - Natural gas
  - Coal
  - Fuel Oil
  - Synthesis gas
  - Biomass: black liquor or other type
  - Bio fuels: bio diesel, bio oil, bio ethanol, pyrolysis oil
  - Other alternative fuels to produce power or mechanical energy.

Energy related issues to cover mill energy demand

According to IEA, pulp and paper sector generates half of its energy needs with biomass residues and has extended experience on combined heat and power plants. The importance of energy generation with biomass residues derives from the raw material of pulp production (wood) and the black liquor as an intermediate product of the same process.

4.3 ENERGY INTENSITIES AND PAPER GRADE

Regarding to the documentation published by IPPC BREF [8], the European Integrated pollution and control bureau (IPPC) has published a method for different industrial activities (included pulp and paper) to control the main environmental parameters and approach the best available technology (BAT) for each activity. Figure 4.2 contains some of the focuses that IPPC treats when preventing and improving the environment in an industrial activity (including energy).

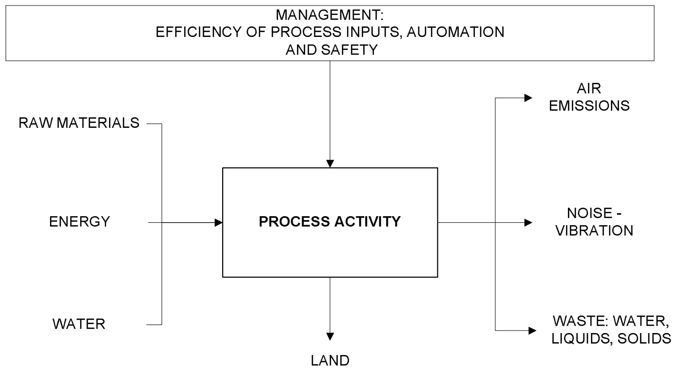

Figure 4.2 IPPC environmental issues according to a process activity

IPPC best available technologies are described by European BREF documents [9]. A BREF document is the result of an exchange of information between European member states and the industry. BREF documents contain a number of elements preceding the conclusions of what the best available techniques (BAT) are in a general sense for the sector referred. The definition of BAT includes intrinsically that the technique proposed can be reproduced in the specified sector and in the proper scale. In the majority of cases, BATs are based on real techniques applied to particular plants. IPPC has reported some representative energy data obtained from studies of Centre Technique du papier (CTP). Table 4.2 analyses the specific electricity consumption of mills that manufacture different types of paper.

The mentioned table specifies the energy consumptions of different type of integrated mills. The energy consumption includes all energy required inside the paper mill starting from pulp storage towers to finishing operations, except water treatment, which is not included. Multiply board and sack paper are the types of paper that have a higher ratio of specific power. On the other side, newsprint and the uncoated fine papers have a minimum low bound on specific power consumption. Tissue paper has a wide range of specific electricity consumption.

Table 4.2 Typical Specific electricity consumption for the production of different types of paper. Source: CTP [2]

PAPER TYPE	Power consumption [kWh/t]
Newsprint	500-650
LWC paper	550-800
SC paper	550-700
Fine paper (uncoated)	500-650
Fine paper (coated)	650-900
Multiply board	≈ 680
Sack paper	≈ 850
Linerboard	≈ 550
Tissue	500-3000

According to Tissue manufacturers, the new equipments for tissue production require higher energy consumption, allowing, on the other hand, a reduction of raw material needs. According to CTP, non-integrated paper mills should add to the specific power consumption, the specific consumption of pulping section (up to 60 kWh/t).

IPPC BREF has compiled heat and electricity consumption of an ideal mill, considering that this ideal mill is equipped with all the BATs. Table 4.3 depicts the energy consumption that should be achieved by different types of paper grades in the case their processes reach the top-level on energy efficiency.

Table 4.3 Energy consumption by BAT and type of paper. Source: Finish Federation [10]

TYPE OF PULP	HEAT [kWh/t]	ELECTRICITY [kWh/t]
Mechanical pulping	-	2083
Chemical pulping	3403	578
Waste paper pulp	139	100
De-inked waste paper pulp	556	450
Coated papers	1458	650
Folding boxboard	1425	800
Household and Sanitary paper	1425	1000
Newsprint	1050	600
Printing and writing paper	1458	500
Wrapping and packaging paper and board	1200	500
Paper and paperboard not elsewhere specified	1356	800

Although part of the paper sector is not yet achieving BATs requirements, IEA [1] states that the efficiency of heat consumption assumed real gains from 1990 to 2003. However, it remains a 14% of improvement potential. On the other hand, the efficiency of electricity consumption remained practically the same in the same period, and still has a 16% of improvement potential. In both cases, the range of improvement is based on the Best Available technologies compiled in the BREF [3].

4.4 PAPER PROCESS. GENERAL VIEW

Paper mills can carry on their manufacturing process separately from the pulp mill. This fact differentiates pulp mills and paper mills that operate in non-integrated mode from the integrated modes.

Papermaking process consists of general equipment and components, such as: pipelines, valves, motors, tanks, agitators, heat exchangers, rolls, wires, felts and particular paper facilities that will be listed in the following sections.

Each piece of equipment is made of components. The number of listed components for a paper machine line can be around 10.000, depending on the definition of a component [11].

In general terms, the primary materials for a manufacturing paper activity are:

- Pulp
- Water
- Fillers
- Chemical Additives

Different types of pulps can be mixed together in different rates in order to produce the required paper:

- hardwood pulp (HW)
- softwood pulp (SW)
- termomechanical pulp (TMP)
- postconsumer pulp: recycled pulp (RP) and de-inked (DIP) pulp
- broke
- pulp from annual plants

According to IPPC [3], almost all types of paper and board-making processes have the following basic units: stock preparation, approach flow system, paper or board machine for web formation and draining section, press section, drying section and finishing section. Figure 4.3 plots the mentioned unit operation sections.

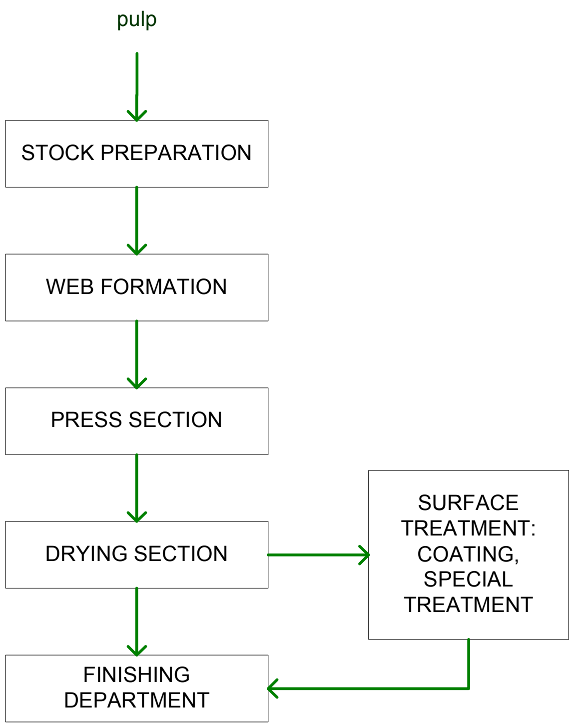

Figure 4.3 Main sections of a general papermaking process.

Depending on the paper and board grade, mills have additional units such as calanders, coaters with the corresponding coating kitchen, winders, rewinders or roll-wrapping stations.

Figure 4.3 shows a conceptual diagram of a general papermaking process. As mills have a variety of unit operations, the diagram might experiment some modifications. However, it shows in essence the structure of a papermaking process.

Regarding energy use, Table 4.4 compiles some indicative energy ratios of the main papermaking sections as well as some notes on energy saving potential in each section.

Table 4.4 Analysis of energy profile in different sections of a paper mill. Source: Centre technique du papier (CTP) [2]

MAIN PROCESSES	MAIN PROCESS UNITS	TYPE AN ROLE OF ENERGY IN EACH PROCESS
Stock preparation	Pulping	Up to 60 kWh power/t to break up dry pulp
	Cleaning Screening	The amount of pumping energy and stock heating depend on the number of stages required and the type of fibre (recycled fibre needs more than virgin); about 5 kWh/t is used for virgin stock
	Refining	Very energy intensive. Electrical energy is mostly used to drive the rotor in the refiner. Depends strongly on the paper properties to be achieved; 100 - 3000 kWh/t
Wet end	Forming and draining	It uses large amounts of electricity for machine drive and vacuum processes. Energy efficient design of the headbox and twin wire machine leads to power savings; About 70 kWh/t is used for vacuum systems (varies with grade and porosity)
Dry end	Pressing	It is not energy intensive in itself but efficient dewatering can give very large energy savings in the dryers
	Drying	Besides refining, it is the most energy intensive process in papermaking. Mostly heat energy
	Size press and 2nd dryer section	Heat energy for after size press drying
	Calendering	Electrical energy for machine drives and pressing
Coating	Coating and dryer	Electrical and heat energy for re-drying

Next paragraphs describe the main sections of papermaking process from an energy point of view.

4.5 STOCK PREPARATION AND APPROACH FLOW CIRCUIT

Stock preparation is the primary step of a paper making process. Stock preparation operations are responsible for preparing pulp (cellulose fibres) for paper web formation. Pulp is processed in pulpers and refiners as a previous stage of the approach flow circuit. In the case of an integrated mill, pulp is pumped directly from the pulp mill into the paper mill. This fact simplifies the stock preparation process and avoids the installation of additional pulpers.

Moreover, approach flow circuit is the circuit link-conveyor between stock preparation operations and the headbox of the paper machine. Figure 4.4 synthesises the stock preparation and approach flow circuit process and unit operations.

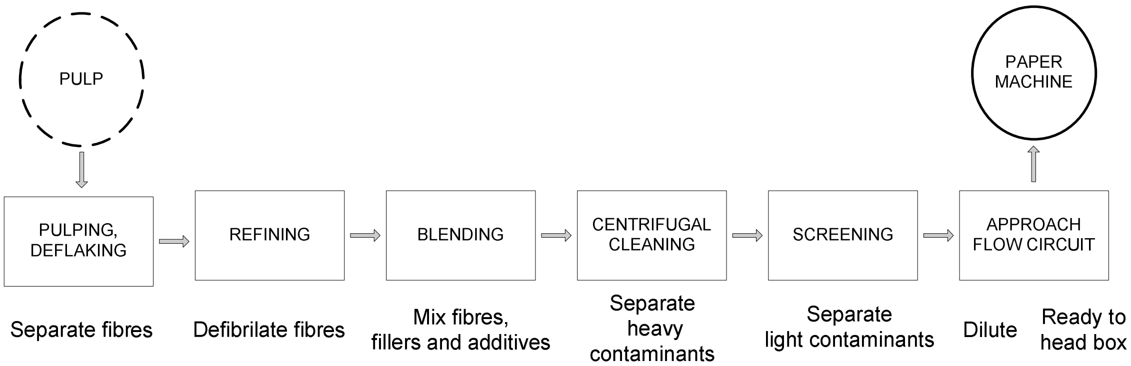

Figure 4.4 Stock preparation and approach flow circuit – unit operation sequences and related process.

The approach flow circuit is in charge of mixing the different fibres conditioned in stock preparation, diluting, adding fillers and chemicals to the fibre suspension, cleaning, aerating, screening and introducing the suspension obtained into the headbox of the paper machine [12].

4.5.1 Stock Preparation

The main unit operations of stock preparation process are pulping, deflaking and refining.

Pulping and deflaking operations facilitate the separation of pulp into individual fibres. Meanwhile, refining process is in charge of modifying the physical properties of the fibres. Each type or quality of paper needs a different grade of refining [13].

Raw materials

In a non-integrated paper mill, pulp comes in form of bales (dry pulp). Bales are thick sheets of paper (just pulp) which retain around a 10% of moisture to avoid fibres bonding between them or collapsing. As mentioned before, an integrated mill directly receives pulp through a water flow suspension (wet pulp).

Furthermore, broke is the additional material introduced in the stock preparation process. Broke is the formed paper that has been generated in the paper process and cannot be shipped to the customer. In a papermaking process, broke is produced at different sections of the mill. In a normal operation mode, broke is produced at the edge trimming on the wire section (wet broke) and at the winders (dry broke). Occasionally, broke can appear in web breaks and in finishing operations. According to IPPC, broke can become about 5-20% of the machine capacity production [3].

The different fibres are usually pulped and refined separately and then mixed together. The same occurs with broke. Figure 4.5 depicts a broke system of a paper mill that manufacturers coated and uncoated paper.

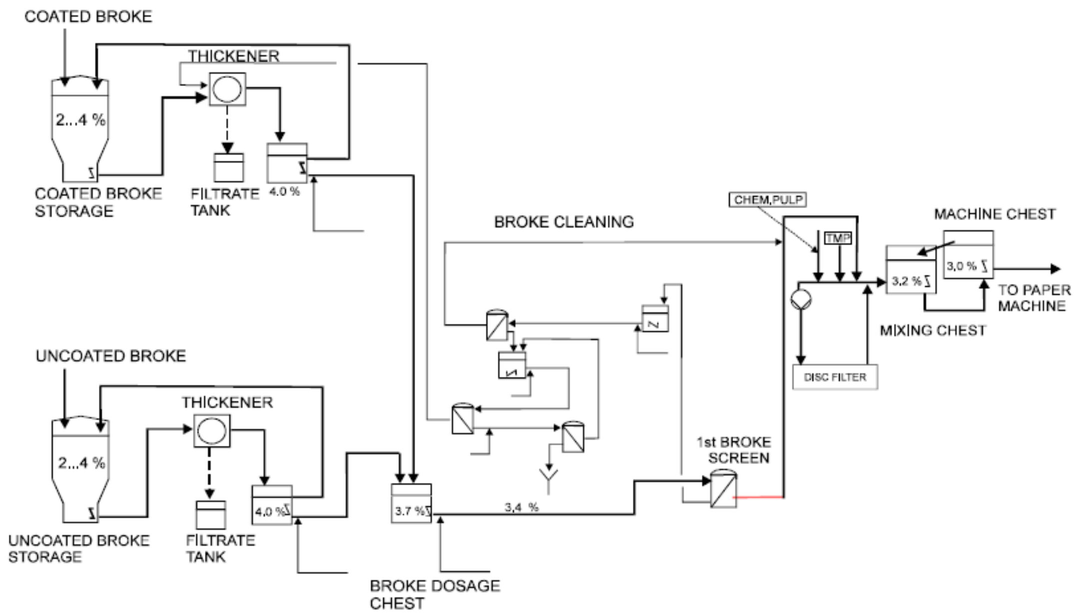

Figure 4.5 Broke system of a paper mill that manufacturers coated and uncoated paper. Broke is derived to thickeners, filters and screeners before reaching the mixing tank.

The main drives of broke systems are the pulpers, pumps and agitators.

4.5.1.1 Pulping and deflaking

Pulping or deflaking are operations prepared to separate fibres. In the case of pulping, wet or dry pulp, broke or postconsumer pulp is introduced into a pulper and diluted with water. A pulper is a large cylindrical vessel fitted with powerful large rotating blades in the bottom. The continuous contact of pulp suspension with its rotating blades produces the separation of pulp into flocks and individual fibres. This phenomenon gets a major grade of disintegration when particles of pulp hit between each other due to the differences of speed and circulation tracks. This situation is achieved at medium and high consistencies. To reach the complete separation of pulp into individual fibres, a great amount of energy is needed. Disintegrated pulp should leave the pulper with a consistency range of 6-12% (dry pulp weight).

Each pulper has its design features, mainly described by its volume capacity, power installed and kind of fibre to be disintegrated.

For instance, to disintegrate broke from wet resistance papers such as labels, it is needed a special pulper with helicoidal rotor with an additional input of hot water and chemicals. This type of pulper requires higher power to produce the same degree of disintegration than a conventional one.

Deflaking is another unit operation designed to separate fibres. A deflaker is a device formed by three cylindrical discs drilled with holes. The disc in the middle is a rotating disc (rotor) and the peripheral discs are static (stator). Pulp enters the deflaker centrally and flows through the holes of the discs and using centrifugal force pulp is conducted out of the deflaker completely disintegrated. A deflaker also prevents fibre plugging.

Broke fibres are not refined. After the pulping, they are conducted to the deflakers. There is no need to defibrillate broke because it has been refined at a previous stage.

4.5.1.2 Refining

Refiners are used to cut and fibrillate fibres by conducting them between the faces of grooved and rotating metal discs or cones. A refiner has similarities with a deflaker. A refiner uses static and dynamic discs or cones (rotor and stator) to modify fibre properties. These modifications consist of:

- Breaking the primary and secondary wall of the cellulose fibre
- Introduction of water inside the fibre
- Fibrillation of fibre (micro fibres are created on the fibre surface)
- Cutting the fibre into small fibres
- Production of fines (little particles and fibres from the fibre surface)

Some of these changes are not desirable. Besides, fibrillation and hydration of fibres favour a better union between themselves.

Refiners are larger purchasers of power energy [14]. To control a refiner, it is necessary to follow its energy demand, as well as the inlet and outlet pressure and the flow of the refined stream and the refiner grade (measured by Schopper-Riegler test).

When determining power consumption of a refining unit, it has to be taken into account the no-load energy. It is defined as the power consumed by the refiner with pulp stock flowing through the refiner when refiner tackles are not working.

4.5.2 Approach flow circuit

As mentioned, the treated fibres are mixed together in different tanks. The operation of mixing different types of fibres plus the addition of fillers and other chemical additives is basically named blending.

The headbox of the paper machine needs to receive pulp solution with a consistency below 1% and exempt of impurities. Because of that, white water from the paper machine is diluting the initial dry or wet pulp to reach the consistency required in the headbox. Afterwards, non-desirable particles have to be eliminated from pulp. There are different types of particle separators that can be used in stock preparation section, such as centrifugal cleaners or screeners.

4.5.2.1 Cleaning

Centrifugal cleaners are used to remove heavy particles. A centrifugal cleaner is a plastic or ceramic cone with two outputs, one at the bottom –to evacuate the rejected material– and another at the top –to get the cleaned material. Pulp is pushed into the cleaner. Using centrifugal forces, the impurities (heaviest materials) are driven to the internal surface of the cleaner and after that to the dejection part. To improve efficiency, various centrifugal cleaners are set together. The main energy purchaser of cleaning operation section is the pumping system.

4.5.2.2 Screening

Another usual unit for particle separation is the screener. Screeners are designed to separate light contaminants.

Up streams from the centrifugal cleaners are conducted to pressured screens. A screener is composed by a cylindrical vessel with metal rotating elements with holds or grooves.

In some cases, last bottom stream (final reject) from centrifugal cleaners is passed through flat screeners in order to recover the last part of fibre content. The stream is also forced to pass into the metal by pressure. Screen vibrations avoid fibres plugging. Heavy contaminants are sent as external reject.

Again, the main energy related issue in this unit operation is the pumping system.

4.5.3 Energy Related issues

According to IPPC, pulpers, pumps and refiners are the main purchasers of electricity. Occasionally some mills using recovered pulp, use heat or steam to separate some heavy impurities.

Following lines compile electricity intensities related to stock preparation operations of paper mills.

IPPC [3] estimates on 200 kWh/t the electricity consumption of the stock preparation section of a non-integrated coated paper mill with a product shipment of 125.000 t/y. The disintegration of pulp has been reported to consume an average of 60 kWh/t (in a non-integrated pulp mill).

Moreover, Table 4.5 presents the specific energy demand for new machine refiners per tone of refined pulp.

Table 4.5 Specific energy consumption for new machines at the refiners per tone of refined pulp. Source: BREF [3]

PULP GRADE	POWER CONSUMPTION [kWh/t]
De-inked pulp	30 - 70
Long fibre (bleached)	100 - 200
Short fibre (bleached)	50 - 100
Long fibre (unbleached)	150 - 300
Short fibre (unbleached)	100 - 150

Manufacturing of pulp is not included in these figures; the higher end of the range refers to lower Canadian Standard Freeness levels. The current power consumed per tonne of end-product depends on the amount of refined pulp used per tonne of end-product (if e.g. only 30% of refined pulp is required the values have to be multiplied by 0.3)

De-inked pulp is the lowest energy purchaser, after bleached and unbleached pulp. Bleaching process modifies the physical properties of fibre (usually by chemical oxidation) and makes it degraded and easier to refiner. In both cases –bleached or unbleached fibre– short fibre requires less electricity for refining than long fibre.

Furthermore, Centre technique du Papier (CTP) has published the range of electricity demand of different refining papers (see Table 4.6). This table notes that energy consumption is directly proportional to the grade of refining.

For example, tissue papers are papers with no need of resistance; consequently, tissue can be produced with a low grade of refining at lower energy consumption. On the other hand, printing and writing papers require higher grades of refining, to ensure enough resistance and avoid breaks when wheeling or printing the paper in high speed paper machines.

Moreover, carbonless paper is used by the newsprint industry; it is a paper with low weight and high resistance, produced with high content of large fibres. As the printing systems are operating at high speed, paper suffers different types of wheels and rewinds. Therefore, carbonless paper needs to prove its resistance with an upper grade of refining. Furthermore, glassine and greaseproof papers have certain grade of transparency. The transparency is achieved with a major grade of refining. A similar case occurs with the tracing papers, where the opacity needs to be ensured with a high refiner grade. The air entrapped between fibres of the tracing paper makes it opaque and look white. If the fibres are enough defined or beaten, all air is taken out and the resulting paper becomes translucent.

Table 4.6 Electricity demand in the refiners of different types of paper. Source: Centre technique du papier [2]

TYPE OF PAPER	GROSS ENERGY [kWh/t]	NET ENERGY [kWh/t]
Tissue	up to 100	-
Printing and writing	90-300	60-100
Carbonless paper	250-500	150-200
Glassine/greaseproof paper	600-1000	450-600
Tracing paper	1600-3000	800-1200

In addition, BREF document reports a range of energy intensities of the approach flow circuit section, distinguishing between fast and slow paper machines (Table 4.7).

Table 4.7 Range of electricity demand of the approach flow circuit of a paper mill. Source: BREF [3]

TYPE OF MACHINE	POWER CONSUMPTION [kWh/t]
Fast machines (> 1300 m/min.)	80 - 120
Slow machines	60 - 100

* The approach flow circuit requires less electricity in the slow machines because the power capacity of pumping system might be lower. Actually, head box feed pump energy increases in the third power when PM speed is increased.

Furthermore, Table 4.8 presents the electricity consumption of stock preparation units excluding pulpers and refiners. Note that the broke pulping system is the largest purchaser of electricity, followed by the pulping circuit of dry pulp conditioning.

Table 4.8 Typical specific energy consumption at stock preparation and white water systems per tonne of paper (refiners, pulpers and approach flow circuit are excluded). Source: BREF [3]

TYPE OF PROCESS	POWER CONSUMPTION [kWh/t]	REMARKS
White water system	20 - 30	Water storage towers, chests, pumps
Broke system	40 - 60	Broke tower, broke screens, tanks and pumps
Mixing	10 -15	Mixing chest, machine chest, pumps and agitators
Bale pulping (only for non-integr. mills)	25 - 40	Bale pulpers and conveyors, tanks and pumps
Pulp dosing (integr.)	5 - 10	Pulp line from storage to mixing chest; tanks, pumps
PM showers	5 - 10	PM shower water system consisting of pumps, filters, screens
Total	70 - 120	

Moreover, IPPC reports in Table 4.9 the BATs energy intensity values of stock preparation section.

Table 4.9 Specific energy demand – BATs of stock preparation section. Source: IPPC BREF [3]

UNIT PROCESS	SPECIF. ENERGY DEMAND [kWh/t]	OPERATING CONSISTENCY [%]
Pulping	10-20	3 - 6
Deflaking	20 - 60	3 - 6
Screening	5 - 20	0,5 - 4,0
Tail Screening	20 - 40	1 - 4
Centrifugal Cleaning	4 - 8	< 0,5 → 4,5 (< 6,0)
Fractionation	5 - 20	3 - 4
Thickening	1 - 10	0,5 → 5 (10)
Dewatering (Screw Press)	10 - 15	2 - 5 → 15 - 50
Dewatering (Double Wire Press)	2 - 4	2 - 5 → 15 - 50
Disperging	30 - 80	22 - 32
Low-Consistency Refining	5 - 25 (per SR* unit)	3,0 - 5,5
High-Consistency Refining	10 - 60 (per SR* unit)	25 - 35
Washing	5 - 20	0,7 - 1,4 → 5 - 12
Dissolved Air Flotation (DAF)	10 - 20	< 0,3 → 0,01
Storing	0,02 - 0,1	3,0 - 5,5 (12)
Mixing	0,2 - 0,5	3,5 - 4,5

*SR Schopper-Riegler freeness

→ Change of consistency range between inlet and outlet of the equipment concerned

Due to the own definition of BAT, specific energy demand of the different sections is lower than the conventional cases exposed in the previous tables.

4.6 PAPERMAKING PROCESS

The simplest description of paper manufacturing process consists of mixing, draining, pressing and drying.

Mixing comprises operations to liberate and prepare fibres, these are stock preparation and approach flow circuit. Draining involves web-forming equipment and pressing concerns consolidation of the web. Finally, the drying process ensures a correct water removal [15].

The first set of operations related to mixing stage has already been described. The rest of the stages are described below.

4.6.1 Web formation: paper machine (wet section)

One of the main sections in the paper making process is the sheet formation. Fibres are bonded between each other in order to form a sheet. This process takes place in the paper machine. The most common paper machine is the Fourdrinier machine, named from their inventors who improved the patented machine of Louis Robert in 1799.

Pulp dilution –from stock preparation section– reaches the headbox of the paper machine. This facility is prepared to distribute with accuracy and uniformity the pulp dilution across the wire of the paper machine, adapting its modus operandi to the machine speed and to the thickness of the paper desired. For that purpose, the headbox is equipped with a slice [12].

The wire consists of belt made of plastic materials in several layers that assists the drainage. Foils and vacufoils help to remove water and also to maintain the wire at place. After vacufoils, paper machine is usually equipped with a dandy roll, used for water evacuation and for unifying web properties. Second units to remove water are the suction boxes, and at the end of the Fourdrinier table is situated a coach roll that uses two levels of vacuum (high and low) with a suction quadrant. The drainage units are assisted by a system of vacuum pumps. Some paper machines have double wire, or forming rolls in order to produce two different layers (test liner, board paper). In other occasions, paper machines have top formers (suctioning rolls at the top side) to enhance uniformity on both sides of the web. Figure 4.6 shows some of the elements that form part of the Fourdrinier table. At the end of the table, the web has about a 20 % of dryness.

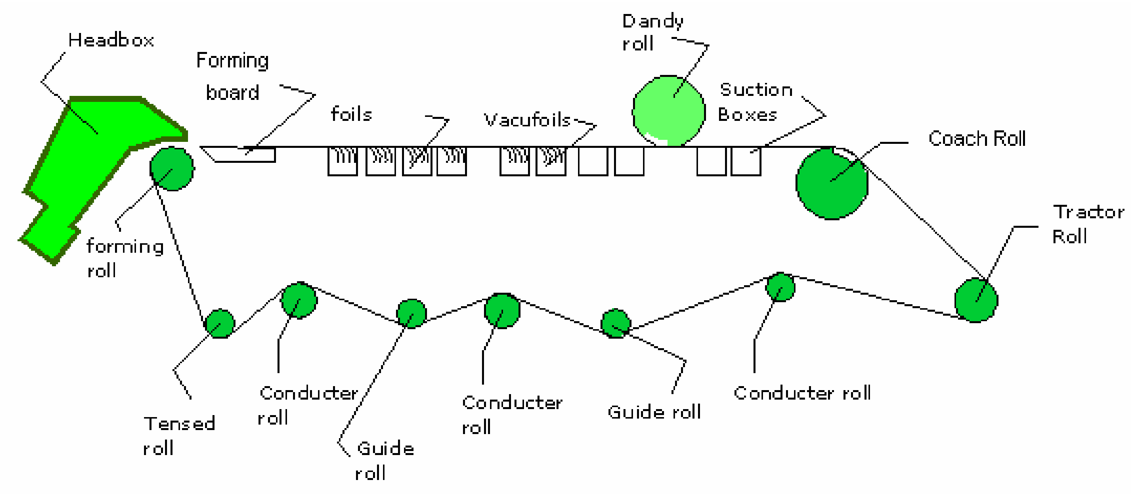

Figure 4.6 Elements of a Fourdrinier table

Occasionally, to favour the pressing process, the web receives a previous injection of direct steam through steam boxes.

The paper sector has other types of web forming tables, such as the cylindrical table or the double caped table.

4.6.2 Vacuum System

The paper machine draining units –vacufoils, suction boxes and suction quadrants– require an efficient vacuum level in order to remove water and consolidate the web.

Vacuum system is usually composed of different vacuum liquid ring pumps. Figure 4.7 shows a vacuum pump of a paper mill.

Figure 4.7 Vacuum pump in a paper mill

Frequently, vacuum system is composed of vacuum pumps working at low and high vacuum levels. Some of the paper machine units such as the coach roll and the pick-up roll operate with the two vacuum levels.

4.6.3 Press section

The already formed web is derived to the press section. In this section water is evacuated by mechanical work. Mechanical forces of two rolls against the paper not only remove water but also contribute to its consolidation. At the end of the press section, the paper sheet should have a 40-50% of dryness. The efficiency of the press section will minimise the steam demand on the next section: the drying section.

A low speed machine can transfer directly the sheet from the wet end to the press section. However, paper machines operating at high speed, need a first unit of press rolls known as pick up. Pick up roll helps to carry out the web from the paper machine into the press section. Press rolls squeeze the web and absorb water with felts. If the manufacturing process runs at high speed, the press rolls might not be able to remove water from the felt and water can remain accumulated in the web. Some of the press-rolls have suction quadrants to mitigate the effect of the speed [16]. Furthermore, in the last decades, paper mills have started to incorporate shoe press systems. A shoe-press is an optimised roll that increases area of pressure between rolls (the nip) –with a subsequent dryness effect. The shoe press improves smoothness and the double-face effect; in addition, it allows a quick response to machine speed variations.

4.6.4 Drying section

Press section is followed by drying section. Heat transfer is used then to eliminate water from the paper web. While increasing web temperature, water is evaporated in a short period.

Mills apply different techniques to dry the web, according to the type of paper produced. The most common techniques are [12]:

- cylinder dryers
- infrared dryers (gas and electricity)
- air dryers (injection of hot air through the web or air impingement drying; usually in tissue paper mill)
- injection of hot air to the face of the paper web (air flotation)
- yankee roll system (special paper)

Following lines are briefly describing cylinders, IR and air flotation dryers as those are common in printing and writing paper processes.

Drying cylinders

Drying cylinders are commonly used in fine paper mills. The web is introduced between them. These drying cylinders dry the paper web by heat transfer; the heat transfer derives to condensed water, which is returned to the circuit using a siphon extraction.

Paper technology sector has developed different techniques to improve the transference of energy from the cylinder to the web [17]. For example, companies are investing in new designs of breaking bars and siphon steam extractions. Steam flows through the drying cylinder and when condensing it has to be removed. At higher machine speeds, the thickness of the condensate rim determines the heat transfer rates for drying. The lower the rim thickness, the higher the heat transfer rates and lower the steam consumption.

In modern paper machines, steam and condensate systems are prepared with a variety of control drying systems, such as cascade systems, thermocompressor systems and flow control systems. They should be designed for maximum energy efficiency, that is, the correct amount and quality of steam input flow should be adjusted to steam transfer in order to minimise the steam blow-through. Moreover, the blow-through should be reused in the process wherever is possible. Experts state that steam condensers should only be used when no other alternatives are available, and systems should be redesigned to reuse the condensate [18].

In the drying section, the web is accompanied by drying felts, commonly named fabrics. This fabric does not absorb water; instead, it presses the web against the cylinders, to facilitate water evaporation.

Infrared radiation groups (IRs)

These types of dryers are usually used to increase the dryness of coating layers. IR dryers are usually fired with gas, although they can either run with electricity. The IRs heat a mesh at a temperature above 1000 -1100 ºC. The mesh has low inertia, something useful in order to control the drying. The water removed and evaporated is extracted quickly through an air flow. The IR dryers that operate with electricity contribute with better moisture profile to the web.

Air flotation dryers

This type of air dryers are equipped with air jets or air cushions that maintain the web stability and provide an efficient heat transfer. Jets are located at two sides of the web. The temperature of operation of this type of dryers is under the evaporation temperature; this fact facilitates the control dimension stability and fibre rising.

New technologies have developed a combined system of IR and air dryers, to join the advantages of the two systems. Table 4.10 compares the energy efficiency ranges of the mentioned systems as well as exposes the advantages, disadvantages and suitability of each type of dryer.

Table 4.10 Comparison of different type of dryers. Source: Fiber and paper [19]

DRYER	RANGE OF EFFICIENCY	POWER CONSUMPTION	MAX. POWER TO THE WEB (LWC)	TARGET	DISADVANTAGE	ADVANTAGE
type	%	kW/m^2	kW/m^2			
Gas IR	30-40	210	70	moisture profiling	Fires, high web Temperature	Profiling
Electrical IR	25-35	310	90	moisture profiling	Fires, high web Temperature	Good profiling
Combined IR + air	30-45	200	80	drying of size and coating	High web Temperature	Better than IR
Air dryer	60-75	110	80	drying of size and coating	Space requirements (two sideness)	Economy, low web temperature
Cylinders	50-70	15 (coat) 45 (size)	10 (coat) 30 (size)	drying of size and tension control	Poor heat transfer todry web, slow control	Economy, tension control

* LWC abbreviates light weight coated paper

As seen in Table 4.10, drying cylinders present different power consumption and maximum power transfer acceptance according to the type of paper that are drying. The moisture content of the web influences the heat transfer. Therefore, drying cylinders are more effective when drying sized paper, as the coated papers have a dry coating layer that insulates the hot cylinder surface from the moist base to be dried.

Hoods

Drying sections are equipped with a hood that is prepared to remove the saturated air from the drying section. Mills might have installed different types of hoods: open or closed hoods, although at current dates open hoods have mostly disappeared. A closed hood recovers part of the air flow heat content through a heat exchanger. In some occasions, the recovered heat is used to condition the building as well as to avoid condensations on the top of the drying section [20].

4.6.5 Surface treatment

Sizing

In some mills, to improve water repellence and to prepare the paper web for a coating process, a layer of chemicals is applied after the drying section. For this purpose, it can be used a water-starch solution or a coating preparation. Size-press (starch) or sizers (pre-coat) are the main devices used for sizing. A second group of drying cylinder dries the starch or the coat layer applied afterwards. Infrared Radiation (IR) units can also be used. Figure 4.8 plots a paper machine line where the web obtained receives a surface treatment with a size-press.

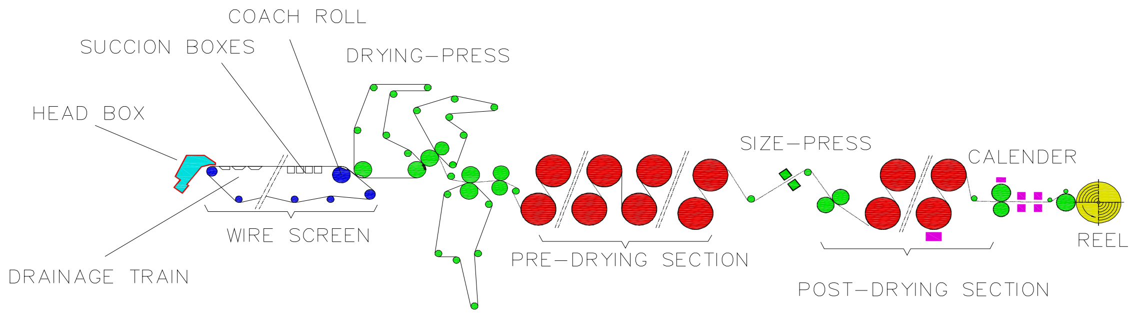

Figure 4.8 Paper making process with a pre-coating treatment. The precoating layer is supplied by a size-press system. Drying cylinders follow the precoating.

In the case of Figure 4.8, at the dry end of the paper machine, just before the reel, there is a calender; the smoothness of the paper surface is adjusted and fine-tuned. Sometimes this calender is heated with steam to improve the web smoothness. This operation prepares the web surface for a next coating machine section. The reel –at the end of the paper machine– winds the paper into a roll. When this roll has arrived to the desired level of diameter, it is changed for another roll automatically. The rolled paper is sent to a coating machine or is directly conducted towards the finishing section.

Coating

Coating is a type of surface treatment [15], where pigments and adhesives are applied to the paper sheet or web. The basic pigments are usually the same added as fillers: calcium carbonate and clay, mainly. These substances have a smaller size than fibres; therefore, the coating process creates a smooth sheet, with a finer pore structure.

The coating process can be integrated in the paper manufacturing process (on-line coating machine), after the sheet formation. However, this process might exist separately, using an off-line coating machine. In both cases, the process follows the following steps:

- Coating application. There are several methods, such as roll coater, blade coaters, mixed systems (roll and blade) coater.

- Coating drying, which comprises:

- Infrared Radiation drying (gas or electrical)
- Air dryers
- Drying cylinders

The coating layer is usually prepared in the coating kitchen. Each mill has its own units to prepare the colour coating. Nevertheless, the kitchen is commonly composed of basic storage tanks, mixed and heated tanks, filter units, pumps and agitators. Figure 4.9 depicts an off-line coating flow diagram.

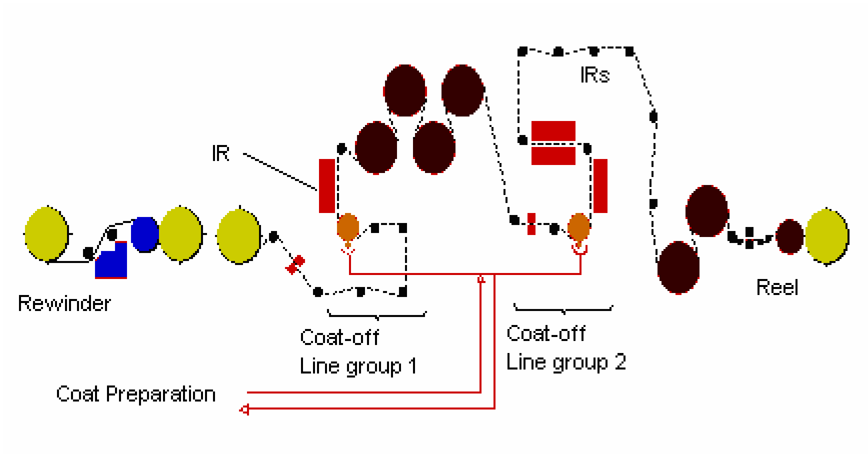

Figure 4.9 Off-line coating process

The coated sheet will be smoother than the uncoated web. For some higher printing requirements, gloss of the coated paper has to be improved. For this purpose it is used a matt-on-line. Sheet is passed through steel and synthetic rolls with one or two nips.

4.6.6 Energy-related issues

With this general approach to the paper machine and coating machine section, it can be deduced that both sections need a considerable quantity of electricity and steam.

Process energy consumption of the paper machine are associated with:

- Pumps as fluid conveyors
- Motor drives of all type of rolls, cylinders, calenders, reels and rewinders
- Vacuum Circuit
- Infrared Equipment –sizer (fed by power energy)

According to Cos [21], the vacuum system is one of the larger electricity consumers inside a paper mill. It is difficult to detect dis-functionalities of a vacuum system because –providing it does not give the necessary vacuum– it is not often taken into consideration. Some of the vacuum systems are over-dimensioned or work at maximum levels with no need. Table 4.11 reports energy intensities of the vacuum system according to the speed of the paper machine.

Table 4.11 Vacuum specific electricity demand of different type of paper machines

TYPE OF MACHINE	POWER CONSUMPTION [kWh/t]
Fast machines (> 1300 m/min.)	70-110
Slow machines	80-120

The specific electricity demand concerning speed of paper machine could bring in some controversy. In fast speed machines, the vacuum system needs higher capacity (and higher electricity consumption) to evacuate water. However, fast machines have a larger production, and a lower specific consumption.

As in the paper machine, the coating machine demands electricity in:

- Pumps to produce and transport coat materials
- Motor drives of all type of rolls, cylinders, calenders, reels and rewinders
- Infrared Radiation (fed by electricity)

Finally, the drying section requests a huge quantity of steam. Steam is needed in paper machine and coating machine as detailed:

- paper machine (occasionally steam direct injection)
- the calender of the paper machine
- the size press
- the drying cylinders
- coating Kitchen
- some other particular auxiliaries

Moreover, natural gas can be burned in the infrared dryer units. In addition, gas can be used to heat process air flows.

To quantify the energy consumptions of both sections, BREF reports in Table 4.12 a representative range of power intensities regarding paper machine unit operations.

Table 4.12 shows how paper machine drives and calenders are larger electricity purchasers.

Table 4.12 Typical energy consumption in paper machine drives. Source: BREF [3]

PAPER MACHINE DRIVES		
TYPE OF PROCESS	**POWER CONSUMPTION** [kWh/t]	**REMARKS**
Paper machine	80-140	(1)
Ventilation, PM	40 - 60	(2)
Ventilation	50 - 80	(3)
Steam and condensates	5 - 10	(4)
Lubrication and hydraulic pumps	15 - 40	(5)
Coaters	15 - 25	
Calanders	100 - 120	
Winders	5 - 10	
Finishing	10 - 15	
Chemicals	5 - 50	(6)

(1) Paper machine drives, former, press, dryer, sizer, reel
(2) Hood air supply, hood air exhaust, air to runability components, wet end ventilation, machine room ventilation, fans and pumps
(3) All equipment after the reel (e.g. coating, calendering, winding area, etc.)
(4) Condensate and vacuum pumps
(5) Lubrication units and hydraulic pumps
(6) Chemical mixer, feed pumps, screens

Both sections are equipped with a considerable number of mechanical rolls drives.

4.7 FINISHING DEPARTMENT

Finishing department comprises last conversion operations of the paper as end-product. In some mills, papers receive special treatment, such as a gloss enhance. For that purpose, paper mills are equipped with supercalenders. Some of the rolls of this unit are steel or filled rolls and these units are designed for 4 to 6 nips.

The rolls produced on the paper or coating machine are rewound and converted in smaller size rolls. The rolls are then introduced into sheeters to get the desired size. Other machines automatically wrap desired sized paper and pack into shipping units. To protect paper products from humidity, packs are retractiled with a plastic material using ovens usually fed by gas or power.

Figure 4.10 plots some of the utilities used in this last step of paper manufacturing.

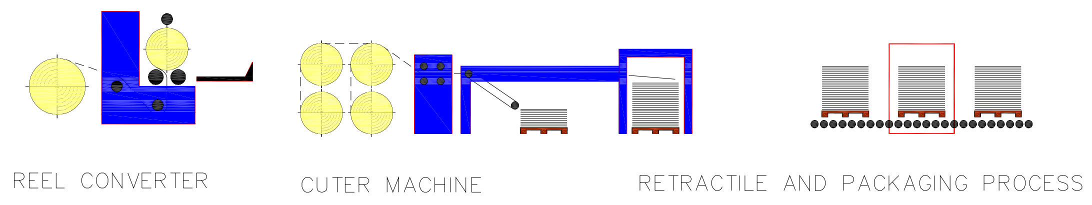

Figure 4.10 Converting section unit operations

In the finishing section, the consumption of energy is mainly attributed to electricity demand. Table 4.12 approaches a range of 10-15 kWh/t of electricity consumption in this section.

4.8 AUXILIARIES

General auxiliaries are commonly playing a global service role through out the paper manufacturing process. These activities can comprise unit operations such as water treatment, steam generation, compressed air system or lighting system.

4.8.1 Water treatment system

A mill usually recovers most of the water (around a 90%) and returns it to the process. However, a 10% of rejects is produced. Therefore, the rejected stream needs to be treated before returned to the environment (usually the river). Furthermore, papermaking process needs different types of water qualities, such as demineralised water to maintain steam and condensates circuit in the right conditions.

From an energy point of view, the water treatment system consumes electricity in pumping and agitating. From an emission point of view, some mills might have installed a microbiological treatment. If this treatment is driven under anaerobic conditions, methane (GHG) can be emitted to the atmosphere (unless it is recovered).

4.8.2 Compressed air system

Compressed air service is used in some standard instrumentation systems of the mill such as valves and regulators. Additionally, compressed air might be required as a conveyor agent, to drive the web from the wet end of the paper machine to the press section.

Compressed air system consists of air compressors and air treatment systems such as water removal and cooling. Air compressors are one of the common auxiliary units that have large electricity consumption, not only at paper mills context but also at the majority of industrial activities.

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5 ALLOCATION METHOD IN PAPER MANUFACTURING PROCESS

5.1 INTRODUCTION

As exposed in Chapter 1, this work proposes a method to allocate emissions through out the paper process in order to achieve an accurate emission management system. From now on, this method is named Allocation Method (AM).

The AM aims to improve the GHG emissions protocol exposed in paragraph 3.2. The improvement is based on a gradual attribution of GHG emissions to the paper manufacturing facilities.

First of all, the AM allocates emissions by end-use such as steam generation, direct gas combustion, power consumption, raw material production or internal transport.

Secondly, emissions are gradually distributed through out the process according to production lines, sections, unit operation and devices. This chapter details and develops the AM according to this gradual allocation.

Nevertheless, the AM success depends on the capacity of data acquisition. Therefore, the metering capacity –particularly the energy metering– becomes an essential step towards an accurate AM application result.

Regarding the metering capacity, this chapter includes a description of some general instruments suitable for the AM appliance. Most of them are frequently used in energy assessment projects.

Finally, results implicitly involve a certain grade of uncertainty. For that reason, a definition of the related uncertainties and its categories, as well as the most frequent uncertainties related to metering instruments, is comprised in this chapter.

5.2 DESCRIPTION OF THE ALLOCATION METHOD

The allocation method aims to achieve the following targets:

- To unify concepts, estimations and calculations concerning GHG emissions.
- To systematise and optimise the energy and GHG emission management of each mill.

- To set reliable results for a successful analysis assessment in terms of energy consumption and emissions.
- To achieve a consistent benchmarking; to compare general or particular manufacturing indicators among either mills or inside production lines.

The structure and design of the allocation method is based on the GHG protocol plan proposal and the IPPC guidelines to recognise energy and emission focus.

As mentioned, allocation method is conceived as a support tool for the GHG emissions protocol. Figure 5.1 presents the structure of the GHG protocol guidelines -already exposed in paragraph 3.2.1 -with some annotations on the side. The annotations depict the new inputs of the allocation method introduced below.

In a first stage, GHG protocol should achieve a new goal. This is to develop a more detailed emissions report (by allocating emissions through process).

In a second stage, the AM adds to GHG protocol a new aspect towards the determining and selection of emission factors –particularly, emission factors related to energy use. As mentioned, the objective is to allocate emissions into energy end use and if necessary, into other final use, such as the raw materials production.

As described in section 4.2, paper plants have available different systems to obtain steam and electricity, such as CHP plant, stand-alone power stations from national grids, different boiler units or a combination of the two systems.

Therefore, emissions could first be allocated into their end-use. For example,

- Emissions due to purchasing or generating electricity
- Emissions due to purchasing or generating steam
- Emissions due to a particular direct combustion for heat generation
- Emissions due to other specific process:
    - Internal transport
    - Anaerobic water treatment
    - Production of carbonates

Nevertheless, the main emission causes are the ones related to energy use; for that purpose, this chapter focuses particularly on them.

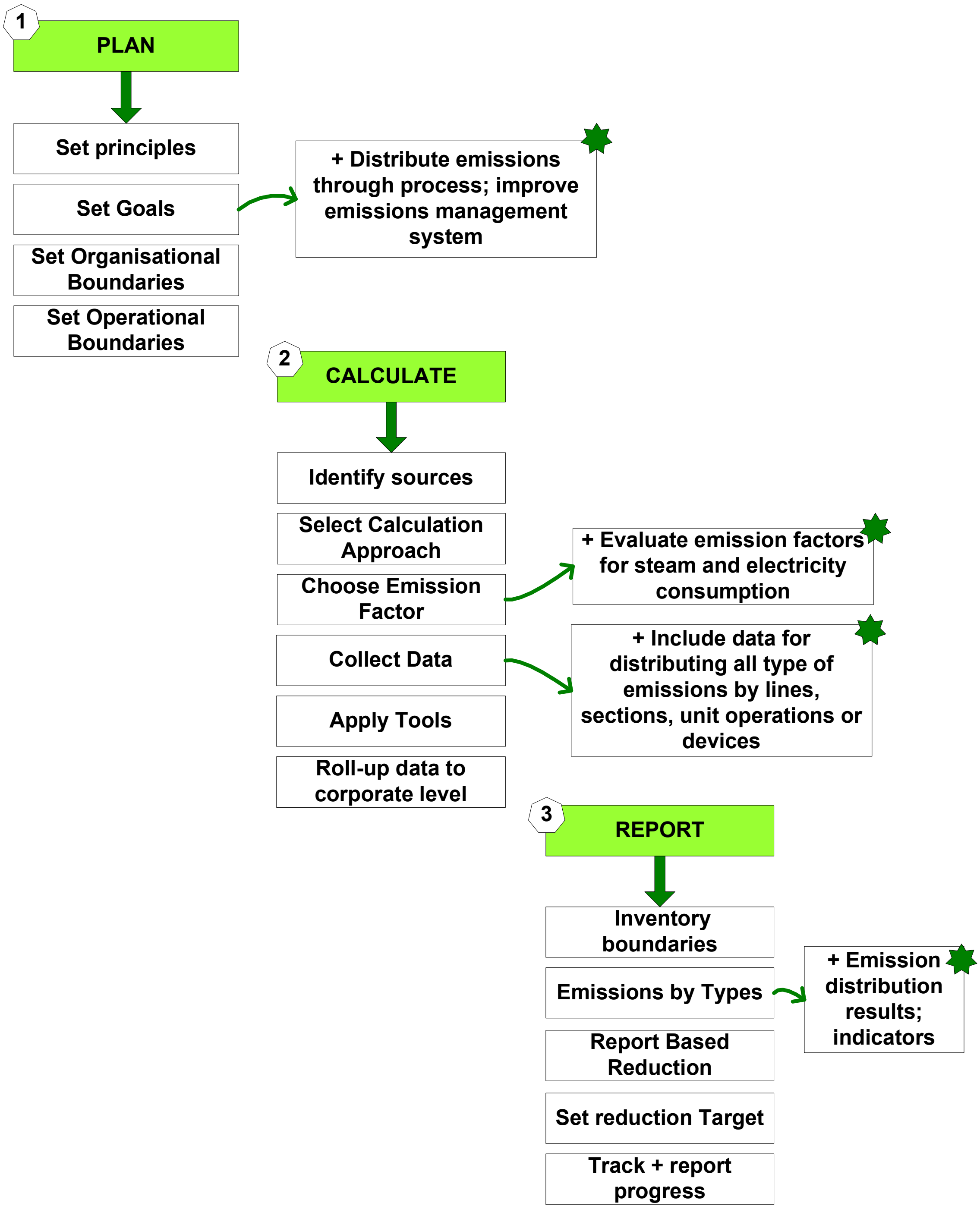


Figure 5.1 Allocation method: New inputs for the GHG protocol

Although steam consumption is not a direct energy source because it is produced in boiler units or in CHP plants, the allocation method considers steam separately; the aim is to detect inefficient sections or facilities properly.

To allocate emissions gradually, the papermaking process is divided in the aforementioned distribution parameters (production lines, sections, unit operations and specific devices). To develop these distribution parameters, the AM comprises the following considerations:

- Mill might have different production lines and various paper machines
- Mill might have different lines of coating processes
- Paper machines might include an integrated coating system
- Mills might have particular operations of surface treatments

Besides, the capacity of metering energy parameters (i.e. internal power or gas meters and standard control and registration systems) delimits the process of allocating emissions according to the mentioned distribution parameters.

The major metering grade, the major the capability of distributing emissions at all levels or parameters (Figure 5.2).

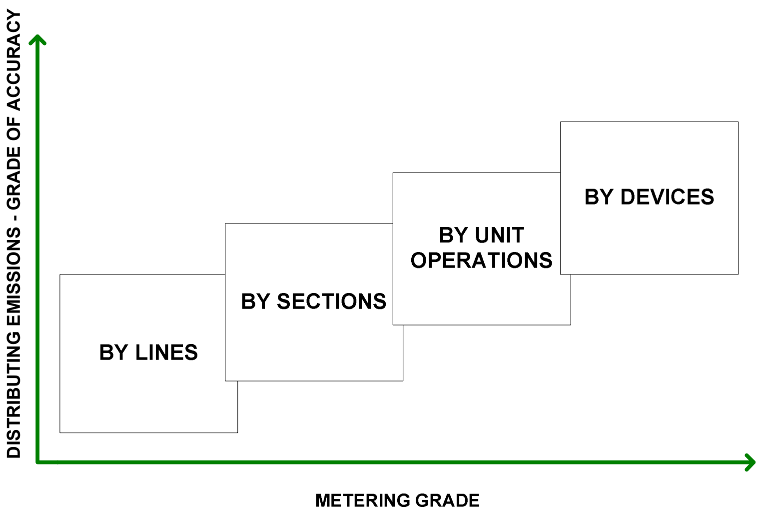


Figure 5.2 Distribution of emissions according to the grade of automation, meters and monitoring

Furthermore, these levels of distribution should not be treated as individual parameters because the boundaries of each level can be interconnected in accordance to the metering capacity. Paragraph 5.6 exposes some instruments and data to put in practice the methodology.

5.3 ALLOCATING EMISSIONS INTO THEIR ENERGY FINAL USE

To study which is the responsibility of each energy final utility (electricity, steam or direct heat), the allocation method associates each energy use with an emission factor. Figure 5.3 shows the possible emission factors that need to be calculated in order to proceed with this methodology.

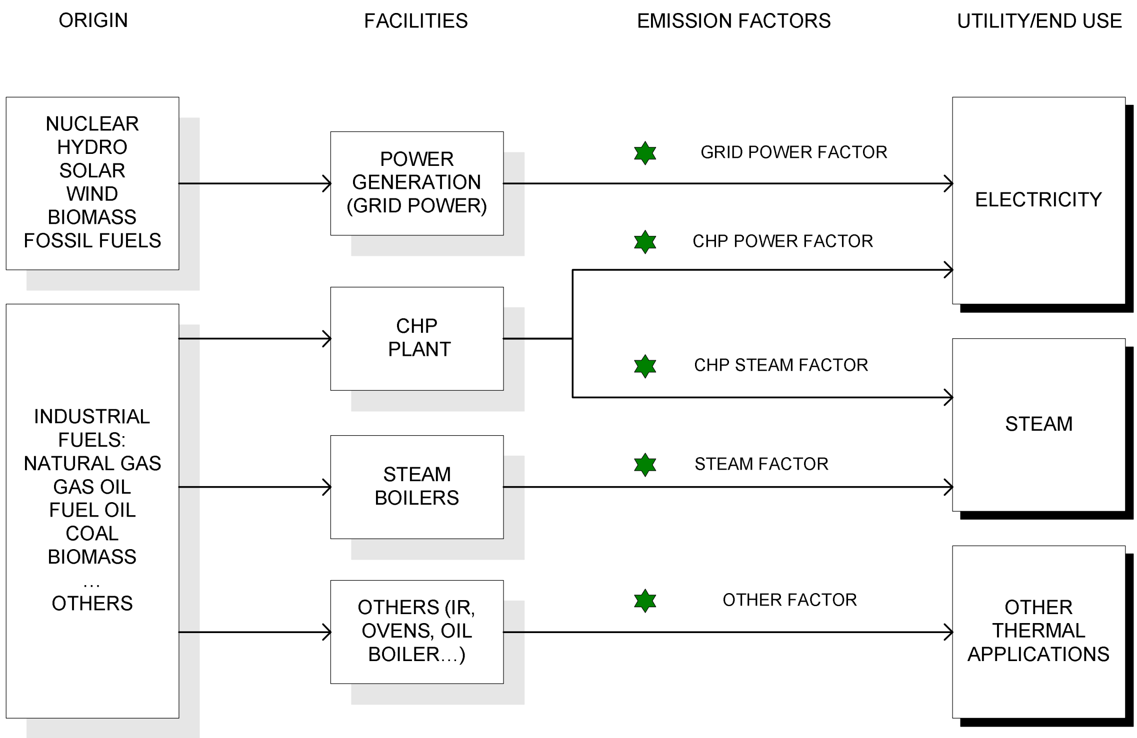


Figure 5.3 Allocating emissions in its energy final use

Methods to obtain such general factors are exposed in Chapter 3. Particular and specific factors referred to CHP systems or grid facilities are comprised in Chapter 6.

5.4 DISTRIBUTION OF EMISSIONS BY ENERGY END USE

Next paragraphs present a methodology proposed to distribute electricity, steam and other type of heat according to the aforementioned distribution parameters of the papermaking process. AM should be consistent with the information detailed in chapter 4 and the principles of GHG protocol stipulated in Chapter 3.

5.4.1 Distribution of electricity emissions through the process

Figure 5.4 proposes the allocation of GHG emissions trough out the manufacturing process in accordance with power end-use. The method considers the possibility that mills might have different production lines. Although Figure 5.4 refers to a mill with two production lines, it is assumed that the AM has to be applied to as many lines as the mill has. The same case occurs when the paper mill has more than one off-line coating machine.

Regarding Figure 5.4, the term devices encloses the equipment that form part of a unit operation.

It is proposed to use the following system to normalise units:

- Absolute electricity values: kWh
- Power intensity values (by line): kWh per tone of shippable paper produced in the respective production lines
- Power intensity values (by mill): kWh per tone of shippable paper
- Absolute emission values: kgCO_2
- Specific emission values (by line): kgCO_2 per tone of paper produced in the respective production lines.
- Specific emission values (by mill): kgCO_2 per tone of shippable paper

The allocation method plotted in Figure 5.4 has been designed with the aim of joining sections or unit operations with the same systematic order as in the manufacturing process. Thus, the allocation method basically follows the structure of the papermaking process described in chapter 4.

5.4.2 Distribution of steam emissions through the paper mill

Steam is widely used as secondary energy source in industrial manufacturing. Its generation requires a relevant amount of fuel or power.

The generation of steam is accomplished in three stages:

- The liquid feed water (return of condensates) is heated to the saturation temperature at a given boiler drum pressure.
- At the saturation temperature, an extra amount of energy is needed to evaporate water to steam.
- In some cases, the saturated steam is further heated to temperatures above the saturation temperature and becomes superheated steam.

POWER RELATED EMISSIONS	ELECTRICITY	EMISSIONS	SHARE
SECTION			
UNIT OPERATION	kWh/t	kg CO_2/t	%
DEVICES			
STOCK PREPARATION			
Pulping			
Pulpers (SF)			
Pulpers (LF)			
Pulpers (Broke)			
Pulpers (Other fibre)			
Deflaking			
Deflakers (broke)			
Deflakers (other fibre)			
Refining			
Refiners (SF)			
Refiners (LF)			
Refiners (other fibre)			
Other auxiliaries			
Pumps, agitators, other			
Other significant facilities			
APPROACH FLOW CIRCUIT			
Mixing, dilluting, cleaning, screening			
Pumps, agitators, other			
PAPER PRODUCTION LINE 1			
Wet section Operations			
Drives (Wet section)			
Vacuum pumps (LP)			
Vacuum pumps (HP)			
Press section Operations			
Press section drives			
Predrying section			
Predrying section drives			
Sizing or precoating			
Precoating section drives			
Kitchen pumps and auxiliaries			
Postdrying section			
Postdrying section drives			
Finishing Base paper			
Calendering and reeling drives			
Off-line or on-line coating			
Kitchen pumps and auxiliaries			
Coating machine drives			
IRs (electrical)			
Reeling drives			
PAPER PRODUCTION LINE 2			
Wet section Operations			
Drives (Wet section)			
Vacuum pumps (LP)			
Vacuum pumps (HP)			
Press section Operations			
Press section drives			
Predrying section			
Predrying section drives			
Sizing or precoating			
Precoating section drives			
Kitchen pumps and auxiliaries			
Postdrying section			
Postdrying section drives			
Finishing Base paper			
Calendering and reeling drives			
Off-line or on-line coating			
Kitchen pumps and auxiliaries			
Coating machine drives			
IRs (electricity)			
Reeling drives			
FINISHING SECTION			
Surface finishing			
Matt-on-line drives			
Supercalenders drives			
Embossing drives			
Other significant devices			
Final Treatings			
Winding drives			
Sheeting drives			
Shiping			
Packaging and wraping drives			
Retractile Oven			
GENERAL SERVICES			
Compressed Air system			
Compressors			
Lighting system			
Lights			
Waste water treatment			
Pumps and agitators			
HVAC			
Heating,Ventilating and Air Cooling (HVAC) systems			
Other auxiliaries			
Other significant devices			

Figure 5.4 Allocation method proposal. Distribution of electricity emissions through a paper mill.

Paper machine and coating machine drying sections have been reported as the major consumers of steam-based processes.

Figure 5.5 presents the proposed steam allocation method. To support the steam allocation task, a schematic steam-piping installation diagram might be requested or built-up. As in the case of electricity distribution, diagram of Figure 5.5 has been designed for sections or unit operations with the same systematic order of the paper process described in chapter 4.

STEAM RELATED EMISSIONS	STEAM CONTENT	EMISSIONS	SHARE
SECTION UNIT OPERATION DEVICES	kWh/t	kg CO_2/t	%
PAPER PRODUCTION - LINE 1			
Wet section operations			
Steam box paper machine			
Drying section			
Drying cylinders (Predrying section)			
Thermocompressors (Drying section)			
Pre-coating kitchen tanks			
Drying cylinders (Postdrying section)			
Other specific devices			
Off-line or on-line coating			
Kitchen tanks			
Drying cylinders			
PAPER PRODUCTION -LINE 2 …			
FINISHING DEPARTMENT			
Surface treatment			
Specific significant devices			
HVAC			
Heating and ventilation systems			
GENERAL SERVICES			
HVAC			
Heating and ventilation systems			
Oil heating			
Oil heat exchanger			
Other significant operations			
Other significant devices			

Figure 5.5 Allocation method proposal– Distribution of steam emissions through a paper mill

In similar terms of electricity allocation method, it is also desirable to unify steam units as following:

- Absolute steam values: kWh
- Specific steam values (by line): kWh per tone of paper produced in the respective production lines
- Specific steam values (by mill): kWh per tone of shippable paper
- Absolute emission values: $kgCO_2$
- Specific emission values (by line): $kgCO_2$ per tone of paper produced in the respective production lines
- Specific emission values (by mill): $kgCO_2$ per tone of shippable paper

For the conversion of steam flow into kWh, it must be taken into account the state of steam, which is fully described by its pressure and temperature. In the case of saturated steam its temperature or its pressure are essential to calculate its energy content –the enthalpy–and its specific volume. In the case of superheated steam, the flow temperature and its pressure are required. Steam energy content can be determined with the following formula:

$$\text{Steam content} = \dot{m} \cdot H(\text{T,P}) \tag{5.1}$$

Where $\dot{m}\cdot$is the steam flow and H is the enthalpy of the steam at a determined pressure and temperature (T, P).

5.4.3 Distribution of other thermal energy through out the paper mill

This part of the method encloses the emissions allocation of different types of thermal energy (steam is exempt) of the mill process. In this sense, thermal energy can comprise:

- Direct heating injection through infrared dryers or through other devices such as retractile oven.
- Thermal oil heating which might be used as a secondary utility at special press rolls or other units of the mill.
- Air heating as an air conditioning or drying service.

Figure 5.6 diagrams the distribution proposed for such type of thermal energy.

OTHER THERMAL RELATED EMISSIONS	DIRECT HEAT	EMISSIONS	SHARE
SECTION UNIT OPERATION DEVICES	kWh/t	kg CO2/t	%
PAPER PRODUCTION - LINE 1			
Pre-coating or sizing drying section			
IR dryers			
Other specific devices			
Off-line or on-line coating			
IR dryers			
Other specific devices			
FINISHING DEPARTMENT			
Surface treatment			
Specific significant devices			
Retractile Oven			
GENERAL SERVICES			
HVAC			
Heat and air ventilation systems			
Other significant devices			

Figure 5.6 Allocation method – Distribution of thermal energy through out the paper mill

As in both cases above, heat values should be provided in kWh units and emissions in $kgCO_2$.

5.5 THE APPLICATION TOOL WORKSHEET

In order to exemplify the previous allocation method proposal, it has been developed a worksheet tool, using Microsoft Excel ®. Some parts of the tool are presented in Annex-1 meanwhile the complete workbook application is attached as e-support in this work.

The tool has been structured in the following worksheets:

- Introduction: presentation of the worksheet tool.
- General Data: general information of the mill, focused on emissions and energy-related issues.

- Emission sources and factors: emissions and factors of the main energy-related issues as well as other factors related to mobility, raw material, water treatment, etc.
- Main focus of emissions: emissions assigned to each main focus. Includes power and steam systems as well as Calculations of direct heat, steam and power factors.
- Main focus diagram: Sankey diagram tool to produce a general Sankey diagram related to emission focus of the mill and related end-use. Sankey diagram application is based on Sankey Diagram Tool macro, which pertains to Sankey Diagram.com copyright ®.
- Power related emissions: allocation of power-related emissions through out the specific paper process, including production lines and general services
- Steam related emissions: allocation of steam-related emissions through out the specific paper process, taking into account production lines and general services.
- Other related emissions: allocation of other-related emissions, such as thermal emissions due to direct fired gas.
- General comments: remarks and comments to be noted, after results obtained
- Support data: Includes default emission factors, net energy heating values and unit conversion.

The tool has been designed in an open framework. The user is able to modify and structure most of the information formulated in the worksheets, to adapt worksheets to the own paper mill case.

5.6 INSTRUMENTS AND DATA

The AM requires handling a wide range of information regarding energy and emission-related issues of the paper manufacturing process. The compiling process is proposed to be managed in two levels. In a first level, it should be gathered general data of the mill such as energy expenditures, product shipments and emissions reports. Secondly, data associated with particular processes should be compiled; for example, energy consumption of production lines, unit operation or specific devices. Some metering instruments might be necessary to achieve the mentioned requirements. The instruments exposed in following paragraphs are commonly used for electricity, steam, heat or other utilities metering purposes.

5.6.1 General Data of the mill

General data is classified into two categories. First category includes essential data for calculations; second category consists of meaningful data to understand the process and delimit –at an early stage– the boundaries of emissions distribution. The first category of essential data is listed below:

- Fuel consumption of a cogeneration plant or stand-alone boilers
- Electricity generation
- Steam generation
- Fuel invoices of the reporting period
- Electricity invoices of the reporting period
- Emissions reported to government
- Production shipments (by lines and globally)
- Maintenance reports

Second category of meaningful data for the allocation method comprises:

- Plant diagram
- Plant flow sheet
- Piping instrumentation diagrams (PID) for steam applications
- Circuit diagrams of high voltage power supply
- Internal or benchmarking reports
- Possible reports on energy diagnosis

5.6.2 Compiling electricity data

As exposed in the allocation method, electricity distribution should be analysed as extensively as the metering technology allows to. Below, some instruments to determine energy power parameters are presented. On one hand, a general power-meter is used to compile the totality of electricity consumed in the mill. On the other hand, partial power-meters can be useful to determine electricity consumption data of some unit operations or specific devices. These types of instruments have a portable version. In addition, some of them are permanently connected to a distributed control system or a central computer in order to monitor the electricity demand in a continuous mode.

Power meters

Power suppliers install this type of devices for billing the energy delivered to the mill. On the other hand, CHP plants have also installed these meters to control the power output sent to grid.

They supply different electric variables, such as phase currents, power factors, active power, and reactive power, in a continuous or accumulative mode. Reading errors can lead to values between 0,2%-0,5% [1]. They can register data every 15 minutes. The paper mill cannot manipulate these meters.

Power system analysers

This type of meters supplies a wider range of electricity parameters in comparison with general power meters installed by the supplier company. They can measure in a continuous mode levels of voltages (phase-to-phase and/or phase-to-ground), currents, active, reactive and apparent power and energy, frequency, power factor, phase angle per phase, harmonics of currents and voltages or total harmonic distortion [2].

According to Cos [3], these instruments are useful for internal control, therefore the error of measure is higher than in the company meter (around 1%). Figure 5.7 shows the electricity meter.

Figure 5.7 Power system analyser - Portable. Circutor AR5. Switched in a general bus-bars of a plant.

Electricity analysers – portable modality

Fixed power analysers might not be useful for the particular information requested in the allocation method proposal. For a punctual measure, portable instruments might be a good solution, because they practically measure the same electrical parameters than the fixed analysers. One of the advantages of these instruments is that they can be applied on-line, without stoping the facility to be measured.

Network-based control systems

Network-based control systems are used in industrial, electrical, computer, instrumentation and control engineering applications to monitor and control equipment with or without remote human intervention. A network control system enables the paper mill to control efficiently its process. Control systems detect quickly non-programmed process interruptions and allow operators to have instant access to diagnosis-windows to help them understanding the control process.

Different structural network controls, such as SCADA and DCS, can be used in paper mills. A SCADA system is the abbreviation of Supervisory Control and Data Acquisition. DCS is the short form of Distributed Control System.

SCADA system is conceived as a control system wherein the supervisor or main control element commands the remote located units and executes sentences if required. On the other hand, a DCS is a control system, which the controller units are not centralised in a specific location: they are allocated through out the system with each element of the sub-system commanded by one or more controllers [4], [5].

In both cases, such systems are useful for compiling electricity data; periodically, the technician in charge downloads recorded data and presents results in terms of consumptions per sub-station.

Figure 5.8 displays the structure of a paper mill distributed control system. The paper mill has various central motor controls and sub-stations that feed the variety of devices of the mill.

Combining data using different instruments

When the mill does not have the adequate meters or instruments to measure the required data of the allocation method, it is still possible to do some estimation.

Power meters or power analysers can deliver an energy consumption value of a physical section or groups of facilities. This data might not match with the data requested to apply the allocation method. In this case, it might be useful to use the information taken from a combination of different instruments.

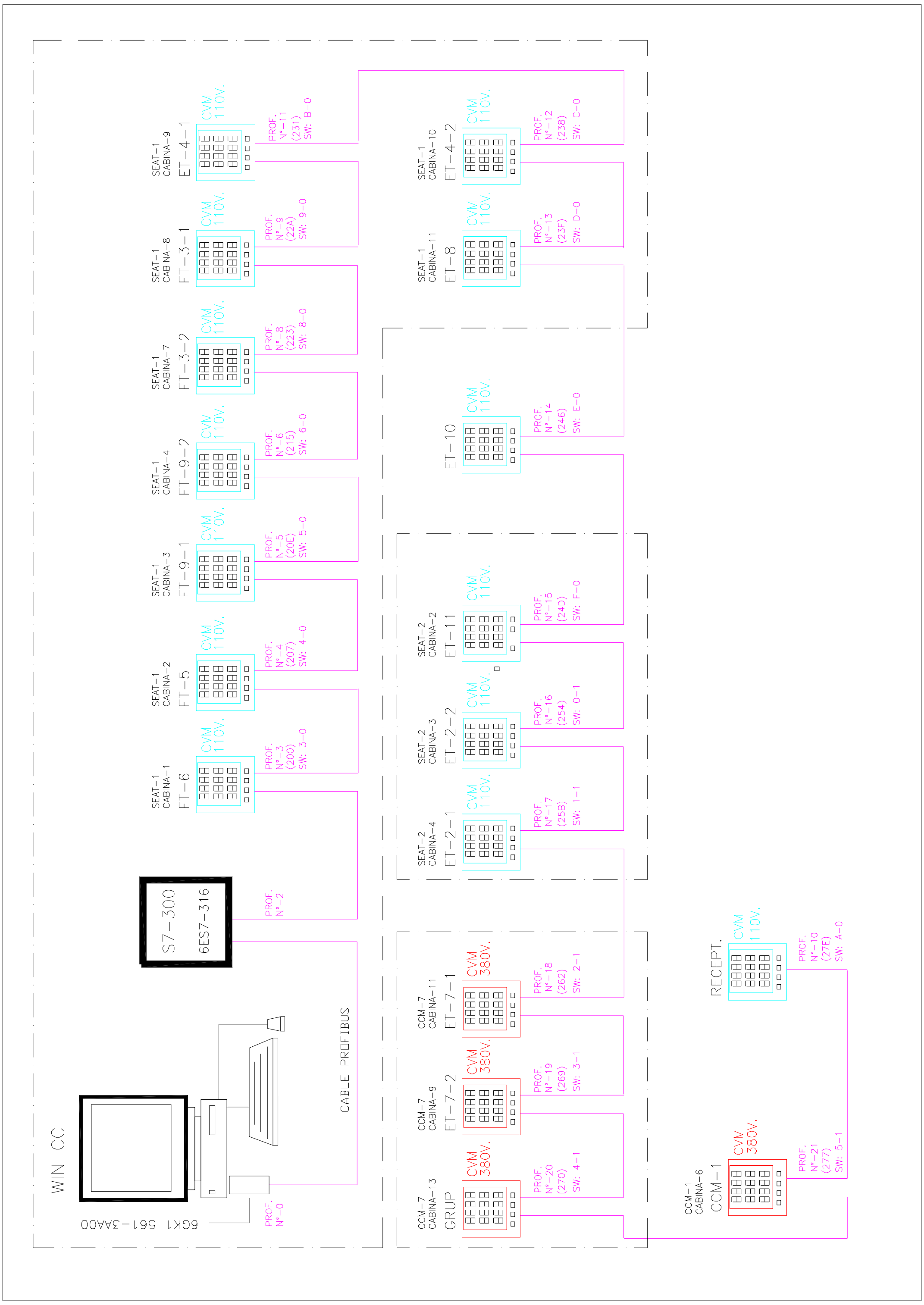


Figure 5.8 Structure of a distributed control system (Mill A)

5.6.3 Compiling steam data

Steam flows can be approached directly –with a steam flow meter– or indirectly. In this last case, the approach is based on net power of fuel and boiler efficiency or mass and energy water balance.

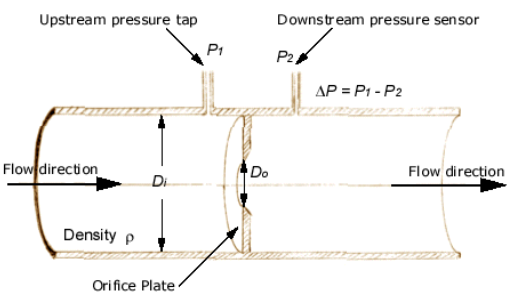
Technology has currently developed [6] many types of steam flow meters:

- Orifice plate flow meters.
- Turbine flowmeters (including shunt or bypass types).
- Variable area flow meters.
- Spring loaded variable area flow meters.
- Direct in-line variable area (DIVA) flow meter.
- Pitot tubes.
- Vortex shedding flow meters.

Common steam flow meters in paper mills are the orifice plate flow meter and the vortex flow meter. These instruments are described in the following lines.

Orifice Plate Flow meter

An orifice plate flow meter is based on the Bernoulli postulate that exposes the relationship between the velocity of fluid flowing through the orifice is proportional to the square root of the pressure [17]. An orifice plate is installed on the steam pipeline providing a restriction to the steam normal track. The differential pressure is measured across the restriction by a differential pressure cell. Pressure and temperature sensors are installed next to the orifice plate in order to enable the system to compensate calculations for changes of fluid density. Determining steam flow (Q) is approached with formula 5.2. (See Figure 5.9)



$$Q = C_f \sqrt{\frac{2(P_1 - P_2)}{\rho}} \qquad (5.2)$$

Figure 5.9 Orifice Plate flow meter. Source:EFUNDA

The flow coefficient C_f has beed defined according to experiments and can be found tabulated in reference books; it ranges from 0,6 to 0,9 for most orifices.

Figure 5.10 shows the main parts of an orifice plate flow meter.

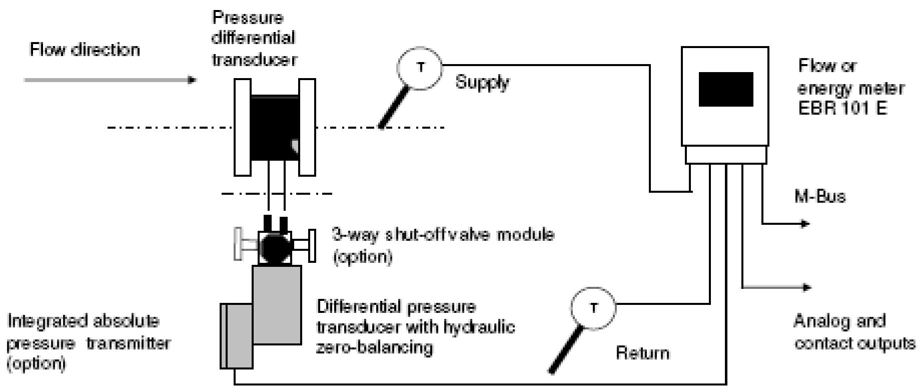


Figure 5.10 Orifice Plate Flow meter. Source: Spirax Sarco [7]

Vortex flow meter

Vortex flow meters are based on the principle that a fluid flow produces regular vortices when a bluff body is placed in the pipe line wherein the fluid is flowing. The generated vortices are proportional to the flow rate and can be detected, counted and displayed by the flow meter. Figure 5.11 shows a vortex flow meter installed on a steam pipe of a paper mill.

Figure 5.11 Steam flow meter Mill A. Vortex type

Steam flow (Q) can be approached with the following formula [8]

$$Q = f / k \qquad (5.3)$$

Where f is the frequency of the Karman vortex train and k is the specific constant related to the flow meter.

5.6.4 Compiling other thermal energy data

Natural Gas

There is usually little problem when obtaining data of gas consumption in comparison with steam data. Gas supplier companies have general meters installed. Moreover, mills usually have partial meters in the main consumption units, such as boilers, IR dryers or turbines. Figure 5.12 shows a partial gas meter of a paper mill.

Natural gas measurements result on two stages. The first measurement meters the volume flow of the natural gas income, at the temperature and pressure of the supplier pipe.

Figure 5.12 Mill B gas meter (elster ETM) and its converter (EK 88)

Supplier companies invoice the gas according to Normal conditions (0 ºC and 1 bar). For this reason, it is needed a converter device transforming the ambient conditions into the normal conditions. Supplier companies tend to install telematic meters, which make possible to acquire a daily gas reading, based on the continuous measures achieved.

According to legislation 2007/589/EC [9], converters and meters need to be calibrated and certified to provide measurement errors and uncertainties concerning emissions allowances report.

In the case of gas, the supplier companies include in their invoices the net calorific value (HHV and the LHV) of the gas –usually in daily values– as well as the cubic meters in normal conditions that the mill has consumed.

Both values indicate the amount of energy released when a fuel is burned completely. The difference between LHV and HHV is the phase of water/steam considered in the combustion process.

Consumption of gas of a particular unit operation without gas meter can be achieved with gas balances. When a common gas meter feeds different utilities, it is useful to measure gas consumption of the individual devices in a normal scheduled or maintenance down time.

Fuel or other liquid flow meters

The flow of a liquid fossil fuel, such as fuel oil is metered by a flow meter primary element. Industry disposes of different types of flow meters that are prepared for measuring liquids. The ultrasonic flow meters are the most accurate and have a user-friendly application. The flow meter transmits a pulse output to a converter which sends a 4-20 mA output signal to a flow computer. The computer system uses default values of fluid density and calorific value to be displayed or recorded in terms of instantaneous and integrated mass flow and energy.

Moreover, the total amount of fuel is controlled by the weight of the truck in the weighbridge at the entrance of the mill. For that purpose, weighbridge is tare weighted periodically, and tare weight is certified by an official administration, according to a calibration system. The same certification guarantees the grade of uncertainty of the measures and complies with the mentioned UE directive 2007/589/EC [9].

5.7 EVALUATING UNCERTAINTIES OF RESULTS

5.7.1 Classifying uncertainties

In a first step, the method proposed is mainly expected to supply results of GHG emissions computation and the distribution of such emissions through out the papermaking process. Such results are implicitly involved to a certain grade of uncertainty.

Uncertainty is the error band that is associated with a particular measurement or derived value.

Uncertainties concerning GHG emission results might be classified into two general categories: scientific uncertainties and estimation uncertainties. Moreover, the allocation method itself –based on instrumental metering and estimation– should implicitly entail estimation uncertainties. Figure 5.13 describes below the categories of uncertainties related to allocation method results.

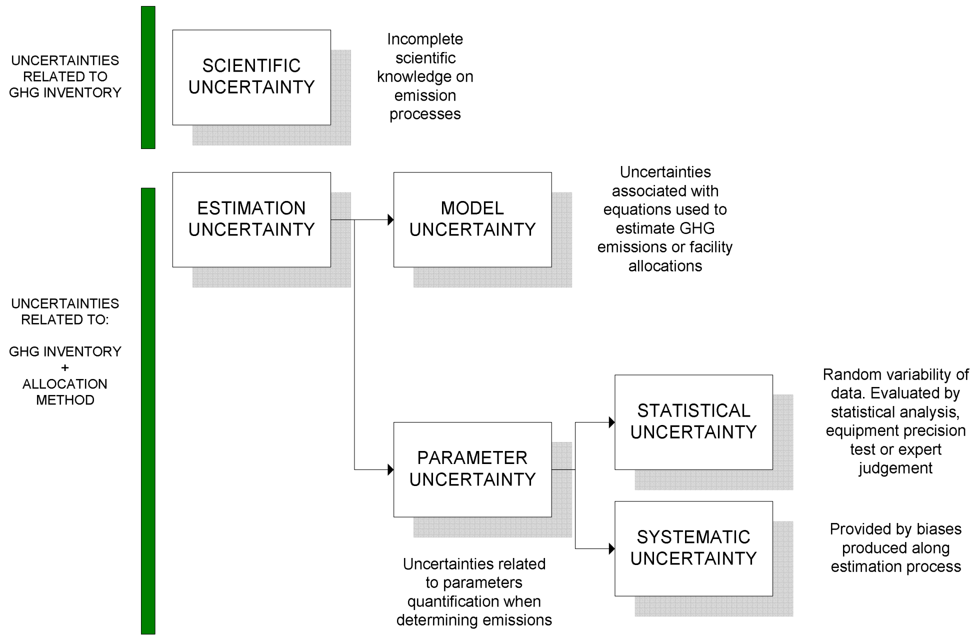


Figure 5.13 Classifying uncertainties related to GHG emissions and allocation method. In general terms, scientific uncertainties and estimation uncertainties are directly related to emissions inventory meanwhile allocation of emissions poses uncertainties regarding instrumental and estimation issues.

GHG protocol tools provide guidance on emissions inventory uncertainties [10]. Moreover, the estimations and uncertainties arising from the emissions allocation method are based on statistics of real operation data treatment [11]. Next paragraphs detail and define each type of uncertainties briefly.

Scientific uncertainty is related to a level of development or concluding state of a specific research. This is the case of global warming potential factors, used to convert the non-CO_2 gases into CO_2 emissions. IPCC estimates that they can carry associated a significant uncertainty. The same occurs with the direct emission factors of different activities, already denoted in Table 3.5 [12].

Estimation uncertainty appears each time GHG emissions are determined. This uncertainty entails two additional aspects: model and parameter uncertainty. The first one refers to uncertainties concerning mathematical equations. Parameter uncertainties refer to computation of parameters that are used as inputs to calculate emissions. For example, activity data such as energy consumption entails parameter uncertainties. This type of uncertainty can be evaluated by statistical analysis, measurement of equipment precision tests or expert criteria.

At the same type, parameters uncertainty can be classified in two subsequent grades: systematic and statistic uncertainty.

Systematic uncertainty is associated with the biased grade of the measured parameter. For example, if a fuel oil meter always provides a higher value than the true value. Such metering problems are difficult to detect, providing a correct quality management system is installed.

Statistic uncertainty appears with natural variations. For example, human errors from the meters use or variations of metering equipment itself.

However, nowadays systems are such monitored that uncertainties are mainly assigned to the instrument that makes the measure.

5.7.2 Calculating uncertainties

A metered or calculated value (y) can depend on a number of measured inputs each of them associated with a particular uncertainty. In that case, the influence of the uncertainty in each of the inputs can be defined with a weighting factor called the sensitivity coefficient. The overall uncertainty U_o can be calculated as the square root of the sum of the squares of each of the input value uncertainties u_{x_i} multiplied by its sensitivity coefficient $\frac{\partial f}{\partial y}$ [11].

$$U_o = \sqrt{\sum \left(\frac{\partial f}{\partial y} \cdot u_{x_i} \right)^2} \tag{5.4}$$

This general calculation method applies whether uncertainties are assigned to single parameters, grouped parameters or to the method as a whole. Despite this fact, when an uncertainty contribution is due to the whole procedure, it is considered that it has a direct effect on the final result. If that happens, or when the uncertainty on a parameter is expressed directly in terms of its effect on y, the sensitivity coefficient $\frac{\partial f}{\partial y}$ gets the unitary value.

5.7.2.1 Standard uncertainties related to gas inventories and allocation method

Most of the emissions that require an indirect calculation are determined by multiplying an activity data by an emission factor (see chapter, formula 3.1). According to this procedure, the uncertainty of either activity (u_{ACT}) or emission factor (u_{FACT}) are directly related to the total emissions result (U_E). Therefore, uncertainty of an emission calculation result can be expressed as in formula 5.5.

$$U_E = \sqrt{u^2_{FACT} + u^2_{ACT}} \tag{5.5}$$

GHG protocol only recommends applying this formula if individual uncertainty in each parameter represents less than 60% of the mean [13].

Furthermore, whether estimating activity data or applying allocation method, it should be taken into account an additional grade of uncertainties; this is the parameter uncertainty produced by the instrument metering.

In order to focus on the scope of this work, uncertainties of the instruments (U_{INST}), below are considered the most common used in paper mills either when evaluating GHG emissions inventory or when allocating them through out the process. Thus, the following paragraphs evaluate the grade of uncertainty of gas meter (U_{GM}), liquid flow meters (U_{LM}), power meter (U_{PM}), steam flow meters (U_{SFM}), thermocouples (U_{TMC}) and pressure meters (U_P).

5.7.2.2 Gas measurements-related uncertainties

As explained previously in 5.6.4, companies use gas meters to quantify gas consumptions.

Companies usually have a general meter revised by the gas supplier company for billing purposes. The gas meter usually has a converter to provide gas cubic meters under normal conditions. The converter transmits the metered signal to a converter, which sends a 4-20 mA output signal to a flow computer.

To quantify the gas consumption in energy units, the calorific values can be taken from the gas bill for the relevant time period. Thus, the global uncertainty U_{GM} aroused from this calculations is referred to particular uncertainties of the gas meter u_{PE} (primary element), the converter u_{CONV} , the transmitter u_{TR} and the gas heat value u_{HV} (see formula 5.6) [14]

$$U_{GM} = \sqrt{u_{PE}^2 + u_{CONV}^2 + u_{TR}^2 + u_{HV}^2} \quad (5.6)$$

According to CHPQA [14] -if good practices steps are taken to remove bias (system uncertainties) in the computation of energy –the additional uncertainty regarding variations in fluid properties of natural gas and LPG should not be considered significant.

In addition, gas meters that are basic for determining emissions at legal scale require a specific calibration to ensure a low range of uncertainties. Frequently, the allowance of uncertainty for these meters ranges less than 2,5%, in order to comply with legislation 2007/589/EC (this is the case of companies with relevant emission allowances, and includes all types of fuels and meters).

5.7.2.3 Liquid measurements-related uncertainties

As in the case of gas measurements, to quantify liquid consumption in energy units, the default calorific values can be taken from supplier. Thus, the global uncertainty U_{LM} arisen from this calculations is related to particular uncertainties of the flow meter u_{PE}, the transmitter, u_{TR} and the computer computation u_{COMP} [14]..

$$U_{LM} = \sqrt{u_{PE}^2 + u_{TR}^2 + u_{COMP}^2} \quad (5.7)$$

The flow meter supplier can provide the specific uncertainties.

Fuel can also be computed by mass balance, by registering the weight of the truck in the weighbridge at the entrance of the mill. For that purpose, weighbridge is tared periodically, and tared weight is certified by an official administration, according to a calibration system. The same certification includes the grade of uncertainties of the measures.

5.7.2.4 Power measurements-related uncertainties

Market is increasing accuracy operation of power meters and power analysers. Uncertainties can be allocated to the meter or analyser itself and suppliers can provide the uncertainties of each device. A proper and scheduled calibration of such devices will ensure a constant uncertainty range.

In general terms, power analysers have a roughly 2% of uncertainties, meanwhile general power meters supply results with a 0,1% of uncertainty.

5.7.2.5 Steam flow meters

As expressed in allocation method proposal, steam demand must be allocated through individual units. The derivation of the final output value (steam flow) in energy units, requires a relevant number of calculation steps.

For example, an orifice plate flow meter produces a differential pressure which a transmitter converts to a 4-20 mA electrical output. The electrical signal is transmitted to a computer device. Computer model converts differential pressure into steam flow. For that purpose, computer model requires steam density -which might be obtained by simultaneous control of pressure and temperature.

The computerised system might supply further information. It can be programmed to use a derived specific enthalpy (this is the case the steam flow meter supplies pressure and temperature data). Enthalpy derives to a steam output in energy units, kW (rate) or kWh (cumulative).

The overall uncertainty is clearly influenced by the uncertainties associated with the steps described to reach the final steam flow in energy units.

For example, the computed mass and energy flow metered with an orifice plate flow meter is based on formula 5.8 [14].

$$U_{SFM} = \sqrt{\left(\frac{\partial f}{\partial y} \cdot u_{PE}\right)^2 + \left(\frac{\partial f}{\partial y} \cdot u_{DP}\right)^2 + \left(\frac{\partial f}{\partial y} \cdot u_{C}\right)^2 + \left(\frac{\partial f}{\partial y} \cdot u_{T}\right)^2 + \left(\frac{\partial f}{\partial y} \cdot u_{P}\right)^2} \quad (5.8)$$

Where uncertainty values for the components that make up the metered energy input are:

- Primary element - orifice plate: u_{PE}
- Differential pressure transmitter u_{DP}
- Flow computer u_{C}
- Temperature transmitter u_{T}
- Pressure transmitter u_{P}

To simplify the equation, ISO 5168:2005 [15], provides a default value of 1/2 to the sensitivity coefficients of u_{PE}, u_{T} and u_{P}. The rest of coefficients are taken as unity because they have a direct effect on the outcome.

The simplified formula is expressed in equation 5.9

$$U_{SFM} = \sqrt{(u_{PE})^2 + \left(\frac{1}{2}\cdot u_{DP}\right)^2 + (u_C)^2 + \left(\frac{1}{2}\cdot u_T\right)^2 + \left(\frac{1}{2}\cdot u_P\right)^2} \quad (5.9)$$

The rest of individual uncertainties can be provided by the steam flow-supplier or estimated using sample data.

However, as this type of formula is difficult to achieve at industrial framework, technicians usually evaluate steam flow uncertainties according to numerical software provided by the flow-meter supplier.

5.7.2.6 Thermocouple

Correas [16] has compiled the uncertainty provided by a thermocouple (U_{TMC}). Formula 5.10 summarises the calculation of uncertainties from temperature measures.

$$U_{TMC} = \sqrt{u_{PE}{}^2 + u_{CJC}{}^2 + u_{CAB}{}^2 + u_{SIGN}{}^2} \quad (5.10)$$

Where,

u_{PE} is the uncertainty of the thermocouple as a primary element, in the case of a thermocouple type k, u_{PE} = 0,0075·T (T, temperature in centigrade).

u_{CJC}=0,005·Range, as the thermocouple uncertainty depends on cold junction temperature compensating range

u_{CAB} is the uncertainty of the extension cables, default value is 2,2

u_{SIGN} is the uncertainty of the transmission signal, default value is 0,5

5.7.2.7 Pressure meters

Gauge pressure meters achieve an average of uncertainties of 0,23% meanwhile differential pressure meters can be characterised with a 0,46% of uncertainties [16].

5.7.2.8 Estimating uncertainties related to energy consumption approaches

Not all the parameters required for the allocation method application can be available by the use of energy-related meters. In some occasions, estimations have to be approached in order to achieve a particular value. For example, when applying the allocation method in a mill case study, the annual power consumption of the vacuum system (P_{vac}) has to be determined. This particular vacuum system is switched to a MCC that feeds two liquid-ring vacuum pumps and one additional long-fibre refiner.

A fixed grid analyser has been installed at the main bars of the MCC. There is no specific meter to individualise the consumption of the two vacuum pumps from the refiner unit. All the three units work in a continuous mode and refiner operates at maximum power capacity. To achieve the desired result, punctual current measures have been taken at the refiner unit and an instant power measure has been determined (P_{ref}). Afterwards, the energy consumption of the vacuum system has been estimated according to the following formula.

$$P_{VAC} = P_{MCC} - P_{REF} \cdot h_{ope} = P_{MCC} - P_{REF} \quad (5.11)$$

P_{MCC} is the power consumption of the MCC for the annual period and h_{ope} are the operating hours of the refiner unit.
In this case, the uncertainties related to this measure have been calculated using a weighted average approach, as the uncertainties are quantified for subtotals and totals of single sources.

$$U_{P_{VAC}} = \frac{\sqrt{(u_{GA} \cdot P_{MCC})^2 + (\cdot u_{CA} \cdot P_{REF})^2 \cdot}}{P_{VAC}} \quad (5.12)$$

Where u_{GA} is the uncertainty of the reading measure concerning the grid analyser and the u_{CA} is the uncertainty that can be caused with a hand-held ammeter.

5.7.3 Qualifying uncertainties after calculations

GHG protocol guidance suggests using an uncertainty range to qualify the results accuracy. For that purpose, the protocol establishes a relationship between quantitative confidence intervals (as a percentage of the estimated measure) and data accuracy qualification (see Table 5.1).

Table 5.1 Qualifying emissions accuracy

DATA ACCURACY QUALIFICATION	INTERVAL AS PERCENT OF MEAN VALUE
High	+/- 5%
Good	+/- 15%
Fair	+/-30%
Poor	> 30%

Considering an application based on multiple results, such as the tool proposed in this chapter, it might be necessary to provide a global review of accuracy by qualifying uncertainties rather than quantifying each of the variables and parameters of the corresponding results.

Note that the emissions management has to assess with maximum quality and data reliability. However, it is considered that the aim of this AM assessment is to set targets and indicators. Indeed, for further and extended results –previous to high investment decisions– a quantified uncertainty value will be required.

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6 ENERGY-RELATED EMISSION FACTORS

6.1 INTRODUCTION

The estimation and evaluation of different methodologies to determine emission factors derived from power and steam demand in paper mills is one of the objectives of this work. This objective is developed through out this chapter. In this context, an emission factor is understood as a value applied to convert a given energy use into GHG emissions.

Paragraphs below present some methods to allocate CHP plants emissions into power and steam output streams. These methods have already been introduced in chapter 3 (paragraph 3.4.4). The aim is determining two additional emission factors: CHP-heat and CHP-power emission factors. Published methods are evaluated using real data of a CHP plant that supplies steam to a non-integrated paper mill.

The results obtained are analysed to select the most appropriate emission factor methodology for the paper sector. As none of the methodologies satisfies the expectations completely, a new method to estimate emission factors in a CHP plant framework is proposed.

Furthermore, paper mills might purchase electricity from an external grid system. Electricity generators belonging to this grid system can be responsible for relevant amounts of GHGs. Therefore, the total electricity consumed in the mill is associated with a grid power factor. For that purpose, this chapter includes a methodology to determine a grid power factor from a group of power facility producers.

In addition, it is specifically evaluated the case of electricity generators in Spain and its autonomous regions. In the Spanish case, the monthly variation of the power factor through an annual period is analysed. Results are compared with grid power factors from other European countries.

6.2 ESTIMATING CHP EMISSION FACTORS

Heat and power produced in a CHP plant usually remain in the same company or process. However, some of these two energy outputs might be exported to other companies. Therefore, it might be interesting to measure each share of responsibility. Although this might have a company interest, it should be denoted that Spanish government allocates to CHP plants the totality of on-site emissions produced.

A suitable method of allocating emissions in a cogeneration system is still a concern and a subject research for scientists, companies and policy makers.

As introduced in paragraph 3.4.4, it has been considered some methods published in bibliography to attribute CHP emissions to power and to heat production. This work has particularly focused on publications of Nyober [1], Rosen [2,3] and GHG pulp and paper tool guidance [4]. The methods presented by these authors have some features in common. All of them estimate CHP system emissions based on fossil fuel combustion and after that, they allocate the total emissions along the different useful output energy streams heat (i.e. steam or hot water) and power.

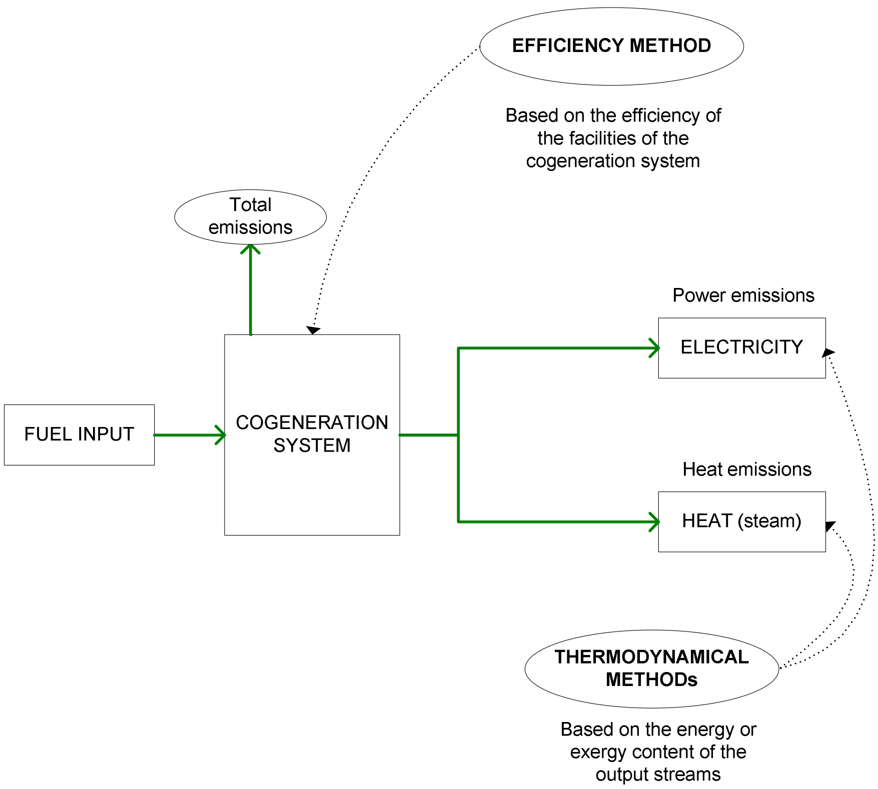


Figure 6.1 Published methods to allocate CHP emissions into power or steam generation. Total emissions can be allocated into heat and power outputs by methodologies based on different criteria. Efficiency method is based on the efficiency of the main facilities of the CHP, meanwhile thermodynamical methods focus on the physical stage of the output streams.

As mentioned in paragraph 3.4.4, this work analyses these methods regrouping them into two categories: methods based on efficiency of energy facilities and methods based on thermodynamical criteria. The description of these methods incorporates some annotations of the different authors' point of view. Finally, some concluding points are expressed after the analysis of each of them.

Equations and methods presented in this chapter have been rearranged into a consistent basis of units and mathematical equations.

To explain the methods properly, Figure 6.2 shows a typical CHP plant configuration of a paper mill. Such a system is mainly composed of a primary energy mover (in this case a gas-fired turbine) with its corresponding generator, a heat recovery steam generator (HRSG), and a back pressure steam turbine with an intermediate steam extraction. The nomenclature used in formulas and equations described below, is based on this figure.

GENERAL NOMENCLATURE

E_{Ff}, total emissions attributable to the combustion of input fuels f, [t CO_2]

E_T, total emissions of CHP plant, [t CO_2], this is $\sum E_{Ff}$

E_{Hi}, emissions attributable to heat production in stream i, [t CO_2]

E_{Pj}, emissions attributable to electric power production via generator j, [t CO_2]

P_j, net power output from a generator j, [MWh]

H_i, heat output contained in steam stream i, [MWh]

$\dot{m}_i$, steam flow i, [t/h]

$\mathcal{H}_i$, specific enthalpy of steam flow i, [MWh/t]

$\mathcal{H}_o$, specific enthalpy of water at reference conditions [MWh/t]

$\mathcal{S}_i$, specific entropy of steam flow i, [MWh/t·K]

$\mathcal{S}_o$, specific entropy of water at reference conditions [MWh/t·K]

T_o, temperature at reference conditions [K]

Ψ_i, exergy of steam stream i [MWh]

η_{Hi}, overall efficiency of producing heat contained in steam stream i

η_{Pj}, overall efficiency of producing electric power via generator j

n, number of steam stream outputs extracted from the plant

k, number of power generators installed in the plant

V_i, volume of natural gas input stream i

LHV low heat calorific value of natural gas

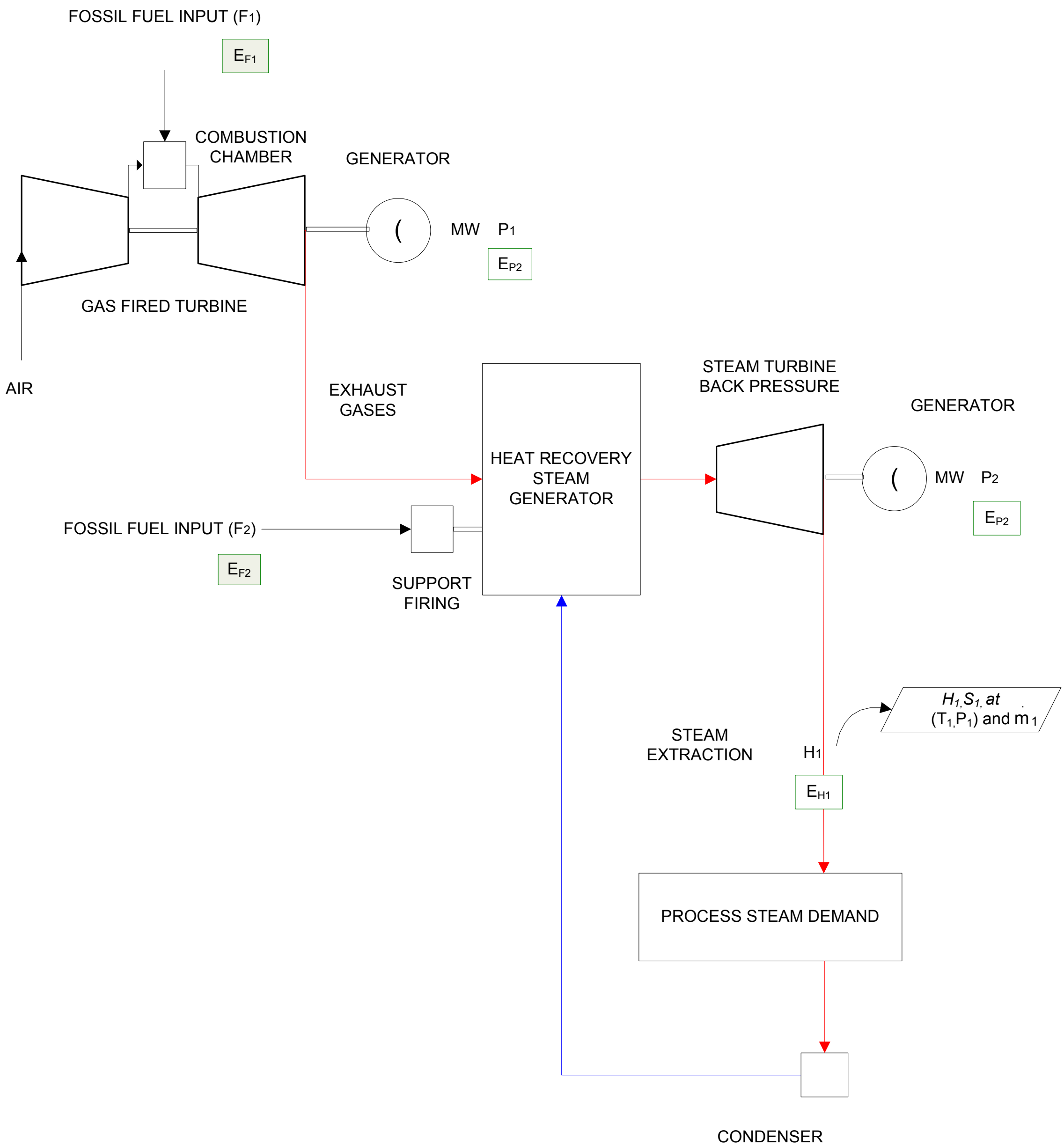


Figure 6.2 Combined-cycle plant configuration. This plant is composed of a gas-fired turbine, a HRSG that produces a HP steam and a steam turbine producing and extra amount of electricity and steam stream (LP). The steam production is derived to a paper mill process.

6.2.1 Method based on efficiency of facilities: Efficiency method

CHP plants produce energy using a variety of generators driven by a range of different motive forces (described in 4.2).

The efficiency method bases its emissions allocation according to the amount of fuel used to produce each energy output. Thus, the method accounts for the efficiency of generating each heat or power output related to a different type of energy. The following formulas reflect the basis of the efficiency method. The efficiency of each utile energy output is weighted according to particular efficiencies of a facility or subsystem that is part of the CHP system.

Emissions assigned to a generic Heat stream output (steam flow H_i) can be determined using formula 6.1.

$$E_{Hi} = \left(\frac{\frac{H_i}{\eta_{Hi}}}{\sum_{i=1}^{n} \frac{H_i}{\eta_{Hi}} + \sum_{j=1}^{k} \frac{P_j}{\eta_{Pj}}} \right) \cdot E_T \qquad (6.1)$$

Emissions assigned to a generic Power stream output

$$E_{Pj} = \left(\frac{\frac{P_j}{\eta_{Pj}}}{\sum_{i=1}^{n} \frac{H_i}{\eta_{Hi}} + \sum_{j=1}^{k} \frac{P_j}{\eta_{Pj}}} \right) \cdot E_T \qquad (6.2)$$

Simplified efficiency method

In some cases, the efficiency method proposed can be difficult to apply because of the complexity of data to be managed.

Consequently, GHG pulp and paper tool guidance [4] proposes a simplified version of the efficiency method using the following criterion:

- There is only one efficiency factor for the total power output (P) and an efficiency factor for the total heat output (H).

Following formulas compile the previous assumptions:

$$E_H = \left(\frac{H}{H + P \cdot \frac{\eta_H}{\eta_P}} \right) \cdot E_T \qquad (6.3)$$

$$E_P = \left(\frac{P}{P + H \cdot \frac{\eta_P}{\eta_H}} \right) \cdot E_T \qquad (6.4)$$

In a system with a gas-fired turbine,

η_H, assumed efficiency of typical heat production (η_H = 0.8 as default value)

η_P, assumed efficiency of typical electric power production (η_P = 0.35 as default value)

Paragraph 6.2.3 develops and details an example using the described methodologies.

6.2.2 Thermodynamic-based methods

Different publications, Rosen [2,3], base CHP emissions allocation on thermodynamic considerations. On one hand, such publications have in common the following assumptions:

- all the energy contained in electrical power is useful and used for calculations
- energy involving output streams is the key strategy to allocate emissions

On the other hand, these methods differ from the evaluation of the thermal energy. The quality of steam and its conceptual final use lead to different methodologies.

- Steam energy basis: the fraction of the total energy in steam is conceived as useful for heat transferring processes.

- Steam exergy basis: the fraction of steam is considered useful for production of the maximum amount of work. Exergy $(H_i - H_0) - T_0 \cdot (S_i - S_0)$ is defined as the *maximum work that can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment* [2]

Both methods take into account that power (electricity) energy can be totally converted into work, meanwhile not all the thermal energy can achieve the same purpose. The method that considers steam as a complete stream used for thermal application –energy basis– applies formulas 6.5 and 6.6 omitting the entropy term: $T(S_i - S_0)$

However, energy basis method just takes into consideration the quantity of energy meanwhile the exergy basis additionally outstands the quality of the energy produced.

$$E_{Hi} = \left(\frac{\dot{m}_i \cdot \left[(H_i - H_o) - T_o \cdot (S_i - S_o) \right]}{\sum_{i=1}^{n} \dot{m}_i \cdot \left[(H_i - H_o) - T_o \cdot (S_i - S_o) \right] + \sum_{j=1}^{k} P_j} \right) \cdot E_T \tag{6.5}$$

$$E_{Pj} = \left(\frac{P_j}{\sum_{i=1}^{n} \dot{m}_i \left[(H_i - H_o) - T_o \cdot (S_i - S_o) \right] + \sum_{j=1}^{k} P_j} \right) \cdot E_T \tag{6.6}$$

The reference conditions are the pressure and temperature conditions of the ambient.

Furthermore, two of the published methods are based on exergy of output streams to allocate emissions. Although both methods can be considered the same because they have the same basis, they differ on the reference environment. Pulp and paper tools protocol [4] names such methodology “work potential method” meanwhile Rosen M.A. [2] defines the mentioned method “exergy basis method”. The exergy basis method described by Rosen recommends as environment reference point the ambient temperature. On the contrary, “work potential” method defines the reference point at temperature of condensates return. The reason is that the method considers that below condensate temperature, the category of work that can be achieved is not utile enough for industrial purposes.

The results of exergy content method vary widely depending on the reference environment. According to Rosen [2], it is important to define them clearly in order to process the right information. The results of the sample case exposed on paragraph 6.2.3 are proving this variability, according to the reference environment selection.

6.2.3 The method put into practice

To demonstrate and to apply the different methods described in previous paragraph, a real CHP plant is used. The normal operation conditions of this plant are described bellow.

6.2.3.1 CHP-1 plant sample case

CHP-1 is a combined heat and power plant, which supplies steam and electricity to a Catalan non-integrated paper mill. CHP-1 operates with natural gas. Steam production in CHP-1 covers the paper mill demand; whereas power production covers the mill demand and the additional power is exported to the Spanish grid.

The CHP receives natural gas from the supplier company at an average pressure of less than 14 bar and ambient temperature. At the same time a system of compressors intake pre-treated air and increase air pressure to 18 bar. Gas pressure is raised at the same pressure level of input air.

The compressed air is introduced into the combustion chamber of the turbine, as well as the natural gas. The combustion reaction and an appropriate turbine design, force the gas to expand. Figure 6.3 details the internal components of the gas turbine in CHP-1 plant.

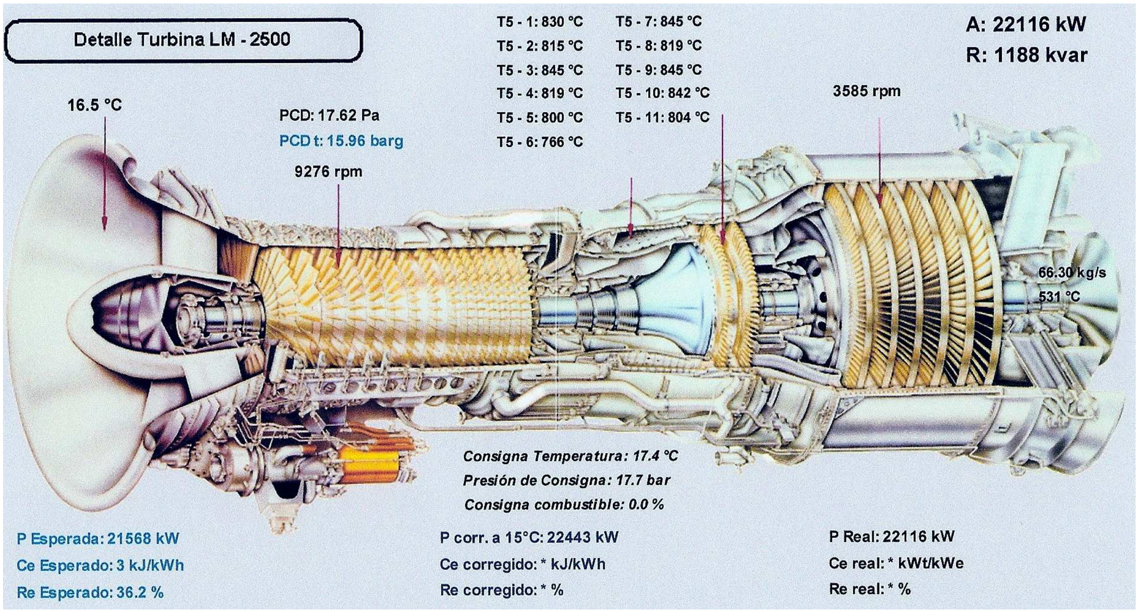


Figure 6.3 Detail of CHP-1 Plant Turbine. This picture is an instantaneous screen display which expresses a punctual mode of operation (2007).

The expansion work produced in the turbine is used to generate electrical power. A power generator is responsible for converting shaft work into electricity. Tension and frequency are synchronised to the standard grid parameters.

Gas turbine produces a large volume of exhaust gases at high temperature. Exhaust gases are derived to a recovery boiler, called heat recovery steam generator (HRSG).

HRSG produces high pressure steam. Steam conditions are 39 bar and 425 ºC (superheated steam).

Additionally, exhaust gases have high oxygen content because the gas-fired turbine operates with high levels of excess air; the turbine use air dilution in combustion to maintain its inlet temperature below design limits.

Therefore, HRSG facility has an auxiliary burner to boost the total available thermal energy and to produce an extra amount of steam (in case it is required by the mill).

Part of this high-pressure steam is sent to the steam header through a pressure-reducing valve. The rest is derived into a steam turbine to obtain an extra amount of electricity.

Figure 6.4 pictures the dual system gas-fired turbine and HRSG of CHP-1 plant.

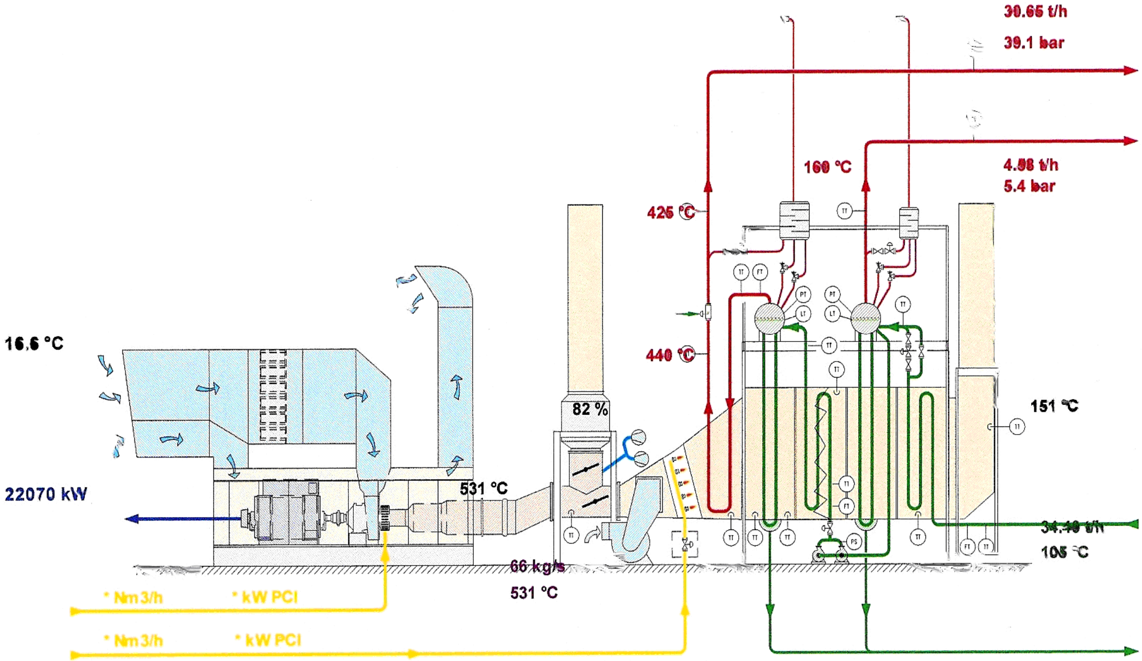


Figure 6.4 Gas Turbine and HRSG system – CHP-1 Plant. Yellow streams correspond to supply gas pipes and the red ones contain the high pressure steam generated in the HRSG. This image is an instantaneous screen display, which expresses a punctual mode of operation in 2007.

As mentioned previously, the auxiliary burner in the HRSG requires some additional fuel to increase the amount of steam generated. A subsequent higher efficiency of the combined system turbine-HRSG is achieved.

HRSG derives two steam outputs. On one side, HRSG produces a saturated steam flow of 4 t/h at five bar that is by-passed to the paper mill header.

On the other side, the main steam flow (30 t/h, 39 bar) is conducted into a steam turbine to generate some extra power (see Figure 6.4).

The condenser steam turbine has an intermediate extraction. The steam turbine is designed to work in two stages; in the first stage, steam suffers an expansion (from 39 bar to 5 bar) and the consequent shaft work of the turbine is used for electrical power generation. At design conditions, from an input steam flow of 30 t/h there is an intermediate extraction of 21 t/h at 165 ºC and 5 bar. This output stream is sent to a steam header. The rest of steam (9 t/h) flows to the second stage of the turbine. Usually steam reaches the condenser at a pressure below 0,1 bar and 50 ºC.

However, the steam turbine is not usually working at the design working conditions. As the mill is requiring a higher quantity of low pressure steam, the extraction step of the steam turbine derives to mill process 28 t/h of steam. Just 2 t/h of steam flows to the condenser. This is the minimum value to accomplish with working specifications. In this case, the thermal stream output of the turbine is working at maximum level meanwhile power efficiency is situated under the designed value.

Steam from the steam turbine is sent to the header as well as the by-passed steam from the HRSG. Header sends part of the steam directly to process meanwhile it directs the rest trough a pressure-reducing valve to achieve the low pressure specifications of the paper mill (3,5 bar). For calculations, steam production is considered at 5 bar, setting the system boundary at the steam main header.

In addition, it should be noted that a diverter valve situated before the HRSG evacuates the exhaust gases of the gas fired turbine to the atmosphere, in case the steam demand of the mill fails. This procedure is justified because the condenser of the CHP-plant is under-dimensioned for such amounts of steam to condense.

The normal operation conditions of the CHP plant with some general data have been diagrammed in Figure 6.5.

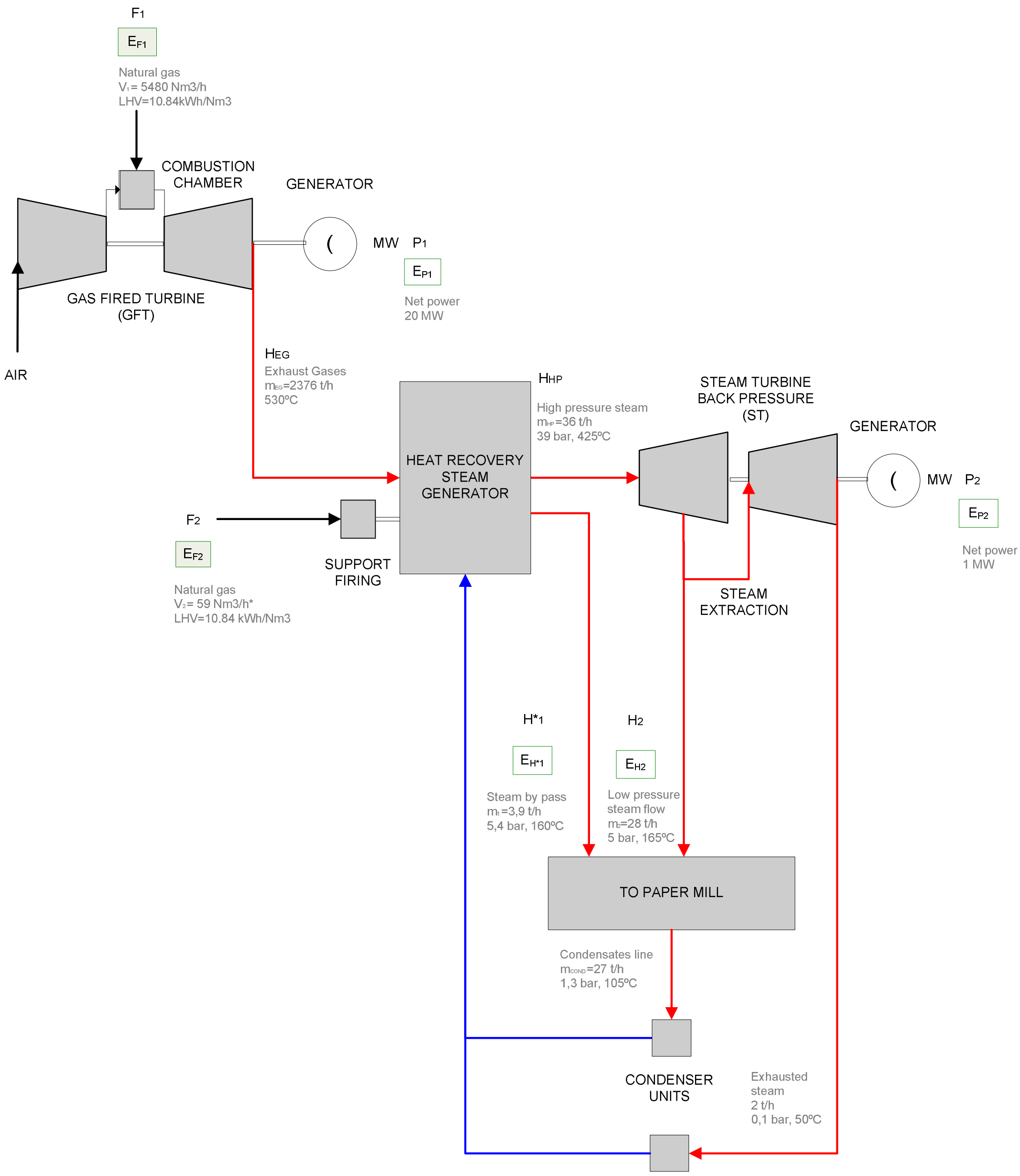


Figure 6.5 Operational data and simplified diagram of CHP-1, according to working annual average results 2006. (*) the gas flow of the support burner is an annual flow average.

Moreover, Table 6.1 summarises the main energy data of CHP-1 plant. The mentioned data is based on operational data of 2006, taking into account that the plant has been working 8.584 hours.

Table 6.1 Energy Data CHP-1 Plant (2006)

CHP-1 PLANT Main energy streams	ANNUAL DATA MWh
Gas Input GFT (F_1)	509.953
Electricity generation GFT (P_1)	171.563
Internal losses GFT	12.749
Exhaust gases GFT (H_{EG})	325.640
Internal consumption GFT	5.695
Gas Input HRSG (F_2)	5.527
Condensates line	24.254
Electricity generation ST (P_2)	7.834
Exhaust gases HRSG	143.414
Steam flow HRSG (HP)	197.866
Steam flow by-pass	26.497
Exhausted Steam ST	12.356
Steam main header (LP)	177.676
Total steam production	204.173

Figure 6.6 presents a diagram of CHP-1 plant with its energy balance based on the annual data from year 2006 (Table 6.1)

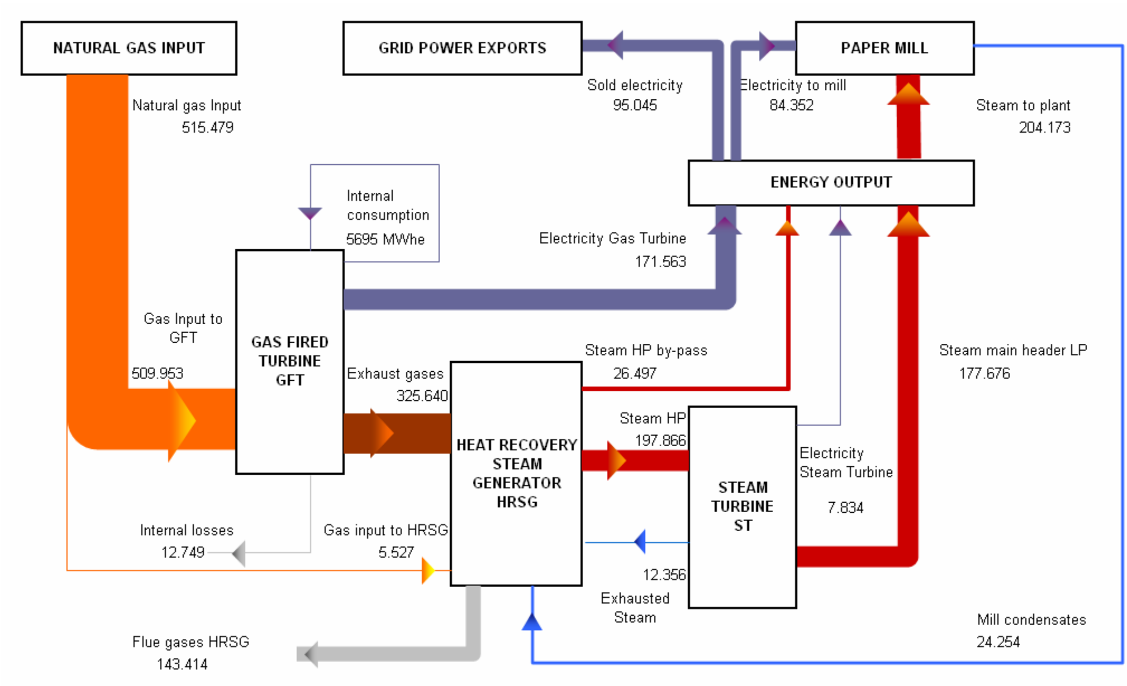


Figure 6.6 CHP-1 diagram. Energy balance using annual data 2006. Values expressed in MWh

As exergy terms are used in exergy basis method, Table 6.2 presents exergy balance resulting from CHP-1 streams. Some indications regarding calculation formulas are added to the corresponding results of the mentioned table.

Table 6.2 Exergy Balance – CHP-1 Plant (annual data 2006)

STEAM STREAMS	MASS [m]	SPECIFIC EXERGY [ψ]	EXERGY ψ=[m·ψ]
	t/y	kWh/t	MWh
Exhaust gases GFT (H_{EG})	1.973.312	65,8	129.851
Condensates line	198.440	12,3	2.450
Exhaust gases HRSG	1.973.312	6,7	13.214
Steam flow HRSG (HP)	240.352	350,8	84.323
Steam flow by-pass	24.235	212,8	5.158
Exhausted Steam ST	17.168	55,2	948
Steam main header (LP)	240.352	211,4	50.808
Total steam production	264.587	211,4	55.931
Gas Input GFT (F_1)			407.962
Electricity generation GFT (P_1)			171.563
Internal losses GFT			12.749
Electric Internal cons. GFT			5.695
Electricity generation ST (P_2)			7.834
Gas Input HRSG (F_2)			4.421

* For exergy balance, T_o =20 ºC, P_o =1 bar. Natural gas exergy is approached by V·(LHV)·W where W is a simplified factor to convert enthalpy of gas to exergy (W=0,8). **m** is the annual mass flow of each stream. The enthalpic mass exergy is expressed with symbol **ψ.** When determining total steam production, it has been approached that the by-pass exergy reaches the same T, P conditions at the main header, (because of pressure losses in steam pipes).

In addition, Figure 6.7 provides a CHP-1 plant diagram according to the exergy balance expressed in Table 6.2. The exergy basis method described in lines below uses results of Table 6.2 for its calculations.

6.2.3.2 CHP Emissions attributable to power and to steam production

Following paragraphs analyse results of emission factors attributable to power and steam, using the methods exposed in the previous paragraphs.

CHP-1 plant has daily net calorific values of natural gas (supplied by the gas company). The annual average of daily calorific values was 10,84 kWh/Nm^3 (LHV) in 2006. The daily values vary an average of $\pm 4\,\%$ from the annual average. The CO_2 emission factor of natural gas has been considered 56 $kgCO_2/GJ_{LHV}$. This factor includes the oxidation factor. This value has been published by Spanish government

[5], and at the same time it is based on IPCC [6]. In equivalent units, the emission factor is 0,202 kgCO_2/kWh (the oxidation factor is included in the emission factor).

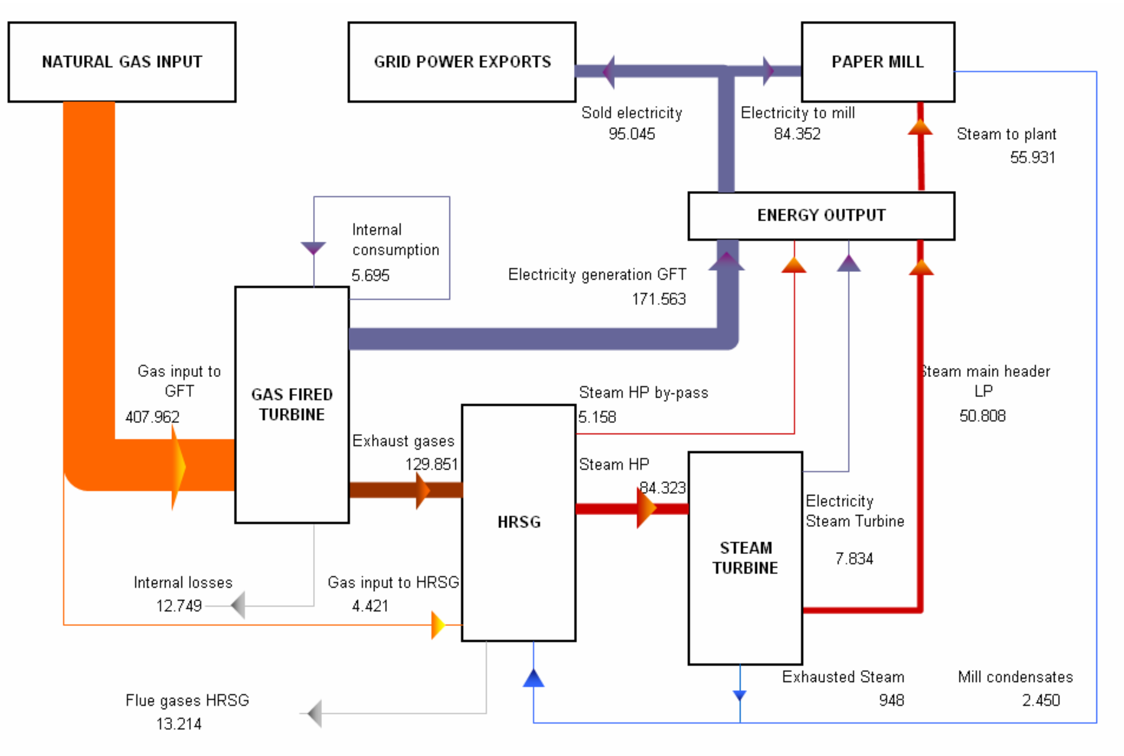


Figure 6.7 CHP-1 diagram. Exergy balance using annual data 2006. Values expressed in MWh of exergy

CO_2 emitted in the gas-fired turbine E_{F_1} is estimated using formulas 3.4 and 3.5 (exposed in chapter 3).

$$E_{F_1} = V_1 \cdot LHV_{NG} \cdot F_{CO_2} = 102.806 \text{ tCO}_2 \tag{6.7}$$

With the same formula, the extra amount of gas boosted in the auxiliary burner (F_2) is responsible for emitting E_{F_2} :

$$E_{F_2} = 1.114 \text{ tCO}_2 \tag{6.8}$$

Therefore, Table 6.3 summarises the annual emissions of CHP-1 plant (2006).

Table 6.3 Emissions of CHP-1 plant (2006)

TOTAL EMISSIONS CHP-1 PLANT	tones CO_2
Fuel Emissions (E_{F1})	102.806
Fuel Emissions (E_{F2})	1.114
Total Emissions	103.921

To estimate emissions according to Spanish legislation, NAP provides to plants a fixed specific heat value. During 2006, the specific heat value (LHV) for natural gas was $38{,}97\cdot10^{-2}$ GJ_{LHV}/Nm^3 (10,83 kWh/Nm^3). This value differs less than 1% from the average of particular heat value provided by the gas supplier of the paper mill.

The following methods are attributing emissions of Table 6.3 into power and steam generation.

6.2.3.3 Allocation based on the efficiency of the system facilities

Efficiency method

Calculations are based on technical data supplied by the manager in charge of the CHP-1 plant. Data is based on operational conditions.

- Gas fired turbine efficiency (to produce electrical power). η_{GFT} = 0,33, the design value is 0,35.
- Exhaust gases efficiency from gas turbine, η_{EG}=0,64. It is supposed a 2,5% of thermal and mechanical internal losses.
- Efficiency of the HRSG, η_{HRSG}= 0,7 without auxiliary burner
- Efficiency of combustion of support burner (SB) η_{SB} ≈1
- Back Pressure Steam Turbine power efficiency η_{ST} =0,12

The efficiency method is based on the efficiency of each stream energy output, which is associated with the corresponding facility. CHP-1 has four utile output streams:

- Electric power generation GFT (P_1)
- Electric power generation ST (P_2)
- Steam output, by-pass (H^*_1) 5 bar 165 ºC
- Steam output, main flow (H_2) 5,4 bar 160 ºC

The efficiency method attributes emissions produced in the gas-fired turbine E_{F_1} to the following streams:

- Electric Power generation GFT: E_{P_1}
- Exhaust gases (of the gas fired turbine): E_{EG}

Following the energy track, the additional emissions produced in the support burner of the HRSG (E_{F_2}) and emissions attributed to the exhaust gases of the gas turbine (E_{EG}) are allocated into the following streams:

- Electric Power generation ST: P_2
- Low pressure steam: H^*_1 and H_2

Moreover, the exhaust gases of the GFT have the following energy content:

$$H_{EG} = 325.640 \ \text{MWh} \tag{6.9}$$

Emissions attributable to exhaust gases are calculated with equation 6.1 from the Efficiency method.

$$E_{EG} = \left(\frac{\frac{H_{EG}}{\eta_{EG}}}{\frac{H_{EG}}{\eta_{EG}} + \frac{P_1}{\eta_{P_1}}} \right) \cdot E_{F_1} = 51.403 \ t_{CO_2} \tag{6.10}$$

Note that η_{P_1} is defined as the efficiency of the gas fired turbine (η_{GFT}).

Thus, emissions attributable to electric power P_1 achieve the same value as the exhaust gases. The reason of such result is that the method weights the share of emissions in equal parts, as the terms H_{EG} and η_{EG} are obtained by energy balance.

$$E_{P_1} = \left(\frac{\frac{P_1}{\eta_{P_1}}}{\frac{H_{EG}}{\eta_{EG}} + \frac{P_1}{\eta_{P_1}}} \right) \cdot E_{F_1} = 51.403 \ t_{CO_2} \tag{6.11}$$

Emissions attributable to low pressure steam production H_2 and to electric power P_2 production have their origin in:

- Fuel combustion in support burner of HRSG E_{F_2}
- Emissions of exhaust gases E_{EG}

Consequently, total emissions attributable to low pressure steam production (H^*_1 and H_2) and steam turbine power (P_2) are the followings:

$$E_{EG} + E_{F_2} = E_{H_2} + E_{P_2} + E_{H_1} = 52.517\ t_{CO_2} \tag{6.12}$$

As it has been explained in the description of CHP-1, a small part of the high pressure steam generated in the HRSG is by-passed to the paper mill (it is not derived to the steam turbine). Therefore, some emissions should be associated with this output steam stream H_1*.

The emission factor of the H_1^* steam by-pass is then calculated as:

$$F_{CO_2}(H_1*) = \frac{E_{EG} + E_{F_2}}{H_1} = 0{,}296\ t_{CO_2}/MWh \tag{6.13}$$

$$E_{H_1^*} = F_{CO_2} \cdot H_1* = 7.831\, t_{CO_2} \tag{6.14}$$

Concerning the rest of the steam flow, two additional efficiencies are associated with steam generation in HRSG. The first one is based on the efficiency of the auxiliary burner and the second is related to the heat recovery capacity.

$$\eta_{H_{HP}} = \eta_{SB} \cdot \frac{F_2}{F_2 + H_{EG}} + \eta_{H_{HRSG}} \cdot \frac{H_{EG}}{F_2 + H_{EG}} = 0{,}705 \tag{6.15}$$

Therefore, efficiency of stream power P_2 can be defined as:

$$\eta_{P_2} = \eta_{H_{HP}} \cdot \eta_{ST} = 0{,}085 \tag{6.16}$$

Therefore, emissions attributed to P_2 and rest of steam flow H_2 are assigned according to formulas 6.17 and 6.18:

$$E_{P_2} = \left(\frac{\frac{P_2}{\eta_{P_2}}}{\frac{H_{H_2}}{\eta_{H_2}} + \frac{P_2}{\eta_{P_2}}} \right) \cdot (E_{H_2} + E_{P_2} - E_{H_1}) = 12.007\ t_{CO_2} \tag{6.17}$$

$$E_{H_2} = \left(\frac{\frac{H_2}{\eta_{H_2}}}{\frac{H_2}{\eta_{H_2}} + \frac{P_2}{\eta_{P_2}}} \right) \cdot (E_{H_2} + E_{P_2} - E_{H_1}) = 32.679\ t_{CO2} \tag{6.18}$$

It has to be remarked that η_{H_2} is equivalent to $\eta_{H_{HP}}$

Table 6.4 compiles the emissions associated with each of the streams according to calculations of the previous paragraph.

Table 6.4 Emissions Associated with each of the energy outputs of CHP-1 (2006 data)

OUTPUT STREAM	EMISSIONS ALLOCATION tCO_2	SHARE
Gas turbine power output P_1	51.403	49%
Steam turbine power output P_2	12.007	12%
Steam (by pass) H^*_1	7.832	8%
Steam (main flow) H_2	32.679	31%
Total	103.921	100%

In addition, Table 6.5 presents the emission factors attributed to steam and power generation.

Table 6.5 Emission factors of CHP-1 using efficiency method

ENERGY STREAM CHP-1	ENERGY MWh	EMISSIONS ALLOCATION tCO_2	EMISSION FACTOR tCO_2/MWh
Steam	204.173	40.511	0,198
Power	179.397	63.410	0,353

According to Table 6.5, it can be observed that the emissions assigned to electricity generation double the emissions attributed to steam production, per MWh of energy.

Simplified efficiency method

As mentioned in the previous paragraphs, the efficiency method can be simplified in the case that CHP plant does not have enough information or does not want to use detailed efficiency information for its CHP utilities.

The simplified efficiency method considers the following default values:

- Efficiency of the steam generation η_H = 0,80
- Efficiency of power production η_P = 0,35

Emissions produced in the gas turbine or in the HRSG have already been estimated in the efficiency method example.

Therefore, once all this information is collected, CO_2 emissions attributable to generation of steam (H) are calculated according to formula 6.3.

$$E_H = \left(\frac{H}{H + P \cdot \frac{\eta_H}{\eta_P}} \right) \cdot E_T = 31.269 \ t_{CO_2} \tag{6.19}$$

In addition, applying formula 6.4 the emissions attributable to power generation are determined bellow.

$$E_P = \left(\frac{P}{P + H \cdot \frac{\eta_P}{\eta_H}} \right) \cdot E_T = 72.651 \ t_{CO_2} \tag{6.20}$$

Table 6.6 compiles the results obtained by simplifying the efficiency method. In the particular case of CHP-1 plant, the efficiency method allocates lower amounts of emissions to steam generation.

Table 6.6 Emission factors of CHP-1 plant using simplified efficiency method

ENERGY STREAM	ENERGY	EMISSIONS ALLOCATION	ALLOCATION SHARE	EMISSION FACTOR
CHP-1	MWh	tCO_2	%	tCO_2/MWh
Steam	204.173	31.269	30%	0,153
Power	179.397	72.651	70%	0,405

Comparing Table 6.5 and Table 6.6 results –in the particular case of CHP-1 plant– it appears a significant difference of results because the normal operation conditions differ from the default or ideal design default value.

To summarise, efficiency methods allocate emissions into energy outputs considering the amount of fuel and the efficiency of individual units of the CHP plant. Efficiency method requires specific data from CHP plant and additional complex calculations. Simplified efficiency method can be defined as an easy-to-implement method.

6.2.3.4 Allocating emissions based on energy content of products

The following methods allocate emissions according to the energy quality of stream outputs.

Energy content method

The energy content method calculations are simple than the previous efficiency method. Power energy content is assimilated to the useful power generated in both turbines and steam energy content is associated with steam enthalpy, taking into account the return of condensates to the CHP plant.

In CHP-1 plant condensate returns at 105 ºC and 1,2 bar. Steam useful energy is calculated using the data exposed on Figure 6.6 and Table 6.1.

$$\mathrm{H} = \dot{m} \cdot \left(H_1 - H_o \right) = 167.563 \text{ MWh} \tag{6.21}$$

Where $\dot{m}$ is the sum of the two main output steam flows derived to energy use

$$\dot{m} = (\dot{m}_1 + \dot{m}_2) \tag{6.22}$$

H_1 is the enthalpy of the steam flow at the main header (5 bar, and 165 ºC). Table 6.7 presents the results of the energy content applied to energy output streams of CHP-1.

Table 6.7 shows how this method attributes approximately the same share of emissions to power and steam generation.

Table 6.7 Energy Content Method Calculations – CHP -1 plant, 2006 annual data

ENERGY STREAM	ENERGY	ALLOCATION SHARE	EMISSIONS ALLOCATION	EMISSION FACTOR
CHP-1	MWh	%	tCO_2	tCO_2/MWh
Power energy Content P_1	171.563	49	51.386	0,300
Power energy Content P_2	7.834	2	2.346	
Steam energy content	167.563	48	50.188	0,246
Total	346.960	100	103.921	

The method assumes steam energy is used for thermal transference and this assumption corresponds to the end-use of the steam in a paper mill. However, if emissions are allocated according to energy content of utile streams, it should be considered the energy content itself, rather than the global enthalpic balance of the steam flow conditions and the reference environment. Furthermore, some experts understand the method simplifies in excess the steam concept; according to Rosen [3] energy content method does not undertake the quality of energy because it just focuses on its quantity.

6.2.3.5 Allocation based on exergy content of products

Exergy method considers the exergy content of power and steam output streams. As mentioned, this method can be applied considering two reference environments.

Reference conditions: Return of condensates

Formula 6.23 presents the exergy content of steam stream output of CHP-1 at the reference temperature of the condensate return line:

$$\psi_H = \overset{o}{m} \cdot \left[(H - H_o) - T_o \cdot (S - S_o) \right] = 18.447 \text{ MWh} \tag{6.23}$$

Table 6.8 Exergy Content Method Calculations CHP-1 (reference conditions: condensates line)

ENERGY STREAM CHP-1	EXERGY MWh	ALLOCATION SHARE %	EMISSIONS ALLOCATION tCO_2	EMISSION FACTOR tCO_2/MWh
Power exergy Content P_1	171.563	87	90.116	0,525
Power exergy Content P_2	7.834	4	4.115	
Steam exergy Content	18.447	9	9.689	0,047
Total	197.844	100	103.921	

Exergy content method highlights exergy of output streams. In this context, exergy concept is introduced to quantify and qualify flow outputs based on this thermodynamical criterion. The useful energy fraction of the total energy in steam corresponds to the maximum amount of work that could be extracted from the steam in a thermodynamically reversible process. GHG pulp and paper tools authors [4] argue that the exergy basis method is focused on the premise that steam streams from the cogeneration systems are derived to mechanical primer movers. Thereby, work potential method should not be appropriate for CHP systems that include a hot water output stream.

Reference conditions: ambient

Table 6.9 shows the application results of exergy content method considering the ambient temperature (20 ºC, 1 bar) as the reference state for exergy calculations.

Table 6.9 Exergy content method Calculation results – CHP-1 (reference conditions ambient temperature)

STREAM EXERGY CHP-1	EXERGY MWh	ALLOCATION SHARE %	EMISSIONS ALLOCATION tCO_2	EMISSION FACTOR tCO_2/MWh
Power exergy Content P_1	171.563	73	75.762	0,442
Power exergy Content P_2	7.834	3	3.459	
Steam exergy Content	55.931	24	24.699	0,121
Total	235.328	100	103.921	

This method attributes less carbon dioxide to power generation than to the steam generation.

Exergy content method is recommended by Rosen [3], whom considers his method prevents underestimating the share of the emissions assigned to electrical power. However, this work states that the selection of ambient temperature as reference environment presumes that steam is derived to mechanical prime movers and exhausted in such systems. It is considered that a CHP-plant that uses steam as a thermal transference vector should use condensate conditions as reference environment.

6.2.3.6 Comparing methodology results of emissions allocations in sample case CHP-1

Table 6.10 compiles the results of the different allocation methods applied to CHP-1. In all the methods applied, the power emission factor is higher than the steam factor.

Table 6.10 Emission Factor CHP-1 using different methods of allocation

ALLOCATION METHOD	POWER FACTOR tCO_2/MWh	STEAM FACTOR tCO_2/MWh
Simplified Efficiency Method	0,405	0,153
Efficiency method	0,353	0,198
Energy Content	0,300	0,246
Exergy Content (cond. ref)	0,525	0,047
Exergy Content (amb. ref)	0,442	0,121

In addition, Figure 6.8 presents the allocation of steam and power emissions based on the different methods applied in the case of CHP-1

On one hand, efficiency method allocates up to 61% of the emissions to power generation and the rest to steam production. On the other hand, the energy content weights in a similar share power and steam generation. Exergy content method (ref. point condensates), provides considerable less weight to steam generation (9%).

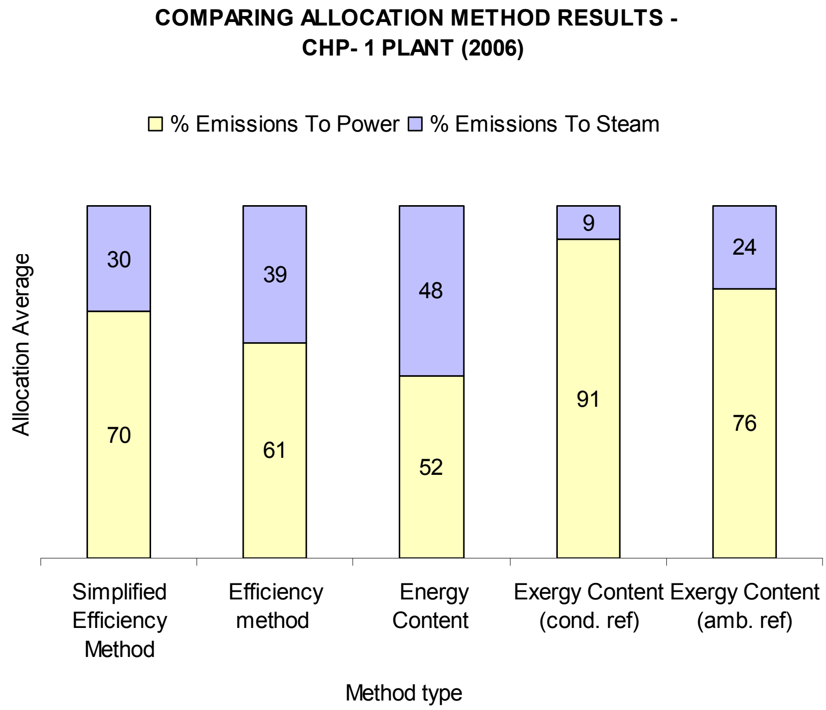


Figure 6.8 Comparing allocation method results – CHP 1 Plant (2006) Cond.ref abbreviates condensates reference, Amb. Ref abbreviates ambient.

Finally, the exergy content method (ref. point ambient temperature) allocates nearly 75% of CHP emissions to power generation.

6.2.4 Concluding remarks of the different allocation methods

This thesis states that each of the methods is based on a consistent principle, thus it is difficult to recommend one of them.

- Efficiency method allocates steam and power emissions according to the efficiency of the facilities that are composing the CHP-plants; this should correspond to the amount of energy needed to generate power and steam vectors.

- Energy content method assumes an emission allocation according to the outputs of the CHP-plant. It does not take into account how those energy vectors have been obtained, as the method focuses on the quantity of energy that the CHP-plant can derive to the near-by consumers. The method is not considering the concept of work potential end-use of these energy outputs.

- Exergy content method is also conceiving the energy amount of the CHP-outputs as the key-base to allocate emissions. However, it clarifies that CHP output vectors have to be characterised not only for their energy quantity but also for the quality of the service that these streams are meant to supply within the plant scope.

Concluding, all methods studied, allocate emissions into power and steam outputs. However, they do not provide enough weight to the inefficiencies of the system, both the intrinsic and the related to operation modes. Otherwise, a considerable quantity of emissions should be attributable to the waste stream of the system itself. Considering a normal HRSG efficiency about 80%, at least 20-25% of emissions can be assigned to flue gases vented to the atmosphere (as in Figure 6.6). The inefficiencies can even increase if CHP plants might not use all the utile heat or steam and consequently condensers or the atmosphere must absorb it, not obtaining utile work. This fact is common when the paper mill has operation downtimes.

Of course, inefficiencies might respond to an incorrect design of the CHP plant. However, it is understood that energy has to be utilised as efficiently as possible. Plants should be designed using thermal demand as limiting factor. Enhancing electricity production might lead to huge quantities of exhaust gases (still with an energy potential) thrown up to the atmosphere.

To conclude, this work proposes an alternative method assuming the whole of the already exposed remarks.

6.2.5 Allocation method new proposal

According to the reasons explained above, it is aimed to add another point of view to the allocation methods.

Therefore, it is proposed a method that undertakes the following points:

- Emissions of fossil combustion in a CHP plant should be attributed to:

   - Heat and power utile streams
   - Non utile streams or inefficiencies

- Heat and power utile streams should be quantified as the net power production and the capacity of thermal transference (if it is the case) of steam or heat, respectively.

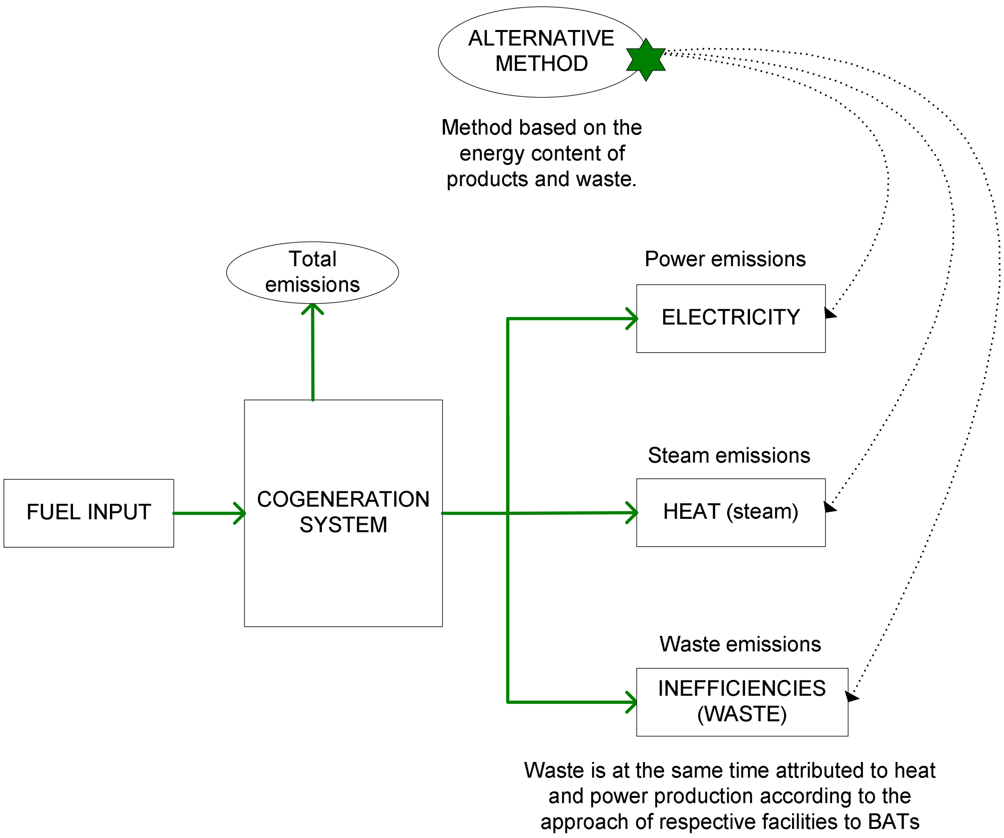


Figure 6.9 Allocation of CHP emissions according to stream outputs and waste

- The inefficiencies or non-utile work should be attributed to the inefficiency of components of the CHP and to the corresponding output streams. For example, if a turbine or HRSG does not work properly, part of the emissions inefficiency concept should be allocated to the power stream and another amount of its emissions to the steam stream. It is proposed to assign the corresponding quantity weighted, according to the BAT efficiency per each CHP-component and technology.

- The inefficiencies of the CHP plant can be attributed to the gas-fired turbine and to the HRSG working conditions. The questions could be: how inefficient these technologies are and how efficiently is the system working, considering the reference point of the BATs? How much can they improve?

According to these presumptions, the emissions to power and steam could be calculated with the following formulas:

$$E_H = \left(\frac{\sum_{i=1}^{n} \overset{\circ}{m}_i \cdot H_i}{\sum_{i=1}^{n} \overset{\circ}{m}_i \cdot H_i + \sum_{j=1}^{k} P_j} \right) \cdot E_T + E_{WH} \qquad (6.24)$$

Where E_{WH} are the emissions attributed to waste heat [tCO_2]:

$$E_{WH} = E_w \cdot F_{WH} \qquad (6.25)$$

Where,

E_W are the emissions assigned to waste heat stream and can be calculated by energy balance [tCO_2]

F_{WH} is the waste heat factor defined as

$$F_{WH} = \frac{\eta_{HBAT} - \eta_H}{(\eta_{HBAT} - \eta_H) + (\eta_{PBAT} - \eta_P)} \qquad (6.26)$$

Where

η_{HBAT} is the efficiency of steam production facility using a BAT process

η_H is the efficiency of steam production facility in the specific CHP plant

η_{PBAT} is the efficiency of main power production facility using a BAT process

η_P is the efficiency of main power production facility in the specific CHP plant

On the other hand, emissions due to electricity production are defined as:

$$E_P = \left(\frac{\sum_{j=1}^{k} P_j}{\sum_{i=1}^{n} \overset{\circ}{m}_i \cdot H_i + \sum_{j=1}^{k} P_j} \right) \cdot E_T + E_{WP} \qquad (6.27)$$

Where, E_{WP} are the emissions attributed to waste power [tCO_2] and defined as:

$$E_{WP} = E_w \cdot F_{WP} \tag{6.28}$$

And F_{WP} is the waste power factor defined as:

$$F_{WP} = \frac{\eta_{PBAT} - \eta_P}{(\eta_{HBAT} - \eta_H) + (\eta_{PBAT} - \eta_P)} \tag{6.29}$$

An example of the proposed method is presented below. The same sample case and data of CHP-1 plant is used for calculations.

Table 6.11 presents the emissions allocation by energy content of utile and non-utile energy stream outputs of CHP-1 plant.

Table 6.11 Share of emissions of the different output streams of CHP-1

STREAM NAME	ENERGY	SHARE	EMISSIONS ALLOCATION	
CHP-1	MWh	%	tCO_2	
Power energy Content	179.397	37%	E_P	38.432
Steam Energy Content	204.173	32%	E_H	33.768
Waste Energy content	168.519	31%	E_W	31.721
Total	552.089	100%	E_T	103.921

The inefficiencies of the CHP plant can be attributed to the gas-fired turbine and to the HRSG working mode. Table 6.12 calculates the ratio of improvements for each of these technologies. The average of inefficiencies emission attribution is calculated by the maximum ratio of improvements that both could achieve.

Table 6.12 Allocating stream inefficiencies to power and steam streams, considering BATs

ALLOCATING INEFFICIENCIES	UNIT EFF. VALUE (η)	BAT EFF. VALUE (ηBAT)	Δ (ηBAT – ηUNIT)	F_W
Gas fired Turbine (power)	33%	38%	5%	0,32
HRSG (steam)	70%	80%	10%	0,68

Energy BREF does not contain the BATs efficiencies for CHP components. However, as reference points, it has been taken other contrasted values from an own benchmarking research.

Table 6.13 presents the results of the emissions allocations according to the method proposed –using formulas 6.24 - 6.29.

Table 6.13 Results of the allocation proposed method

UTILE STREAM	EMISSIONS ALLOCATION	ALLOCATION SHARE	EMISSION FACTOR
CHP-1	tCO_2	%	tCO_2/MWh
Power production	48.950	47%	0,273
Steam production	54.971	53%	0,269

CHP-1 plant emissions are being allocated in a major grade to steam generation. Concluding, if a CHP plant is capable to produce a large quantity of steam but it just leaves exhaust gases through the diverter valve and misuses its energy consumption, emissions should be allocated to steam production rather than to power production. In addition, if the power engine is not working at the design value, some of the emissions should weight this fact.

6.3 ESTIMATING GRID POWER FACTOR

As it has been expressed earlier in this work, paper mills can also depend on a grid system to cover its electricity demand. A grid system consists of an interconnected group of power facilities, wherein electricity is generated using a variety of technologies and raw materials. Some of the electricity producers of the system emit significant amounts of GHGs, mainly in form of carbon dioxide gas. The totality of emissions produced by the system is used to determine a grid-power emission factor, which should globally quantify GHG emissions per megawatt-hour of electricity generated.

Such factor should be used to approach the indirect emissions of the company, in the case of power purchase from a grid system.

The following paragraphs describe a methodology to calculate a grid power emission factor. This methodology is applied to the national grid power system of Spain.

Consequently, lines below review the state of the electricity generation in Spain, the available data on electricity production and CO_2 emissions assigned to this production as well as the assumptions and calculations achieved in order to determine a national grid power factor.

As denoted later in results, grid power factor is not at all a fixed value. The electricity generation mix (role, type and number of power producers) adds to this factor fluctuant features. Climate and weather conditions might lead to peak-loads on hydro or wind power plants, meanwhile market peak-demands might derive to over-operation of coal or thermal plants. The preventive down-times of nuclear plants can also entail some fluctuations. Therefore, power emission factor will fluctuate according to plants operation profiles.

Furthermore, as Spain is formed by 17 autonomous regions, grid power factors have been determined for each of the regions.

Although Spanish government has not publicly disclosed a grid power factor, the factor obtained in this work is compared with the one published by International Energy Agency. In addition, the obtained factor is compared to the factors of other countries, by means of the same source.

6.3.1 Calculating grid power factor of a group of facilities

It is proposed to determine a Grid Power Factor (F_{CO2}) using the following formula:

$$F_{CO_2} = \frac{\sum^{i} EP_i}{\sum^{i} P_i} \tag{6.30}$$

Where,

F_{CO_2} is the grid power factor [tCO_2/MWh]

i is the number of electricity producers that compose the system

EP_i are the emissions attributable to each electricity producer in a particular time-period [tCO_2]

P_i is the power production of each power generator in the same time-period

Nevertheless, the power factor obtained with this formula encloses the emissions produced by the system, but it does not include power exchanges with other systems neither the distribution losses achieved at the end of the chain supply, the final consumer.

To quantify indirect emissions related to power consumption it is proposed to take into account the emissions produced by the system and the inefficiencies of transmission losses. It is not taken into consideration the emissions that could be allocated to imports and exports. This thesis fixes the last mentioned assumption, understanding that the operational approach boundary is reproduced in this inventory (see chapter 3, paragraph 3.2.2.3).

Therefore, equation 6.31 presents the power factor - F'_{CO_2} - that should be applied when quantifying emissions from power consumed in a paper mill.

$$F'_{CO_2} = \frac{\sum^{i} EP_i}{\sum^{i} P_i}(1 + T_l) \qquad (6.31)$$

T_l is the coefficient of transmission losses, calculated as the unitary average of grid transference inefficiencies according to the range of transmission-level voltage.

6.3.2 Description of the electricity system of Spain

To supply Spanish energy demand, the country has different power production facilities, such as:

- Hydro power plants
- Nuclear plants
- Thermal plants
- Renewable energy plants such as biomass, wind power or solar photovoltaic

As an additional support, Spain is interconnected to Portugal, France and Morocco. Electricity from international exchanges ensures the safety and quality of the Spanish demand.

In Spain, Red Eléctrica Española (REE) is the company in charge of the whole grid transmission, to transfer electric power from the areas of production to the areas of consumption. This company also controls the power operation system of Spain. It ensures the technical conditions needed to enable power to flow continuously from the power generators to the centres of consumption.

REE allows generators to sell electricity to the system in a regulated tariff or in a liberalised market modality.

In addition, according to the scale of generation and technology, power generators are categorised as ordinary and special rating producers.

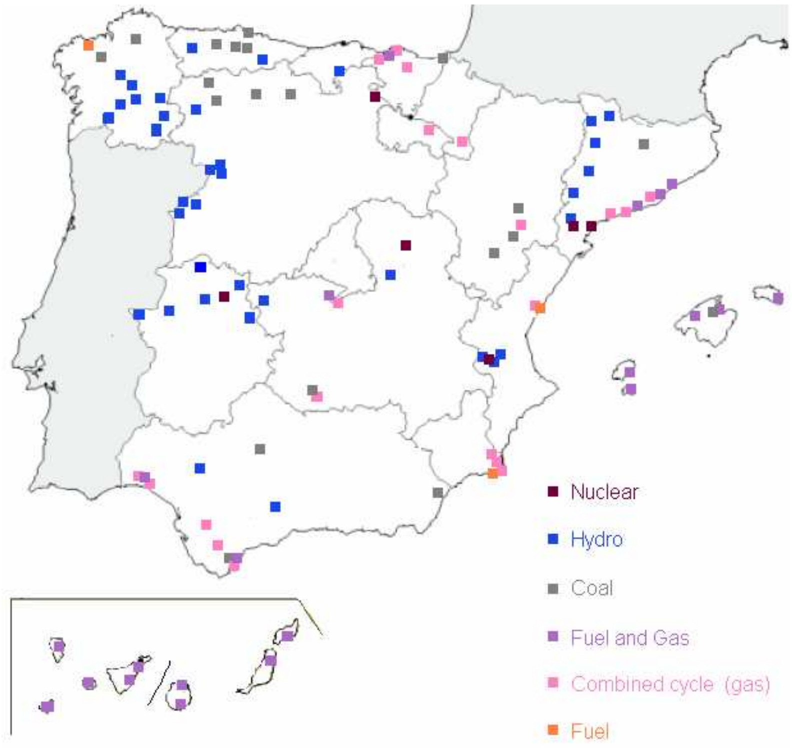


Figure 6.10 Power generation mix in Spain. Based on REE data [8]. The northern regions have a considerable number of coal plants meanwhile islands are covering their electric demand by fuel or gas thermal plants.

Ordinary rating production includes high capacity and conventional generation plants, such as

- Hydro power
- Nuclear plants
- Conventional thermal plants
- Combined cycled plants (gas)

Figure 6.10 shows the electricity facilities of Spain, operating in terms of ordinary rating.

Meanwhile the special rating production includes:

- Solar plants (photovoltaic)
- Wind power plants
- Small hydro power plants
- Thermal waste plants, such as municipal solid waste plants
- Biomass plants
- Cogeneration plants (low power capacity in comparison to combined cycle plants)

Figure 6.11 and Figure 6.12 depict the total installed power in Spain considering the two ratings of electricity generation.

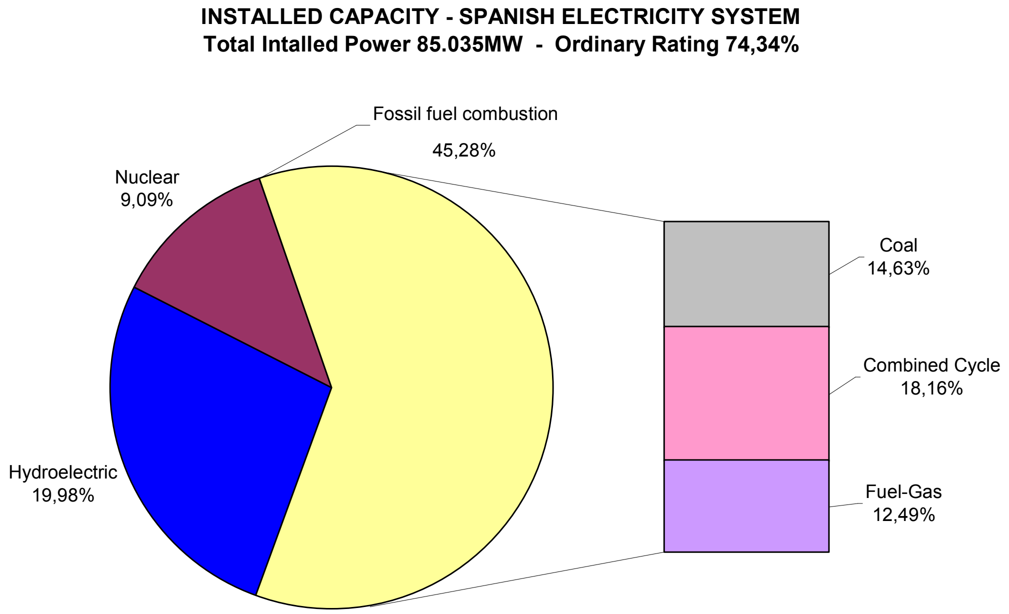


Figure 6.11 Installed Power in Spain 2006. Ordinary Rating. Based on UNESA data [7] Nearly 75% of the installed power in Spain corresponds to facilities working on ordinary operating conditions.

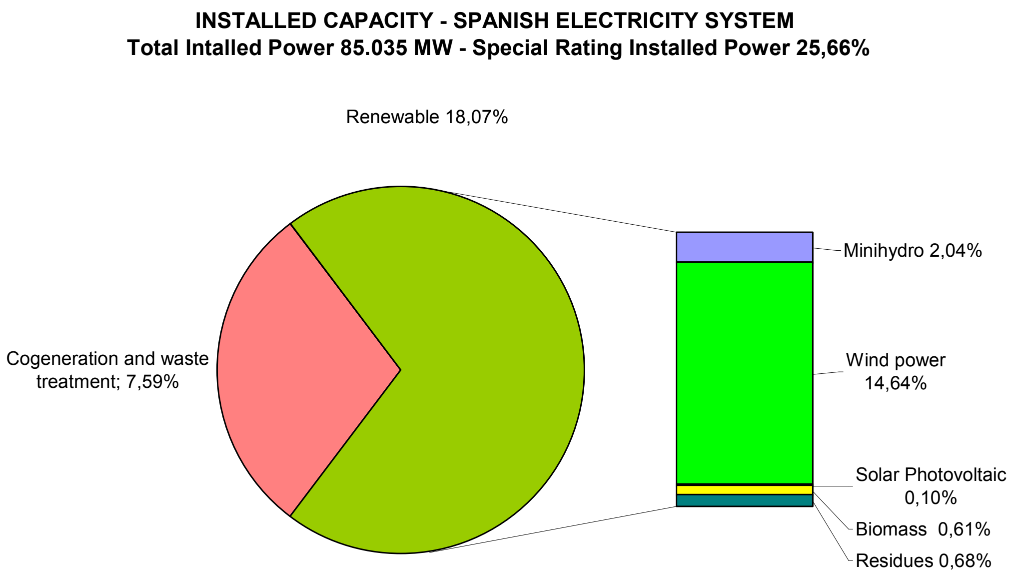


Figure 6.12 Installed Power in Spain 2006. Special Rating. Based on UNESA data [7]. Special rating includes cogeneration systems and wind power.

6.3.3 Spain electricity system and its productivity profile

Figure 6.13 presents the evolution of Spanish electricity system during the period 2004 -2006. This figure shows how Spain is reducing coal generation plants by promoting the activity of combined gas cycles and maintaining the activity of nuclear power plants. The renewable energy sector is slowly reinforced, particularly due to investment in wind power plants. In the term “non renewable –special rating” are included some small thermal or cogeneration systems using fossil fuels. These facilities have lowered their activity over the period 2004-2006. This fact is due to the closure of some fuel oil cogeneration plants and the reduction of working hours of the rest of cogenerations.

From another point of view, Figure 6.14 shows the energy distribution ratios of electricity productivity in 2006. It should be outlined that coal, nuclear and combined cycle (gas) plants are responsible for the 3/4 of the total electricity produced in Spain. The rest of the production is covered by hydroelectric, other renewable energies and thermal special

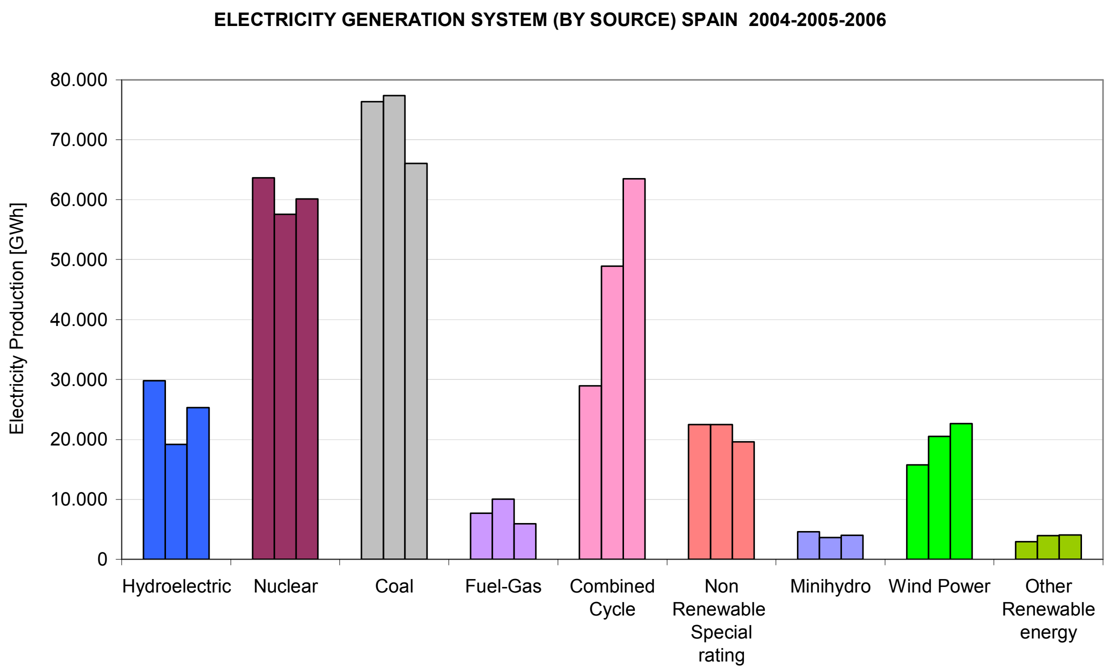


Figure 6.13 Electricity Generation in Spain (peninsular system) by type of activity. Based on REE [8]. * None-renewable includes: natural gas, refiner and fuel, coal CHP plants; other renewable includes: solar photovoltaic, biomass and thermal residues. The three columns correspond to energy data from 2004-2005-2006 from left to right.

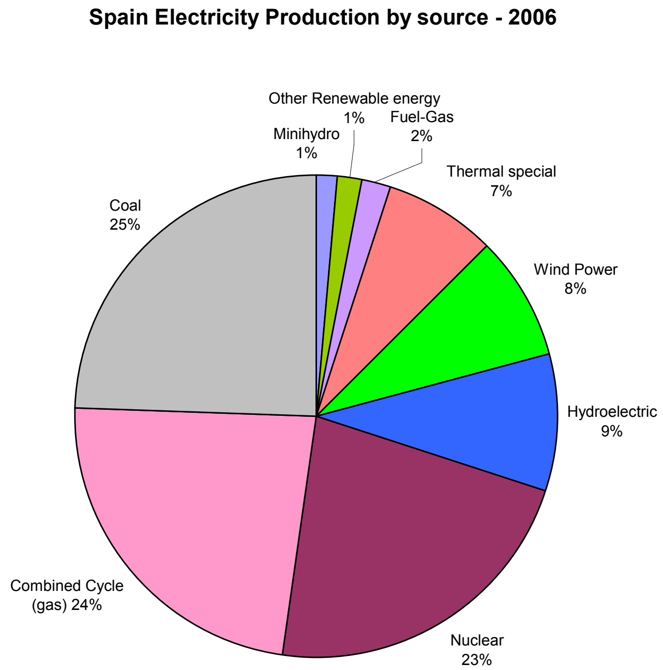


Figure 6.14 Electricity Generation System. Spain 2006. Main Activities. Based on REE data [8] Average of the electricity produced by the different power generators of the Spanish system. Nuclear, combined cycle and coal facilities were the main electricity producers in 2006.

As mentioned, Spanish system has an extra support of electricity derived from international exchanges. Figure 6.15 denotes that France is the major supporter of the Spanish electrical system and Spain exports the exceeding energy to Andorra, Portugal and Morocco.

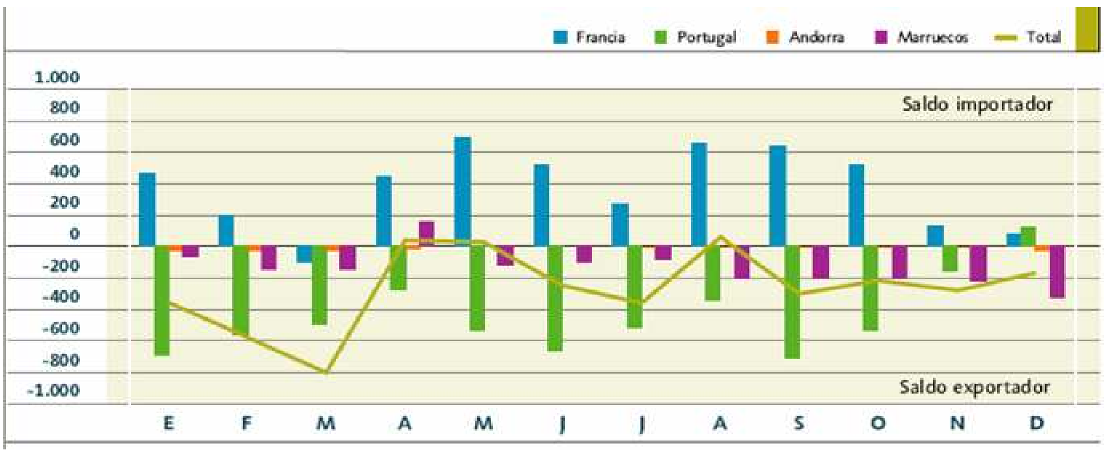


Figure 6.15 Monthly International Exchanges in GWh. Spain 2006. Source REE [8] Spain exports electricity to Portugal and mainly imports it from France.

Note that Spain exchange balance for the 2006 is positive because its outputs overcome France imports (see Annex 2 for further information).

Table 6.14 summarises the Spanish electricity production system of the period 2004-2006. This data is reported by REE, which publishes data of ordinary and special rating generation.

Table 6.14 Annual Electricity Balance – Spain 2004-2006

Electricity Balance (GWh)	2.004	2.005	2.006
Ordinary Rating	**206.412**	**212.999**	**220.873**
Hydroelectric	29.777	19.169	25.330
Nuclear	63.606	57.539	60.126
Thermal Conventional	**113.029**	**136.291**	**135.417**
Coal	76.358	77.393	66.006
Fuel-Gas	7.697	10.013	5.905
Combined Cycle	28.974	48.885	63.506
Consumption in generation	-8.649	-9.082	-8.907
Special Rating	**45.778**	**50.605**	**50.239**
Non Renewable Special Rating	**22.481**	**22.463**	**19.587**
Residual Heat	201	293	262
Coal	716	693	748
Fuel-gasoil	3.273	2.889	2.045
Refinery gas	592	460	294
Natural Gas	17.699	18.128	16.238
Renewable	**23.297**	**28.142**	**30.652**
Minihydro	4.596	3.653	3.971
Wind Power	15.753	20.532	22.631
Other Renewable energy	2.948	3.957	4.050
Biomass	1.639	2.072	2.167
Waste- Industry	725	818	820
Municipal Solid Waste	567	1.028	966
Solar (photovoltaic)	17	39	97
Net Generation	**243.541**	**254.522**	**262.205**
Consumption in pumping	-4.605	-6.358	-5.261
Brute Generation	248.236	260.882	267.465
International Exchanges	-3.027	-1.343	-3.280
Inputs	8.112	10.212	9.093
Outputs	-11.139	-11.555	-12.373
Transport Demand	**235.999**	**246.822**	**253.664**

6.3.4 Determining grid power factors

Not all the power generators are responsible for emissions. Emissions are mostly focused on thermal (and CHP) plants that combust fossil fuels. Natural gas, coal gas or fuel oil plants are the most frequent fossil fuel facilities.

To determine EP_i (formula 6.30) it has been taken into account the following published data:

- Spain Industry Ministry report on Installations affected by GHG emissions 2006 (published on May 2007) [9]. This document compiles the emissions assigned and verified in 2006 from the 944 installations subjected to law 1/2005 and included in RENADE (national register of emissions).

- Monthly and annual reports of Red Eléctrica Española [12]
- Annual Report Red Eléctrica Española 2006 [8]

The installations subjected to emissions verification are classified in different categories:

- Electricity generation: coal, fuel or combined cycle
- Combustion plants
- Industrial activities (textile, pulp and paper, ceramics, refineries, etc)

The aim is to achieve a coal, natural gas or fuel emission factor based on real data of Spanish power facilities. This fact implies gathering the totality of certified emissions of electricity generators and collecting the electricity production in bus bars. When dealing with such information some inconsistencies appeared due to some missing information on Ministry emission report.

Therefore, instead of using the complete list of installations, the emission factors have been calculated with the information of 15 coal generation plants, 15 combined cycle plants and 10 fuel thermal plants.

Table 6.15 compiles the mentioned information and presents the resulting emission factors. The complete list of plants that has been used to elaborate Table 6.15 is attached in Annex 2.

Table 6.15 Emission factors using certified emissions and published power generation of the respective facility

FOSSIL COMBUSTION POWER GENERATION	EMISSIONS VERIFIED 2006 [tCO_2]	POWER GENERATED 2006 [GWh]	ASSOCIATED EMISSION FACTOR [tCO_2/MWh]
Coal generation	59.521.047	61.974	0,960
Fuel generation	3.061.677	4.449	0,688
Combined cycle generation	14.408.442	40.232	0,358
Total /average	76.991.166	106.655	

* based on the data compiled for 15 coal plants, 10 fuel plants, and 15 combined cycle plants. The emissions have been correctly certified and have been obtained from the publications of Environmental Ministry reports and the power generated derives of REE annual reports. Calculations included in Annex 2.

Moreover, when dealing with especial rating data, a problem on data consistency has appeared from two sides:

- Cogeneration plants are not always included as separate installations in the Ministry reports. In some occasions, CHP installations are included within the industrial activity emissions. For example, emissions of a paper mill can include the emissions generated by its on-site CHP plant; this situation makes difficult the calculation of a CHP emission factor based on real data of Spanish governmental reports.

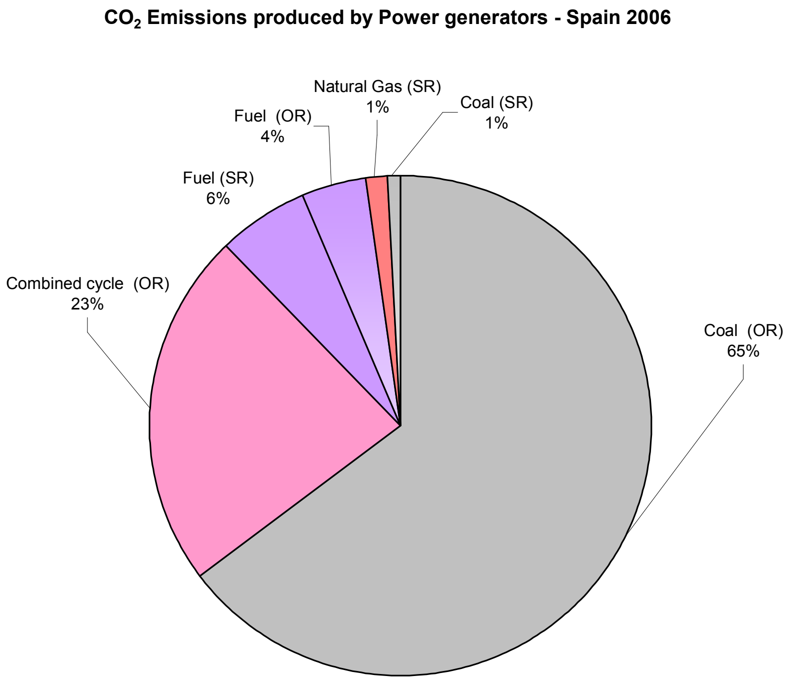
- Emissions of cogeneration plants are comprising both power and thermal energy outputs. In this sense, an allocation method should be applied in order to distinguish the emissions related to power generation.

- Red Eléctrica Española publishes partially the amount of electricity generated on "none-renewable/special rating" plants. Data published considers approximately the electricity that CHP plants sells to grid, and it does not consider the electricity generated on the plant but already consumed in the on-site process.

Concerning the previous remarks, it has been assigned to the emissions factors of gas fuel and coal cogeneration and thermal plants operating in special rating, the same emission factors of combined cycle, fuel and coal-fired plants in the ordinary rating (Table 6.15).

Figure 6.16 presents the totality of carbon dioxide emissions published by the Spanish grid power system.

The F_{CO2} considers just the emissions produced in Spain electricity system and does not enclose the emissions from international exchanges.



FOSSIL COMBUSTION IN POWER GENERATION	**ESTIMATED EMISSIONS** [$MtCO_2$]
Coal (OR)	63.393
Combined cycle (OR)	22.743
Fuel (SR)	5.815
Fuel (OR)	4.064
Natural Gas (SR)	1.407
Coal (SR)	718
Total Emissions	98.142

Figure 6.16 Carbon dioxide emissions by electricity generation facilities – Spain 2006
OR abbreviates ordinary rating, and SR especial rating. Production of electricity in coal plants is responsible for the major amount of emissions.

Table 6.16 presents the grid power factor, estimated according to assumptions and results obtained in the previous tables.

Table 6.16 Grid power factor of Spanish peninsular system (average 2006)

GRID POWER FACTOR 2006	
Total Emissions [$MtCO_2$]	98.142
Total Electricity generated [GWh]	262.205
Power Factor [tCO_2/MWh]	0,374

This power factor embeds the facilities of Spain Peninsula. Islands are exempt of the national grid system.

6.3.5 Grid power factor fluctuation

The emission factors estimated in 2006 total annual period (Table 6.15) have been used to calculate the monthly grid power factors 2004-2006. Figure 6.17 denotes that emission factors vary widely regarding the hydro power plants profile and thermal plants peak-loads.

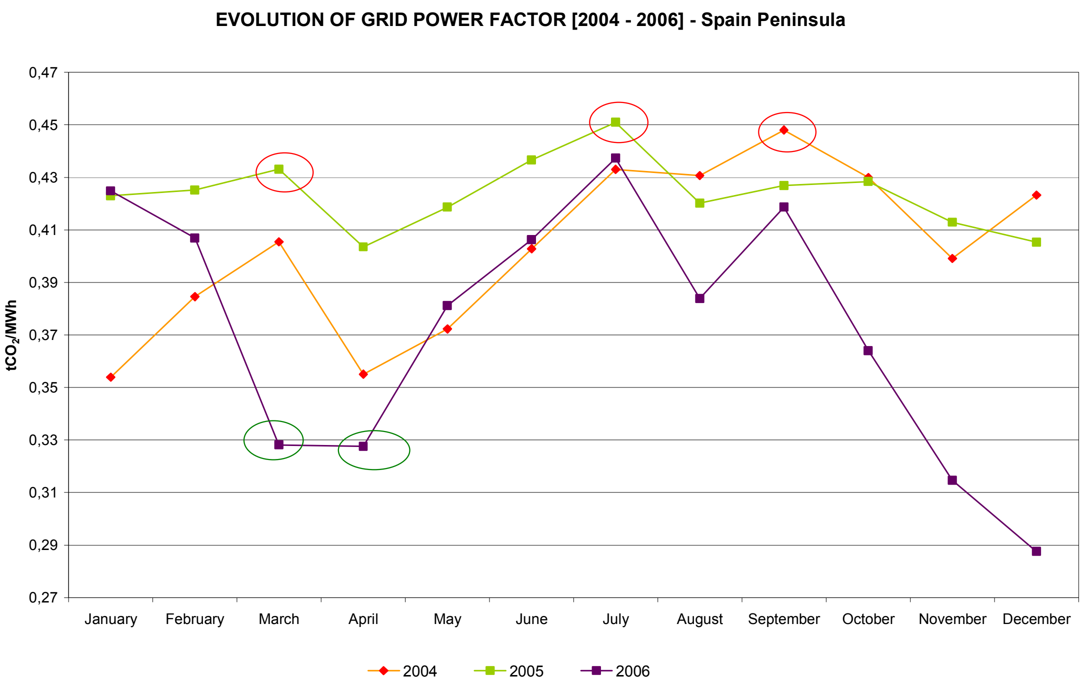


Figure 6.17 Evolution of Spanish Power factor. Monthly profile according to the operation of different types of power plants. Red circles denote dry months and an over-operation of thermal plants, meanwhile green circles highlight a relevant role of hydro power and wind power plants with less dependency on the thermals.

Figure 6.17 visualises the monthly variability along three-year period. Grid power factor can range a variation of ± 15% from one month to the other. This fluctuation responds to hydro plants capacity, the peak loads to be covered by thermal demand or failures on nuclear plants.

6.3.6 Regional-grid power factors

Moreover, Figure 6.18 presents the main differences of grid power factors according to the type of electricity facilities of the different autonomous regions of Spain.

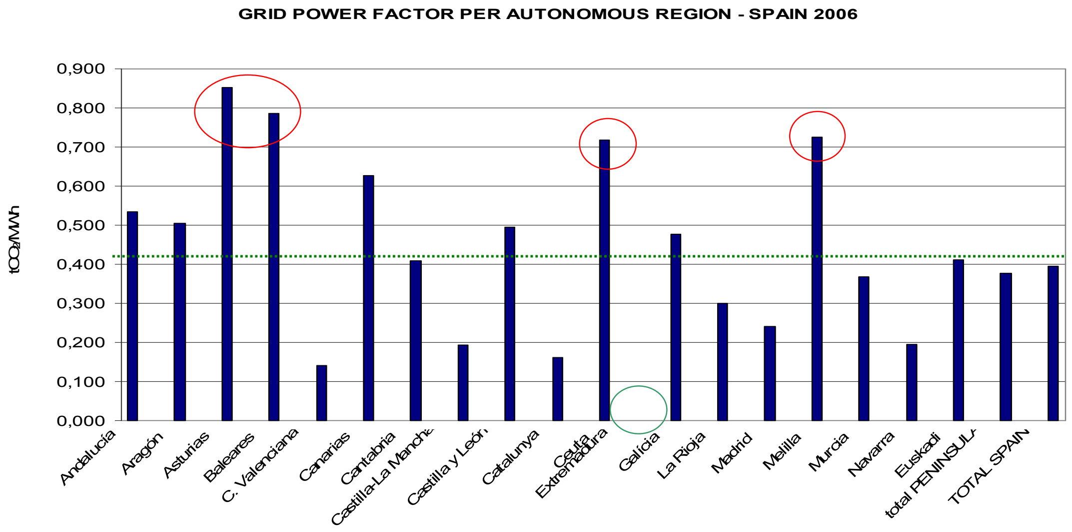


Figure 6.18 Grid power factor per autonomous region. The autonomous regions of Baleares, Ceuta, Melilla have a high grid power factor. Their isolation forces them to generate power with fuel plants with a consequent high emission factor.

Figure 6.18 is tighten to the location of the different electricity generators in Spain. Therefore, Extremadura is a region with a zero emission factor, because its generation mix is based on nuclear and hydro facilities.

6.3.7 Benchmarking of other national grid power factors

In order to compare the electricity generation emissions between countries, International Energy Agency published in 2006 a heat and power national factor. This factor considers *CO_2 emissions from fossil fuels consumed for electricity, combined heat and power and main activity heat plants divided by the output of electricity and heat generated from fossil fuels, nuclear, hydro (excluding pumped storage), geothermal, solar and biomass. Main activity producers and auto producers have been included in the calculation of the emissions*. Table 6.17 presents some of the results.

According to Table 6.17, the value of the Spanish heat and power factor is very close to the calculated in this thesis for 2006, which only focuses on electricity generation. However, there is still a relevant difference with grid power factors from Norway, Sweden and France, which have the most environmentally friendly electricity generation systems.

Table 6.17 National Power and Heat Factors by IEA – 2005

COUNTRY	ELECTRICITY AND HEAT GENERATION FACTOR [tCO_2/MWh]
Norway	0,007
Sweden	0,051
France	0,087
Finland	0,261
Spain	0,383
Italy	0,455
Germany	0,456
United Kingdom	0,467
Ireland	0,573
USA	0,576

This fact is better understood if it is taken into account that in 2005 France covered its electricity production with over 78% of nuclear power [10]. Norway electricity system is 99% covered by hydro power that is the reason for which they have the lowest emission factor. Sweden has also a low factor because it generates electricity in a 50-50 system combined by nuclear and hydro power [11]. USA is the queer on this list of factors, due to its petroleum dependency.

6.3.8 Quantifying indirect emissions

Grid power factors obtained are not taking into account the inefficiencies of transmission in the grid distribution lines. Table 6.18 presents the published estimation average of grid transmission inefficiencies and denotes how transmitting electricity in high-tension levels is more efficient than in low tension.

Table 6.18 Power Transmission Losses Spain 2006. Source: REE [12]

LINE VOLTAGE	% TRANSMISSION LOSSES
Bus bars	0
U>145kV	1,52
72,5kV <=U <145kV	2,87
36kV <=U <72,5kV	4,14
1kV <=U <36kV	5,93
low tension U<1kV	13,81
Arithmetic Average	5,65

The grid power factor needs a corrective factor, considering line voltage transmission. Consequently, when estimating indirect emissions of purchased electricity it should be taken into consideration the grid transmission losses T_l –expressed in formula (6.31). For example, if a paper mill purchases electricity from Spanish grid and its supplier line voltage is 25 kV, the power factor is expressed in formula 6.32.

$$F'_{CO_2} = \frac{\sum^{i} EP_i}{\sum^{i} P_i}(1+0{,}059) = 0{,}396 \text{ tCO}_2\text{/MWh} \tag{6.32}$$

Uncertainties of grid power factor

As mentioned in chapter 5, emission factors –included grid power factors– involve certain grade of uncertainty. The uncertainty of already calculated grid power factor is difficult to evaluate. The uncertainty range includes the mentioned CO_2 emission factor and the uncertainties of instruments such as power and gas meters of each facility. It also includes the uncertainties regarding assumptions due to missing information.

It is proposed to calculate the uncertainty of the grid power factor (U_{GPF}) according to formula 6.33.

$$U_{GPF} = \sqrt{\left(\frac{\partial f}{\partial y}\cdot u_{EF}\right)^2 + \left(\frac{\partial f}{\partial y}\cdot u_I\right)^2 + \left(\frac{\partial f}{\partial y}\cdot u_A\right)^2} \tag{6.33}$$

Where u_{EF} is the uncertainty of the direct emission factor (7%), u_I is a general uncertainty of the measure by the particular meter –which is approached to 2,5% (paragraph 5.7.2). Moreover, the author assumes a 5% of uncertainties from the assumptions (u_A) that have been practiced during the simplification of data concerning power generators and report inconsistencies.

The uncertainty of the power meters at the bus bars is considered negligible [13]. The individual coefficients $\frac{\partial f}{\partial y}$ are taken as unity because they have a direct effect on the outcome.

Consequently, the uncertainty of the grid power factor is referenced in the following formula.

$$U_{GPF} = \sqrt{(u_{EF})^2 + (\cdot u_I)^2 + (u_A)^2} = 8{,}9\% \qquad (6.34)$$

The currently calculated power factor will be used in Chapter 7 to calculate the indirect emissions of Mill A. Finally, it could be thought of using the power factor of the particular autonomous region where the mill is located. In this context, the autonomous region factor encloses the reality of the generation mix of each region. Using Spanish emission factor might not favour or advantage autonomous regions that are enhancing the renewable energy market. However, the author prefers using the Spanish one because there is a unitary electricity-market pool for the totality of autonomous regions and the economic cost of the electricity is unified, and directly related to all power facilities, cost of operation, raw material cost and energy policies.

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7 APPLYING EMISSIONS ALLOCATION METHOD TO PAPER MILLS

7.1 INTRODUCTION

In this chapter, the allocation method proposed in Chapter 5 and the emission factors calculated in Chapter 6 are implemented in two paper mills. Both mills are situated in Spain and produce printing and writing paper. The mills have been selected as case studies because they are considered representative of Spanish paper mills. Paper mills in Spain have a low-medium productivity profile and are usually equipped with slow speed paper machines. Another key-selection point has been the type of energy supply. Mill A operates with a SHP system and Mill B has a CHP plant. The fact of using or not a CHP plant is going to be analysed and compared from both energy and emission points of view. In order to maintain mills data in privacy, from now on mills are named Mill A and Mill B.

This chapter briefly describes each mill taking into consideration emission sources and energy related issues.

To apply the allocation method to each of the mills, it has been used the monthly invoices of natural gas and electricity of both paper mills as well as the information compiled in part of the internal maintenance reports, and the gathered experience of technicians along facilities of the mill.

It presents the difficulties and limitations to introduce a conceptual objective into real mill context, where –in the cases studied– mills are not prepared for such levels of energy and emission control and monitoring.

Finally, results obtained in the allocation method of the two mills are exposed and analysed according to energy efficiency criteria and indicators presented in Chapter 4. It is concluded with a comparison and evaluation of the emissions benchmarking achieved.

7.2 MILL A

7.2.1 General description and outstanding data

Mill A is a non-integrated and an offset printing paper mill with a production oriented to coated paper, silk and gloss, with a basis weight range from 170-350 g/m^2. The mill normally produces the following paper types:

- high quality gloss art paper
- gloss coated paper
- silk coated paper
- coated embossed paper

Table 7.1 offers general data of Mill A during period 2002-2006. The mentioned table compiles general information related to shippable production as well as raw materials (pulp, chemicals and water) and main energy expenditures.

Table 7.1 Mill A General Data

GENERAL DATA MILL A		2002	2003	2004	2005	2006
Production	Shippable paper, all types [t]	112.521	122.252	124.450	130.161	138.836
Raw materials	Pulp [tones 100% dryness]	50.686	49.393	55.186	56.945	61.183
Chemicals and fillers	$CaCO_3$ and kaolin purchased [t]	53.205	77.633	77.193	78.853	84.721
Water	Fresh water intake [m^3]	887.272	914.113	920.437	932.711	812.517
Natural Gas	Consumption [MWh_{LHV}]	168.027	187.687	193.178	191.991	203.363
Fuel-oil	Consumption [MWh_{LHV}]	1.041	1.075	1.529	1.384	1.527
Electricity	Consumption [MWh_e]	62.254	64.151	65.745	65.919	66.766

Figure 7.1 presents the evolution of the main energy expenditures of Mill A.

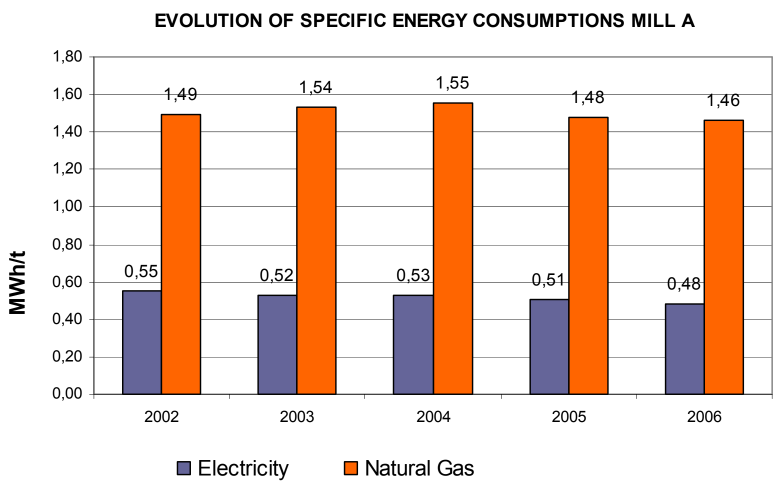


Figure 7.1 Evolution of the main specific energy consumptions Mill A 2002-2006. During this period, natural gas and electricity specific consumption slightly decay. Fuel consumption is not significant in comparison with the two other sources (not appearing in the figure).

Mill A has a single line of paper production; therefore, Mill A is equipped with a single paper machine, an off-line coating machine and a complete finishing section. Figure 7.2 presents a basic process flow diagram of Mill A.

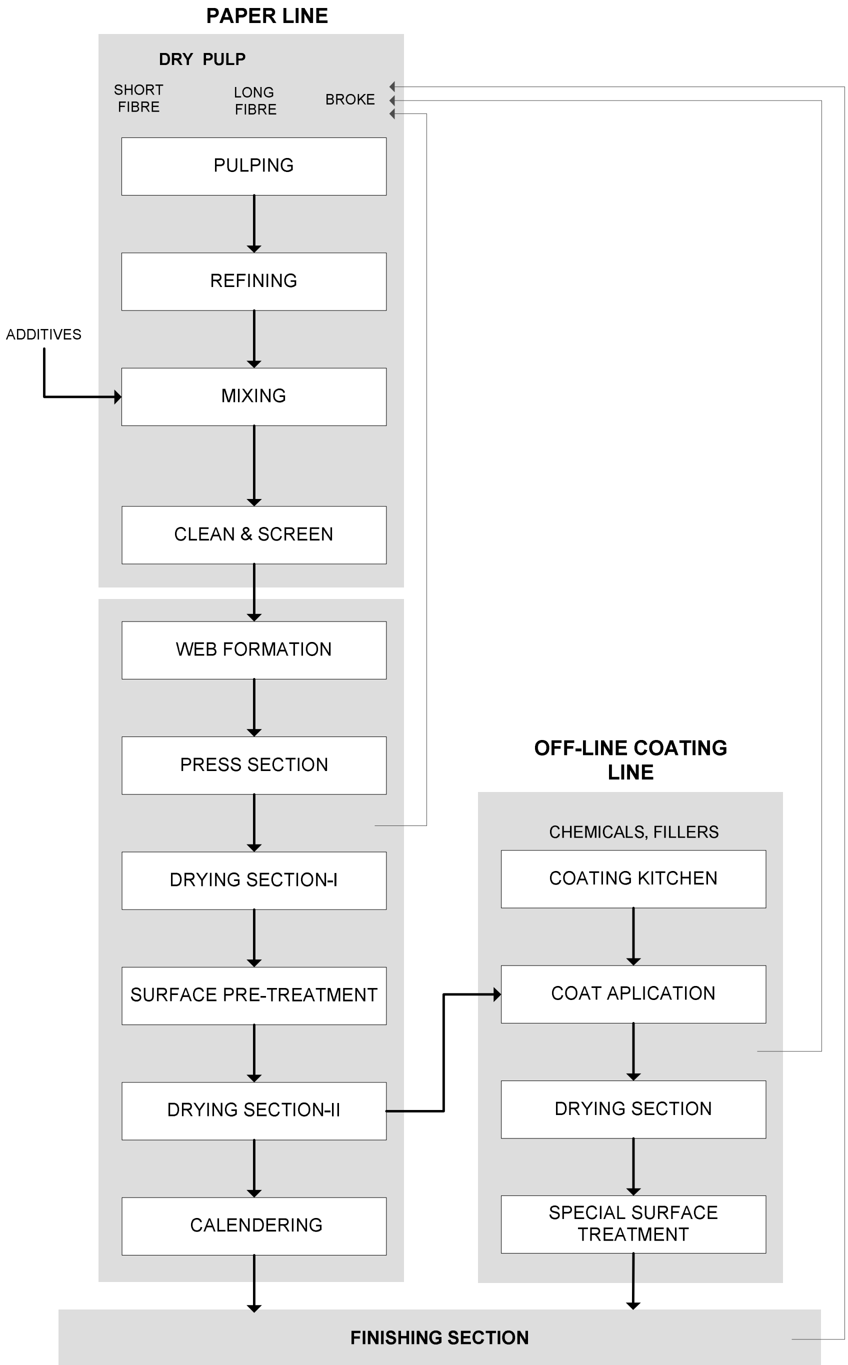


Figure 7.2 Mill A Basic process diagram. The papermaking process consist on a standard Fourdrinier paper machine followed by a coating machine and a complete finishing section.

As showed in Figure 7.2, Mill A uses as basic raw material dry pulp and broke (generated in the same mill). The mill uses a mix of pulp, consisting of approximately

20% of bleached long fibre (pine softwood) and 80% of bleached short fibre (eucalyptus hardwood).

Following paragraphs provide a general process description of Mill A.

Stock preparation

The stock preparation section of Mill A is equipped with nine conventional pulpers, three of them with a high nominal power. These pulpers slush short and long fibre separately. The rest of the pulpers have a lower installed power and usually slush the broke (generated in continuous) in the paper manufacturing process. The mill also has five refiners, eight deflakers (one of them of high capacity) and a broke screener. The multi-cyclone depuration is carried in five stages and has a totality of 110 cleaners. A pressurized screen ensures in two phases a correct separation of light impurities.

Paper Machine

Mill A owns a Fourdrinier paper machine, single side, 3.2 meters of width. It is a low-speed machine (280-600 m/min). The vacuum system is composed of seven vacuum pumps to force the water drainage in vacuofoils, suction boxes, couch roll and pick up roll in the wet section. The vacuum system is also used in the press section (suction press and felts). The press section has four press rolls: one of them is a suction roll press, two of them are conventional rolls and the last one is an offset press roll. The drying section is composed of 42 drying cylinders. A speed sizer applies a precoating layer in the paper web. IR groups (natural gas fired) are located after the precoating section to dry the coating layer. These groups are followed by a battery of 9 drying cylinders. A closed hood covers the whole of the drying section with four heat recovery systems, three of them situated in the pre-drying section and one of them in the post-drying section.

Off-line coating machine

The off-line coating machine is a two-sided coating machine (four coating heads) that incorporates 10 drying cylinders and 4 IR groups of natural gas fired to ensure a perfect drying. The coating process is doubled; each coating layer has two units per side and two units per web. The speed of this machine ranges 550-650 m/min.

Finishing operations

The coated paper can be calendered or embossed in order to reach final surface requirements. After this surface treatment, the paper is wound, sized, wrapped and ready to ship.

Mill A has a biological water treatment system with aerobic bacteria.

7.2.2 Mill A energy related-issues and emission focus

To cover its energy demand, Mill A purchases electricity from Spanish national grid and generates its process steam in its own boilers (Figure 7.3).

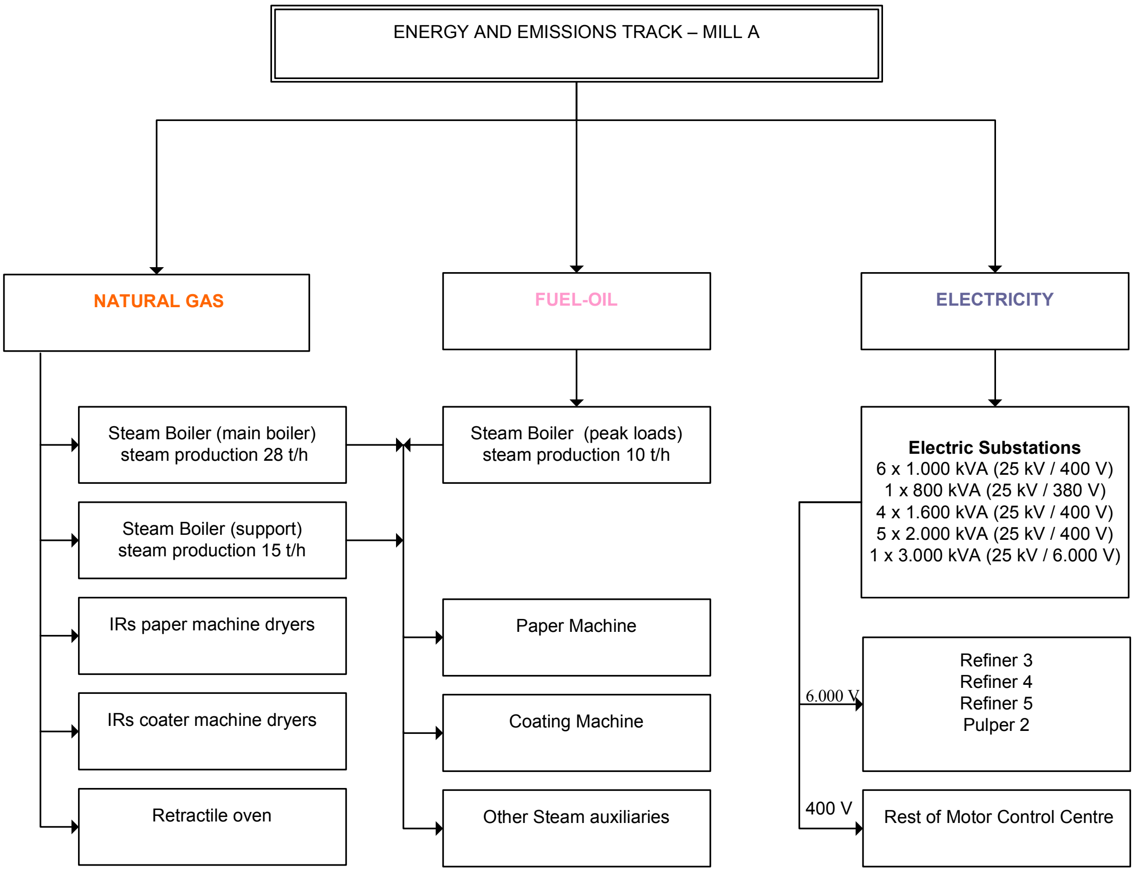


Figure 7.3 Energy track Mill A (2006). The main energy sources of Mill A are gas, fuel and power. Power is mainly focused on machine driving whereas gas is used in steam boilers or in direct heat utilities. Values of steam production are nominal values.

The following points detail briefly some of these basic energy issues:

- Mill A receives electrical power from Spanish peninsular grid. The inlet voltage level is 25 kV. The mill has two high voltage stations. Power is transformed into low and medium voltage and derived to 17 main substations that feed 11 motor control centres; some of them are doubled.
- Mill A covers its process steam demand with three boilers. Two of them use natural gas and the other one fuel oil. The fuel-oil boiler plays an auxiliary role whereas the natural gas boilers are the most used facilities. One of the gas boilers works in continuous and the other one covers the possible peak loads. The main boiler provides superheated steam at 40 bar and 420 ºC; a pressure reducing valve conditions steam to process operations (6 bar, and 3 bar).
- Mill A has eight infrared radiation units installed in the coating and paper machine drying sections. IR dryers are fired with natural gas.
- The finishing section of the mill has a retractile oven (gas fired). This oven melts polypropylene film to protect the paper pallets from humidity and transport inconveniences.

Obviously, the covering of such energy requirements includes some GHGs focus.

Moreover, collateral aspects of the paper process can become an additional source of GHGs:

- Mill A uses chemical pulp as raw material. Pulp production might lead to GHG emissions. These emissions are mainly related to heat and power requirements. However, pulp mills are using biomass by-product as energy source of pulp manufacturing. Lignin enclosed in black liquor is burned to recover chemicals. Pine bark is also combusted for an extra thermal generation. The consequent thermal energy is usually used to produce high pressure steam. Steam is derived to a backpressure steam turbine that produces power and thermal energy for the pulp plant. Pulp mills could also have assigned emissions from make-up carbonates.
- Most of the employees of the mill use private transport to go to work.
- The paper manufactured in Mill A is sold to a wide market, such as EU community countries, USA and South America. The commercial market of the manufactured paper involves a convenient logistic transport, which is responsible for a significant amount of GHG emissions.

- Paper previously manufactured in the mill is a potential final disposal in landfills. The subsequent degradation of organic materials under anaerobic conditions leads to methane generation (a GHG).

Considering an emission scope framework (described in paragraph 3.2.2.4), Mill A emissions are approached to the following scopes:

- Scope 1: fuel combustion (natural gas and fuel-oil) from stationary combustion
- Scope 2: electricity purchased from peninsular grid
- Scope 3: emissions assigned to the whole of paper life cycle (pulp production, mobility of employees, product distribution and its final degradation (production of methane in landfills)

Setting boundaries

As mentioned in the objectives of this work, emissions included in Scope 3 are not taken into consideration.

All GHG emissions of Mill A are assumed as carbon dioxide emissions. The rest of the non-CO_2 gases are not taken into consideration according to the following reasons:

- N_2O emissions: as exposed in chapter 3, fossil combustion can derive to nitrous oxide emissions. However, the concept of materiality exposed in chapter 3 and the information of Table 3.4 denote relevancy on emissions of N_2O is not significant enough. In addition, the grade of scientific uncertainties associated with the N_2O emission factor (Table 3.5) has lead to dismiss this type of GHG emissions.
- CH_4 emissions: methane is usually formed in anaerobic water treatment systems. As Mill A has a water treatment system with aerobic bacteria, Mill A is considered exempt of methane formation. Methane could be emitted in a non-correct combustion or pipe-leak of natural gas. However, regular checks are made to pipes and steam boiler burners pass combustion tests.
- HFCs, PFCs and SF_6: the mill is not using any of these gases, neither for refrigeration in the office site.

7.2.3 Estimating Emissions

The previous paragraph 7.2.2 denotes that the totality of emissions included in Scope 1 and 2 have an energy-use origin. Mill A direct emissions derive from natural gas and fuel-oil combustion whereas indirect emissions have an electricity origin. This means that the energy consumption of the paper manufacturing process is responsible –directly or indirectly– for the emissions produced in the mill. Figure 7.4 presents the distribution of emissions according to its origin, focus and its final energy use.

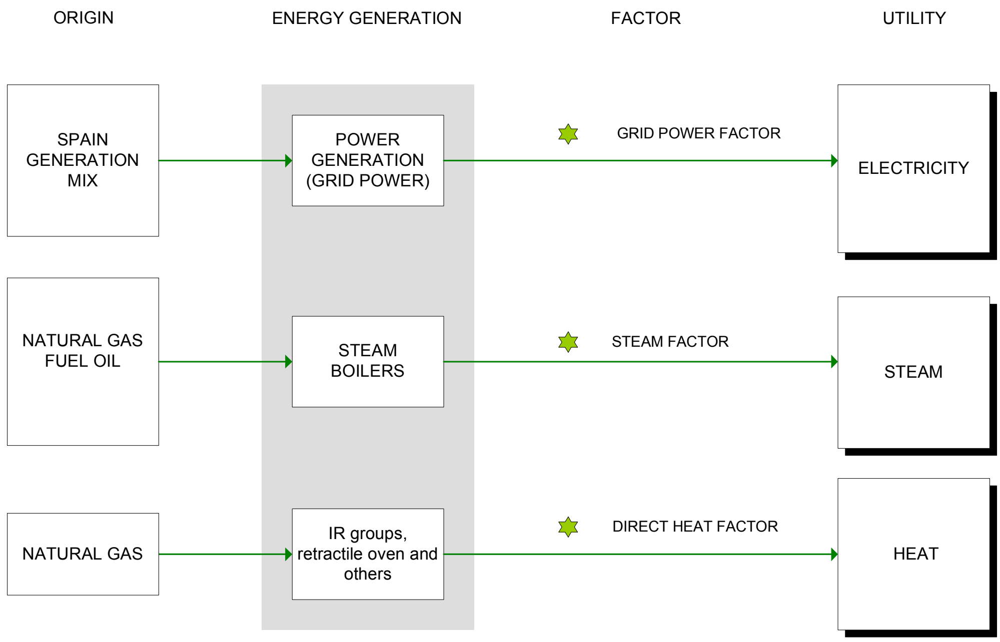


Figure 7.4 Mill A – Main emission focus map by sources and final utilities (2006)

Emission factors assist the allocation of the emissions produced as energy utilities through the paper process. Therefore, Table 7.2 presents Mill A emission factors for the annual period 2006 and specifies which has been the method utilised to obtain them –see Chapter 6 for further information.

Table 7.2 CO_2 emission factors Mill A 2006. Values and Calculation Method

EMISSIONS ORIGIN	EMISSION FACTOR [tCO_2/MWh]	CALCULATION METHOD
Natural Gas Emission Factor *	0,202	Factor based on IPCC and Spanish NAP
Fuel Oil Emission Factor *	0,274	Factor based on IPCC and Spanish NAP
Electricity Emission Factor	0,396	Calculations according to Grid emission Factor 2006 (detailed in paragraph 6.3.8)
Steam Emission Factor	0,220	Steam production divided by fuel oil and natural gas boilers consumption. Based on data of Figure 7.5

* Fossil fuel energy units expressed in LHV, oxidation factor included in emission factor.

Table 7.2 exposes how emission factors due to fossil combustion (gas and fuel oil) have been calculated according to emission factors values provided by Spanish NAP [1] and based on IPCC [2]. The power emission factor concerning Spanish electricity grid has been calculated according to formulas detailed in paragraph 6.3. In this last case, the power emission factor takes into account the possible transmission losses of the grid system. As the electric line that reaches Mill A has 25 kV voltage, the grid power factor includes the corresponding joule effect of the transmission line. In this sense, the power emission factor corresponds to the sample case of paragraph 6.3.8.

Moreover, Mill A produces steam in three on-site boiler units; steam emission factor is the result of the sum of emissions of natural gas and fuel oil combustion assigned to the corresponding boiler unit divided by the annual steam quantity produced (in MWh). This factor is based on data included in Figure 7.5.

General distribution

Table 7.3 presents the total emissions of the main energy sources of Mill A, according to the energy consumed and the emission factor defined in Table 7.2.

Table 7.3 Mill A Main emission focus, energy and emissions associated (2006)

ENERGY SOURCE	ANNUAL DEMAND		ANNUAL EMISSIONS		EMISSION'S SHARE
	MWh	kWh/t	t CO_2	kg CO_2/t	%
Natural Gas	203.363	1.468	40.998	296	60
Fuel Oil	1.527	11	418	3	1
Electricity	66.766	482	26.472	191	39
Total	271.656	1.961	67.888	490	100

* Fossil fuel energy units expressed in LHV

Moreover, Figure 7.5 advances the results that are going to be exposed in detail in next paragraphs. As shown in Figure 7.5, steam generation is the main cause of emissions, followed by the indirect emissions of electricity consumption.

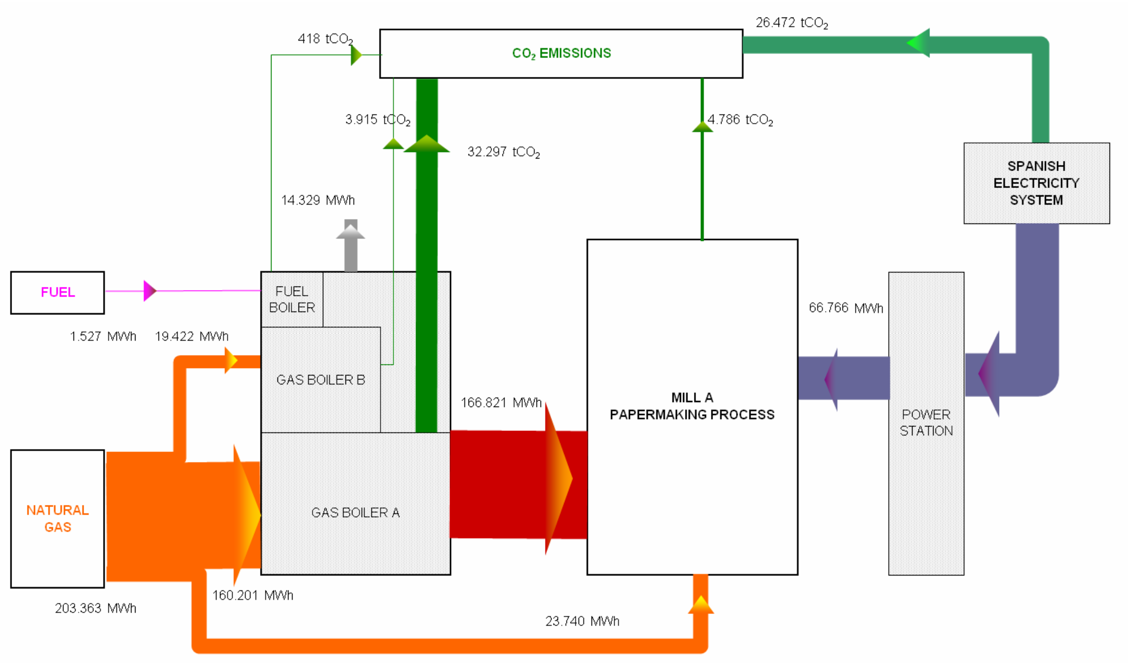


Figure 7.5 Mill A Energy balance and emission focuses. Based on annual data 2006. Steam is coloured in red, electricity in blue and emissions in green. Steam is produced by stand-alone boilers (fuel oil and gas) whereas electricity is purchased from national grid system. Natural gas is also demanded in papermaking process in terms of direct-heat (IRs and oven)

Furthermore, Figure 7.6 presents the same balance considering exergy of each of the energy streams.

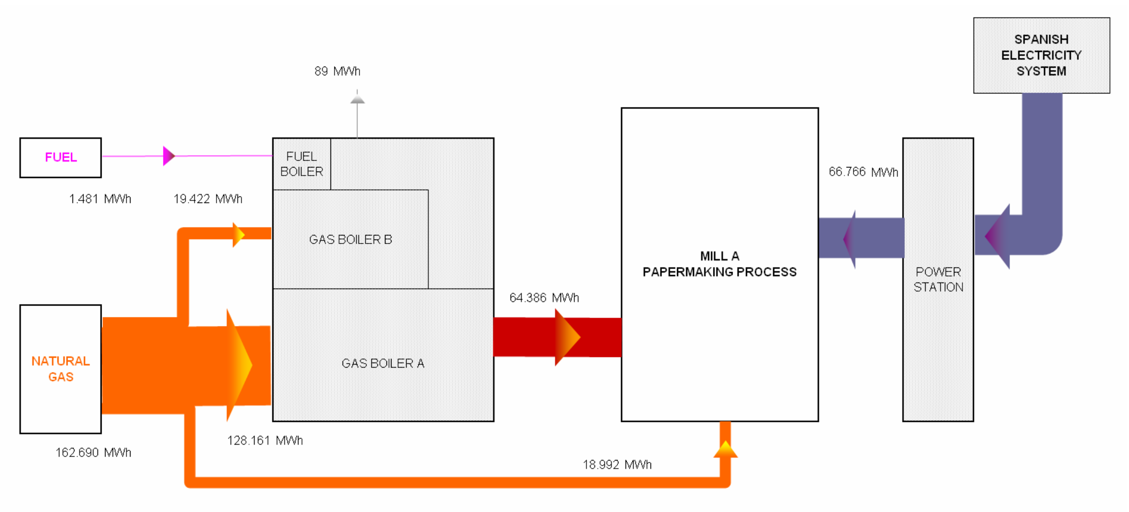


Figure 7.6 Mill A exergy balance. Exergy reference point is the ambient (20 ºC and 1 bar). Values are expressed in MWh (exergy).

As seen in Figure 7.6, steam generation of Mill A has a high work potential (due to its high-pressure conditions 40 bar and 420 ºC).

7.2.4 General emissions allocation according to energy use in Mill A

As exposed in previous paragraph, the totality of Mill A emissions are assigned to the mill energy use. Paragraphs bellow describe the compiling data process achieved to apply for Allocation method in Mill A.

Some general and specific data is required to approach the allocation method. Paragraph 5.6 lists the necessary data for calculations.

Mill A has a distributed control system (DCS) that provides electric data compilation. DCS supervises motor control centre consumption and other independent meters. A motor control centre is an assembly of one or more enclosed sections that have a common power bus and mainly contain motor control units. Mill A has some reliable steam flow meters to control steam demand and local gas flow meters to control the gas consumed in the main units.

Figure 7.7 summarises the allocation method results that are going to be exposed along this paragraphs.

7.2.5 Allocating emissions due to electricity demand

According to Table 7.3, the 40% of the total emissions of the mill are attributable to electricity demand. To distribute electricity emissions through the paper process, this work has localised the existing power-metering points of Mill A. Most of this power meters are supervised by the main distributed control system (DCS). The DCS supervises 11 motor control centres (MCC), each fitted with its corresponding power meter, and 6 additional power meters that measure consumption of 5 refiners (four refiners for short fibre, one for long fibre) and one deflaker.

The mill disposes of an inventory of MCC and electrical devices. Each device of the mill is switched to a MCC. Each device has been described with some electrical parameters, such as the nominal power, nominal current or circuit breaker. Relevant data is attached in the Annex 3 of this work. Operators control the working hours of some specific devices, such as some rewinders of the finishing department.

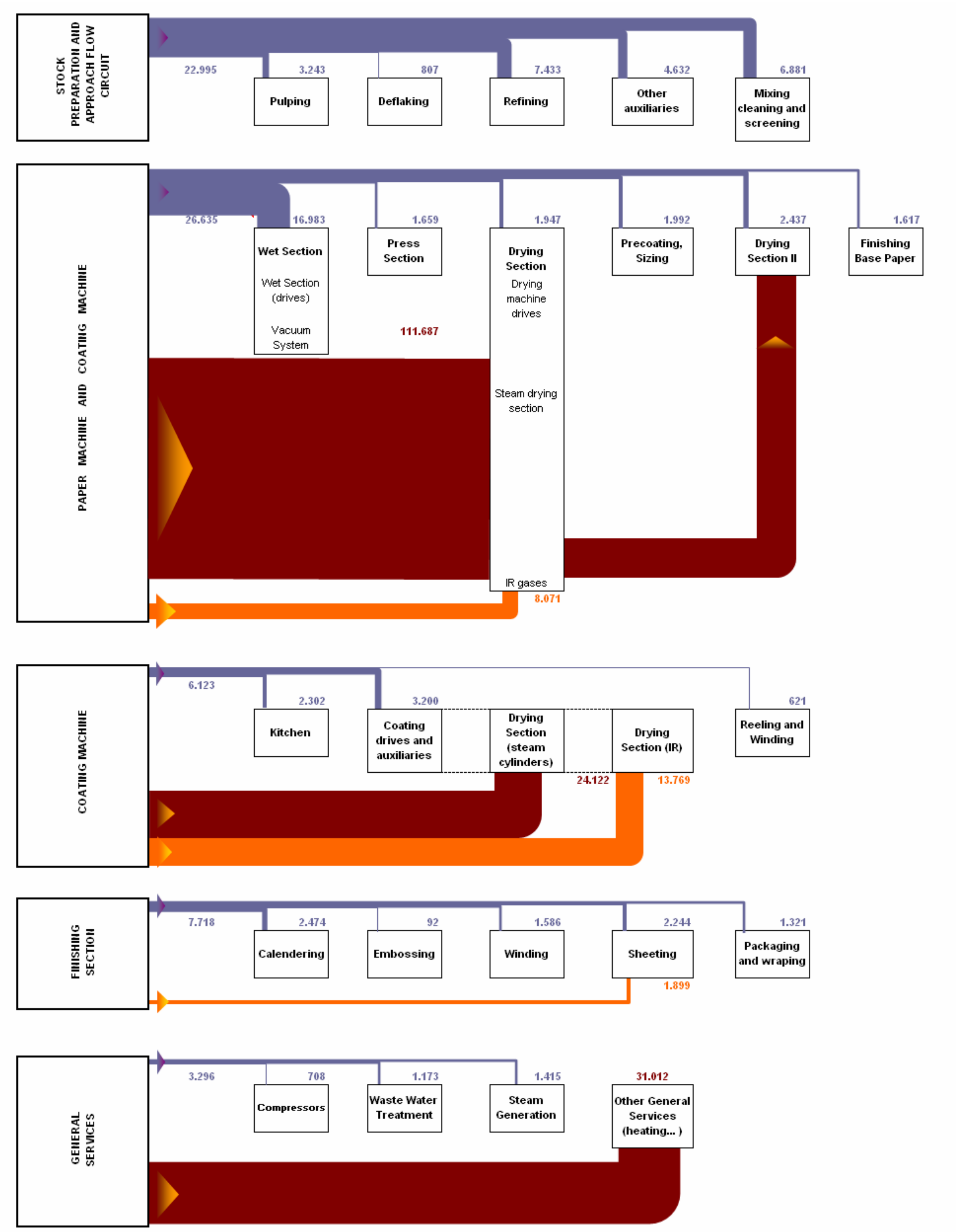


Figure 7.7 Allocation of power, gas and direct heat through out the process. Mill A (2006). Values are expressed in MWh. Steam flow is coloured in red, direct heat in orange and electricity in blue.

Furthermore, maintenance technicians control and regulate the possible out-of-phase with voltage and current signals that are returned to grid. Reactive power is returned to grid with a cosϕ near value 1. Therefore, active power is taken into account for allocation purposes.

In order to apply the allocation method, the main devices or unit operations have been linked to their respective motor control centre. Figure 7.8 presents a plot of the main devices attached to each MCC.

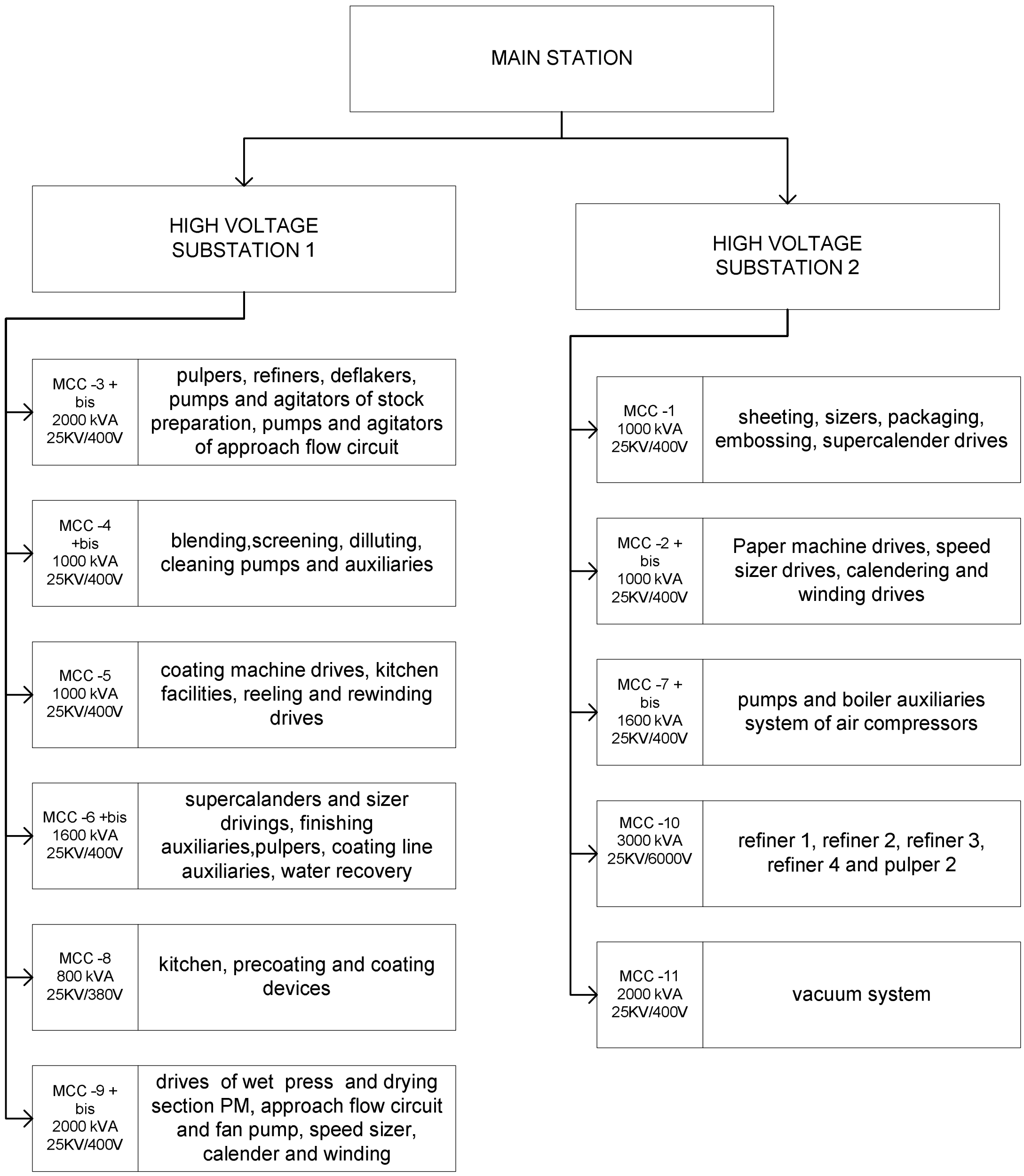


Figure 7.8 Electricity substations and motor control centres of Mill A (2006). Main devices attached to each of them.

The same figure denotes that MCC and its power meters are grouped by proximity and not installed into the sequential structure of papermaking process.

Thus, the plan structure of MCC responds to the location and proximity of each device to its MCC. Subsequently, the electricity allocation method proposed in paragraph 5.4 cannot be completely filled because not all the sections proposed in the allocation method have its own power meter or grid analyser.

However, some estimations and assumptions have been defined in order to proceed with calculations. The electricity and emissions allocation through out sections and unit operations is based on the following assumptions:

- Most of the devices of stock preparation, approach flow circuit and paper machine sections work in continuous.
- The power meters and grid analysers work properly and supply measures with the implicit commercial uncertainty (no biases are detected).
- Motor drives have been properly installed and designed to work in its efficiency load regime

According to these assumptions, the electricity consumption of a device or unit operation is estimated according to its MCC consumption and the share of its nominal power through the total installed power of the specific MCC. Paragraph 7.2.9 evaluates the uncertainties, which such assumptions undertake.

Figure 7.9 pictures an adaptation of this electricity allocation, according to the fixed boundaries of electricity meters and the configuration of the plant itself. Figure 7.9 highlights in green colour the achieved approaches of Mill A allocation method to ideal electricity distribution (proposed in Chapter 5, see Figure 5.4).

Next lines present the results of the allocation method according to the diagram of Figure 7.9.

Furthermore, Figure 7.10 pictures the share of Mill A electricity emissions by main section. This figure is based on the distribution diagram of Figure 5.4 and the aforementioned conditioning of electrical information (exemplified in Annex 3).

POWER RELATED EMISSIONS SECTION UNIT OPERATION DEVICES	ELECTRICITY kWh/t	EMISSIONS kg CO_2/t	SHARE %
STOCK PREPARATION			
Pulping			
Pulpers (SF)			
Pulpers (LF)			
Pulpers (Broke)			
Pulpers (Other fibre)			
Deflaking			
Deflakers (broke)			
Deflakers (other fibre)			
Refining			
Refiners (SF)			
Refiners (LF)			
Refiners (other fibre)			
Other auxiliaries			
Pumps, agitators, other			
Other significant facilities			
APPROACH FLOW CIRCUIT			
Mixing, dilluting, cleaning, screening			
Pumps, agitators, other			
PAPER PRODUCTION LINE 1			
Wet section Operations			
Drives (Wet section)			
Vacuum pumps (LP)			
Vacuum pumps (HP)			
Press section Operations			
Press section drives			
Predrying section			
Predrying section drives			
Sizing or precoating			
Precoating section drives			
Kitchen pumps and auxiliaries			
Postdrying section			
Postdrying section drives			
Finishing Base paper			
Calendering and reeling drives			
Off-line or on-line coating			
Kitchen pumps and auxiliaries			
Coating machine drives			
IRs (electricity)			
Reeling drives			

POWER RELATED EMISSIONS SECTION UNIT OPERATION DEVICES	ELECTRICITY kWh/t	EMISSIONS kg CO_2/t	SHARE %
FINISHING SECTION			
Surface finishing			
Matt-on-line drives			
Supercalenders drives			
Embossing drives			
Other significant devices			
Final Treatings			
Winding drives			
Sheeting drives			
Shiping			
Packaging drives			
Retractile Oven			
GENERAL SERVICES			
Compressed Air system			
Compressors			
Lighting system			
Lights			
Waste water treatment			
Pumps and agitators			
HVAC			
Heating,Ventilating and Air Cooling (HVAC) systems			
Other auxiliaries			
Other significant devices			

Green colour highlights the available data, white colour points out the non-available data and grey letters note the data is not applicable to the mill case

Figure 7.9 Allocation of emissions due to electricity consumption – Mill A.

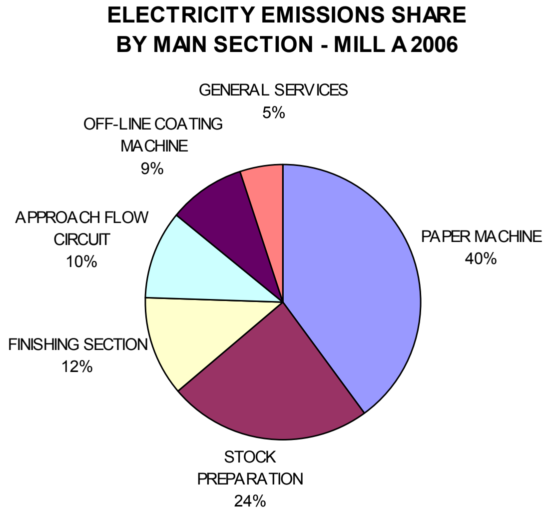


Figure 7.10 Allocation of Electricity emissions by main Sections – Mill A (2006). Each main section of the mill has allocated an emissions amount, according to the mill's total power consumption and its corresponding grid power factor.

Figure 7.10 shows how the major grade of power emissions is allocated in the paper machine section, followed by stock preparation, finishing section and approach flow circuit. The rest of sections: coating, finishing operations or general services are requiring the resting quarter.

7.2.6 Stock preparation and approach flow circuit

Table 7.4 presents the distribution of electricity and emissions associated with stock preparation section and approach flow circuit of Mill A.

The sections of stock preparation and approach flow circuit consist of unit operations with high grade of electricity demand. Refiners, the pumping system and agitators from the approach flow circuit and the stock preparation are requiring up to the 34% of total mill electrical power.

Pumps and auxiliaries surrounding stock preparations section have a high grade of electricity demand. When analysing such results with technicians and mill managers, appeared that the broke system is over-operating. Some of the broke pulpers operate in continuous mode. The broke produced in the paper machine is introduced constantly in the pulper, although in some occasions, the quantity to pulp only represents a 10% of the pulpers maximum load.

Table 4.7 shows some specific electricity ratios of approach flow circuit section according to the Best Available Technologies and the speed machine.

Thus, specific energy demand of approach flow circuit operations ranges 60-100 kWh/t. In the case of Mill A, the consumption of approach flow circuit section is 50 kWh/t (Table 7.4). Taking into account this reference range, the minimum recommended value is already achieved.

Table 7.4 Power Distribution Mill A – Stock Preparation and approach flow circuit (2006)

SECTION	UNIT OPERATION	DEVICES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
STOCK PREPARATION	Pulping	Pulper (LF)	3	1	2
		Pulpers (SF)	15	6	9
		Pulpers (broke)	6	2	4
	Deflaking	Deflaker (broke)	6	2	4
	Refining	Refiners (LF)	4	1	2
		Refiners (SF)	50	20	30
	Other auxiliaries	Pumps, agitators, other	33	13	20
APPROACH FLOW CIRCUIT	Mixing, dilluting, cleaning, screening	Pumps, agitators, other	50	20	30
		Total	166	66	100

Concerning pulping operations, to improve energy efficiency of pumps and other auxiliaries it could be studied the installation of a level control system in the main pulpers.

7.2.6.1 Paper machine section

Table 7.5 shows how 37% of the emissions allocated in electricity use of paper machine section are attributable to the vacuum system. Drives of different parts of the paper machine are also requiring a significant part of the electricity of this section. Therefore, the vacuum system should be one of the first systems to be analysed for energy efficiency purposes.

As previously introduced, the mill has seven ring vacuum pumps assisting Fourdrinier wire (vacuofoils, suction boxes, couch roll, pick up) and the press section (suction press and felts). Reducing valves regulate the vacuum system.

Table 7.5 Power Distribution and Emissions MILL A – Paper Machine Section (2006)

SECTION	UNIT OPERATION	DEVICES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
PAPER MACHINE	Wet Section	Wet Section Drives	52	21	27
		Vacuum Pumps	70	28	37
	Press Section	Press Section Drives	12	5	6
	Drying Section I	Drying Section Drives	14	6	7
	Precoating, Sizing	Precoating Kitchen	9	3	4
		Precoating Drives + Speed Sizer	6	2	3
	Drying Section II	Drying drives	18	7	9
	Finishing Base Paper	Calendering and Reeling drives	12	5	6
		Total	192	76	100

According to BREF (Table 4.11), slow paper machines (speed < 1300 m/min) can be equipped with a vacuum system that consumes a range of 80-120 kWh/t. Mill A has a slow paper machine (speed 280-600 m/min) with a vacuum system requiring 70 kWh/t of electricity; the consumption is lower than the standard values. Despite accomplishing the standards, some energy analysis of the vacuum pumps should be performed. This measure is later evaluated in Chapter 8.

Furthermore, BREF provides a range of global power consumption values for the rest of the paper machine operations (vacuum system exempt). Such consumption comprises 80-140 kWh/t (see Table 4.12). Mill A allocation method estimates an electricity demand of 122 kWh/t for the same unit operations.

7.2.6.2 Off line Coating Machine

Table 7.6 presents power emissions of coating machine section allocated according to the proposed method.

Drives of coating machine followed by the kitchen facilities that prepare the coating colour are the major power demanders of this section.

Table 7.6 Power Distribution and Emissions Mill A – Coating Machine Section (2006)

SECTION	UNIT OPERATION	DEVICES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
OFF-LINE COATING MACHINE	Coating	Pumps, agitators and auxiliaries	17	7	38
		Coating machine drives	23	9	52
		Reeling and winding machine drives	4	2	10
		Total	44	18	100

According to BREF, coating machine should use 15-25 kWh/t of electricity. Table 7.6 confirms that Mill A power coater machine demand is comprised in BREF reference values (see Table 4.12).

7.2.6.3 Finishing Section

Table 7.7 shows the result of the emissions distribution in this section. Calendering and sizing operations are the major consumers of the finishing section.

Table 7.7 Power Distribution and Emissions Mill A. Surface Treatment and Finishing Section (2006)

SECTION	UNIT OPERATION	DEVICES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
FINISHING SECTION	Calendering	Calender drives and auxiliaries	18	7	32
	Embossing	Embossing calender drives and auxiliaries	1	0	1
	Winding	Winding machine drives	11	5	21
	Sheeting	Sheeting drives and auxiliaries	16	6	29
	Packaging and Wraping	Packaging and Wraping machine drives	10	4	17
		Total	56	22	100

7.2.6.4 General Services and Auxiliaries

Mill A has a MCC substation specifically related to general services of the mill, such as compressors, wastewater treatment circuit or other pumps and auxiliaries of the boiler house. However, Mill A has no meters to distinguish consumptions in a more accurate way. Table 7.8 expresses the results according to the substation consumption and the nominal power of the main devices.

Table 7.8 Power Distribution and Emissions MILL A – Auxiliaries (2006)

SECTION	UNIT OPERATION	DEVICES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
GENERAL SERVICES	Compressors	Compressors and air treatment	5	2	21
	Waste Water Treatment	Pumps, agitators and auxiliaries	8	3	36
	Steam Generation	Pumps and auxiliaries	10	4	43
		Total	24	9	100

Feed water pump and the air fan of the main gas boiler should be equipped with variable speed drives (VSD), in order to reduce the energy consumption.

7.2.7 Allocating emissions due to steam demand

As shown in Figure 7.5, steam generation is the main source of CO_2 in Mill A. As mentioned, Mill A generates steam in its stand-alone boilers. Mill A has two natural gas boilers and a fuel-oil boiler. Figure 7.11 presents a basic diagram of steam distribution system and the related-meters available.

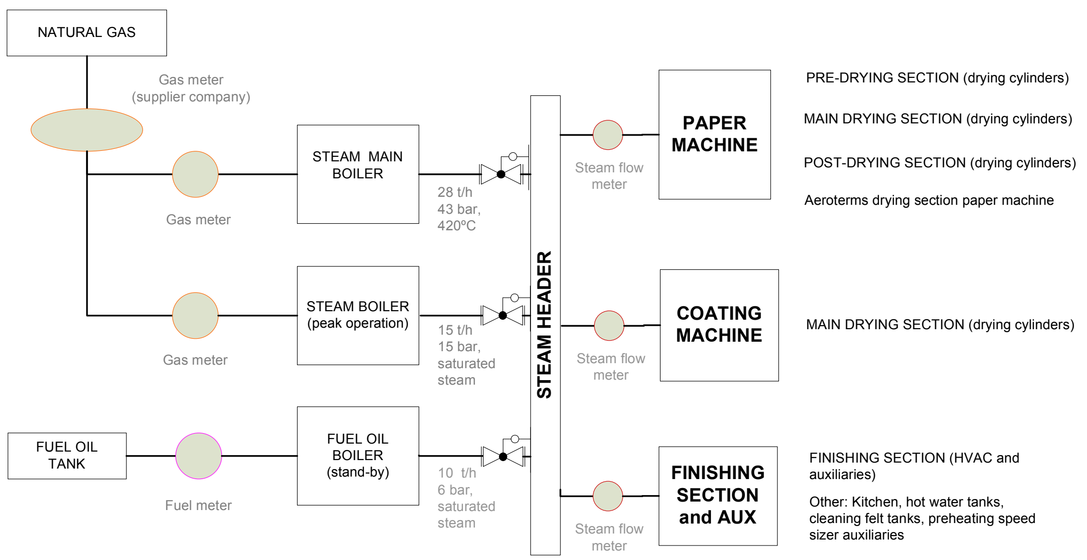


Figure 7.11 Steam distribution through out Mill A

There is a limited number of steam flow meters that can supply an accurate steam distribution system. Therefore, the allocation method proposed in Figure 5.5 cannot be completed; its scope is exposed on Figure 7.12.

STEAM RELATED EMISSIONS	ELECTRICITY	EMISSIONS	SHARE
SECTION / UNIT OPERATION / DEVICES	kWh/t	kg CO_2/t	%
PAPER PRODUCTION - LINE 1			
Wet section operations			
Steam box paper machine			
Drying section			
Drying cylinders (Predrying section)			
Thermocompressors (Drying section)			
Pre-coating kitchen tanks			
Drying cylinders (Postdrying section)			
Other specific devices			
Off-line or on-line coating			
Kitchen tanks			
Drying cylinders			
PAPER PRODUCTION -LINE 2			
FINISHING DEPARTMENT			
Surface treatment			
Specific significant devices			
HVAC			
Specific significant devices			
GENERAL SERVICES			
Air heating			
Heating air flow			
Oil heating			
Oil heat exchanger			
Other significant operations			
Other significant devices			

Figure 7.12 Mill A – Steam allocation method applied into real case. Green colour highlights the available data, white colour points out the non-available data. Only drying and finishing sections have a steam flow meter.

To achieve detailed information of the steam allocation points, the mill would need an investment in steam flow meters. This investment should be understood as an improvement in steam use and potential savings. Table 7.9 summarises steam data allocated through paper manufacturing sections of Mill A -according to the boundaries expressed in Figure 7.12.

Table 7.9 denotes how the major steam demand is allocated in paper machine section. Coating machine section has a lower demand because the drying is mostly achieved with IR dryers.

Table 7.9 Steam Allocation – Mill A (2006)

SECTION	STEAM kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
DRYING SECTION PAPER MACHINE	806	177	67
DRYING SECTION COATING MACHINE	174	38	14
HVAC SYSTEM -FINISHING SECTION	224	49	19
Total	1204	264	100

The drying section of the paper machine process is the major consumer of steam and it points out that drying system itself, the heat recovery system and hood efficiency are susceptible to be studied deeply.

Hoods from the drying section of both paper and coating machines have a heat recovery system; however, this is not the case of hoods from the pre-drying section, the speed sizer and the IR dryers.

Paper dryness at the paper machine and the coating machine is regulated by a cascade control system that regulates flash steam in 5 of the 7 flash tanks. The drying section has one thermo compressor, wherein steam is also monitored and controlled.
Steam is derived to each battery of drying cylinders. At the end of it, there is a flash tank. Condensed steam is removed at the flash tank and the rest of steam (flash steam) is derived to the next battery of drying cylinders (at a lower pressure). As steam is not properly regulated, part of the flash steam remains at the end of the drying system. In this case, auxiliary condensers have to complete condensing-stage in order to return flash steam to the condensates line. This fact produces thermal losses of the drying system. To estimate the thermal losses at the condensers, the specific cooling power has been calculated. DCS has registered inlet and outlet temperatures of the five related condensers and it has been noted the water volume flow and the current production rate. With this data it is achieved the cooling power, which can be translated into thermal losses (see Table 7.10). Mill technicians have supplied this data.

Table 7.10 Steam condensers. Thermal Losses estimations in drying section of paper machine and coating machine

	INLET TEMPERATURE ºC	OUTLET TEMPERATURE ºC	FLOW m^3/h	COOLING POWER kW	PRODUCTION RATE t/h	SPECIFIC LOSSES kWh/t
Paper machine	20,9	25,9	63	366	16,3	22
Coating machine C1	15	41	12	357		
Coating machine C2	15	20	29	145		
Coating machine C3	20	27	29	253	25,9	
Coating machine C4	14	15	37	30		
Total coating condensers				784		30

At the paper machine, the losses are 22 kWh/t, which is close to the reference value defined as 20 kWh/t. At the coating machine, the losses are estimated on 30 kWh/t, which is less than the reference value of about 70 kWh/t. The company in charge of the control system has supplied these reference values [3].

7.2.8 Allocating emissions due to other thermal energy (heat) demand

As shown in Figure 7.13 some natural gas combustion produces direct heat (and CO_2 emissions) in infrared dryers and in the retractile oven of the finishing section.

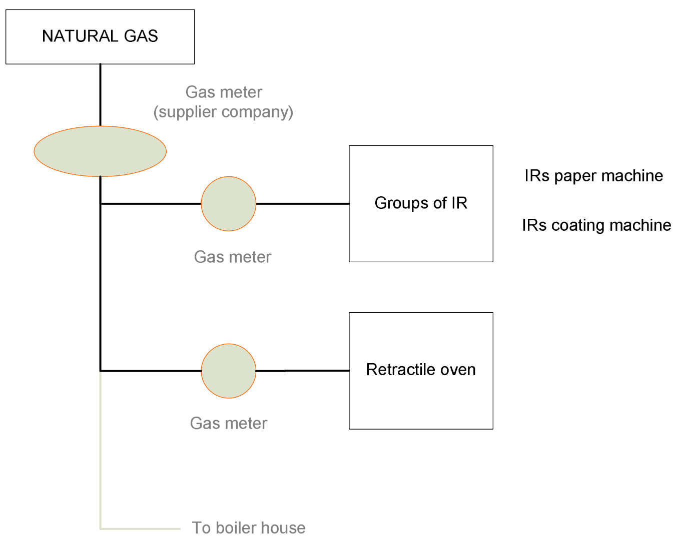


Figure 7.13 Direct heat allocation through paper mill. Gas meters used to distribute emissions.

To distribute heat emissions through out Mill A process, periodic readings of two gas meters have been compiled. One of them measures the IRs gas consumption (installed in paper and coating machine, respectively) and the other one measures the retractile oven consumption (see Figure 7.13).

To allocate the gas consumption of the IR groups at the coating machine, it is used an individual consumption ratio estimated during a downtime of the paper machine.

Figure 7.14 shows the allocation method available applying the AM proposal in Figure 5.6.

OTHER THERMAL RELATED EMISSIONS SECTION UNIT OPERATION DEVICES	DIRECT HEAT kWh/t	EMISSIONS kg CO2/t	SHARE %
PAPER PRODUCTION - LINE 1			
Pre-coating or sizing drying section			
IR dryers			
Other specific devices			
Off-line or on-line coating			
IR dryers			
Other specific devices			
FINISHING DEPARTMENT			
Surface treatment			
Specific significant devices			
Retractile Oven			
GENERAL SERVICES			
HVAC			
Heat and air ventilation systems			
Other significant devices			

Figure 7.14 Mill A – Other thermal allocation proposal applied in a real case. Green colour highlights the available data, grey colour points out the non-applicable data

As seen in Table 7.11, IR dryers of the coating machine are the most important focus of direct heat emissions. Obviously, because the coating IR group requires a high amount of energy to dry a thick layer of coating paper and the IR paper machine needs less energy to dry a thinner layer of precoating paper.

Table 7.11 Direct heat emissions allocation – Mill A (2006)

SECTION	DIRECT HEAT kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
PAPER MACHINE IR GROUP	58	12	34
COATING MACHINE IR GROUP	99	20	58
FINISHING SECTION (OVEN)	14	3	8
Total	171	35	100

Finish Federation define as BATs for printing and writing papers a specific heat demand of 1.458 kWh/t (Table 4.3). In the case of Mill A, the sum of steam and heat demand reaches 1.375 kWh/t. Mill A is accomplishing with BAT efficiency ranges. However, it should also be specified and analysed the grade of coating and the basis weight of the BATs reference value.

7.2.9 Uncertainties related to emission results of allocation method

As mentioned in Chapter 5, results are embedded with a certain grade of uncertainty. The results of the allocation method entail two types of uncertainties. The first uncertainties are referred to the emissions quantification and the second ones are related to the emission distribution through out process.

At the same time, the quantification of emissions involves two additional types of uncertainties, these are related to direct emission factor and to measures of the utile-energy itself. Table 7.12 summarises uncertainties formulated in paragraph 5.7.2. These formulas are meant to be useful for determining both types of aforementioned uncertainties.

For that purpose, the following information regarding uncertainties is listed bellow:

- Uncertainty of CO_2 emission factor comprises an average value of 7% (see Table 3.5)
- Uncertainty of CO_2 grid power factor has been estimated as 8,9% (see 6.3.8)
- Boiler gas meter of Mill A registers gas with an average metering error of 0,47% and an average of uncertainties of 0,3% [4]
- Power meter measures with a grade of uncertainty of 0,1%
- Weighbridge measure uncertainty is been certified as 0,83%

Table 7.12 Uncertainties associated with application of allocation method

EVALUATION OF UNCERTAINTIES	
Emission factors	
Emission factor- fossil fuel, industrial activities (U_{FACT})	7%, based on IPCC
Emission factor-grid power factor (U_{FACT})	8,9%, based on assumptions paragraph 6.3.8
Metering energy parameters U_{ACT}	
Steam flow (U_{SFM})	$U_{SFM} = \sqrt{(u_{PE})^2 + \left(\frac{1}{2} \cdot u_{DP}\right)^2 + (u_C)^2 + \left(\frac{1}{2} \cdot u_T\right)^2 + \left(\frac{1}{2} \cdot u_P\right)^2}$
Gas flow (U_{GM})	$U_{GM} = \sqrt{u_{PE}^2 + u_{CONV}^2 + u_{TR}^2 + u_{HV}^2}$
Power (U_{PM})	U_{PM}< 0,1%, supplier company, U_{PM}< 2%, internal
Fuel (U_F)	$U_{Fuel}= U_{weighbridge}$
Determining emissions (global)	
Emissions (U_E)	$U_E = \sqrt{u^2_{FACT} + u^2_{ACT}}$

* Nomenclature of this table is already defined in paragraph 5.7.2.

As mentioned, the allocation method involves a second type of uncertainties. These are the ones included in steam-flow meters, partial gas meters readings and the assumptions of distributing power emissions through out the process.

The type of steam flow meters used in Mill A is:

- Smart Vortex Flowmeter - Rosemount Mesurament type 8800

According to the supplier data, Table 7.13 summarises the partial uncertainties associated with steam flow metering and provides the global uncertainty result.

Table 7.13 Uncertainty of steam flow metering – Mill A. Source:Rosemount Catalogue [5]

UNCERTAINTIES STEAM FLOW METER	u %
Primary element - vortex flow meter: u_{PE}	1,5
Differential pressure transmitter $u_{\Delta P}$	0,5
Flow computer u_C	0,025
Temperature transmitter u_T	0,4
Pressure transmitter u_P	0,08
Global Uncertainty U_{SF}	1,53

The uncertainty of result is calculated according to Table 7.12, which compiles formulas supplied in Chapter 5.

Moreover, internal gas counters have a 2% of uncertainty, according to the supplier [6]

Regarding the power distributing assumptions, it has been contrasted some specific points:

- The total annual electricity consumed by the five refiners and the deflaker, differs a 7% of the resulting estimation considering the nominal power of each refiner and the share of it in the respective MCC annual consumption.
- The vacuum system requires a specific energy demand of 70 kWh/t of paper produced according to its MCC substation consumption. A specific energy reading and monitoring for vacuum system followed during four working days determined a specific ratio of 74 kWh/t.

Indeed, the distribution method results can bring higher uncertainties upon results, particularly in the case of the power allocation method.

This work considers that such errors need to be taken into consideration, although results are reliable enough for the expected targeting-objective of the application method. In this context, the power allocation method has been applied according to the information of the nominal power installed in the mill, the power meters of the motor control centres and the specific power meters installed in some devices. In some occasions, support of punctual measures has been used to validate results.

Furthermore, each specific unit operation and device can have assigned one or more types of emissions, i.e. steam, heat and power-related emissions. This fact derives to determine from one to three types of emission uncertainties per unit operation or device. This work considers that the calculation of the several individual uncertainties might dilute the results and the specific objective of the allocation method. For that reason, it is considered a meaningful solution to evaluate results uncertainties according to a “qualification” criterion rather than to quantify them in accordance with each individual result. As proposed in Table 5.1, the emissions accuracy could be qualified in categories of high, good, fair and poor according to a particular range of uncertainties.

Considering the aforementioned criterion and particular uncertainty results, the results exposed in the allocation method of Mill A have a grade of uncertainty with a qualification of “good”.

7.2.10 Concluding points of emissions allocation method in Mill A

The allocation method proposed in Chapter 5 has been put into practice with some limitations and arrangements. Checking Figure 7.9, Figure 7.12, Figure 7.14, it seems that the allocation method cannot be entirely put into practice, especially in steam and electricity allocation. The mill would need more power meters and steam flow meters in order to obtain reliable data.

Although emissions allocation results are not as accurate as expected, summary tables of each section presented in previous paragraphs are providing some concluding information. Steam generation is the main cause of Mill A emissions, followed by electricity consumption. Thus, the regulation and heat recovery of paper machine drying section should accurately be evaluated as well as the generation of steam itself.

Regarding power consumption compiled in Table 7.4 to Table 7.8, it is denoted that the vacuum system and the driving section of the paper machine followed by refiners, pumps, and auxiliaries from the approach flow circuit are the major power demanders of Mill A.

If trying to fix some specific and detailed study, this work would recommend starting with the vacuum system and the refining system as well as the drying system regulation and heat recovery.

Although motor drives from paper machine and pumping system from approach flow circuit have both a high grade of consumption, vacuum system is composed of seven pumps and refining system of four refiners. Thus, less devices to focus on potential reduction, might lead to major energy savings.

Finally, Table 7.14 summarises the energy distribution by main section and energy final use of Mill A.

Table 7.14 Energy attributable to power, steam and gas – Main Sections – Mill A (2006)

ENERGY FINAL USE MAIN SECTION ALLOCATION	ELECTRICITY kWh/t	STEAM kWh/t	DIRECT HEAT kWh/t	TOTAL kWh/t
STOCK PREPARATION	116			116
APPROACH FLOW CIRCUIT	50			50
PAPER MACHINE	192	806	58	1.057
OFF-LINE COATING MACHINE	44	174	99	318
FINISHING SECTION	56	224	14	293
GENERAL SERVICES	24			24
Total	482	1.204	171	1.857

As presented in Table 7.15, to produce a tone of paper, it has been emitted an average of 490 $kgCO_2$. The main responsible for emissions is the paper machine section, from both sides, the power and the steam demand.

Table 7.15 Emission Distribution by Focus and Main Section –Mill A

EMISSIONS FINAL USE MAIN SECTION ALLOCATION	ELECTRICITY $kgCO_2/t$	STEAM $kgCO_2/t$	DIRECT HEAT $kgCO_2/t$	TOTAL $kgCO_2/t$
STOCK PREPARATION	46			46
APPROACH FLOW CIRCUIT	20			20
PAPER MACHINE	76	177	12	265
OFF-LINE COATING MACHINE	18	38	20	76
FINISHING SECTION	22	49	3	74
GENERAL SERVICES	9			9
Total	191	264	35	490

Concluding, the distribution of emissions is not reaching the desirable detail and accuracy although the results are acceptable for a benchmarking between mills at section or unit operation levels.

According to the reference bibliography described in chapter 4, Mill A keeps the main trends of the expected energy consumption. Although it still can optimise the identified electricity and steam red points.

7.3 MILL B

7.3.1 General description and outstanding data

Mill B is an offset printing paper mill that produces two different grades of papers: coated and non-coated paper. Mill B produces coated demi-matt paper with a basis weight of 90-175 g/m^2 plus uncoated paper with a basis weight range between 50-200 g/m^2.

This mill has two paper machine lines, one line for coated paper (CL) and the other one for the uncoated paper (UL). A paper machine produces uncoated paper and a second paper machine produces basis paper to coat afterwards in an off-line coating machine. Both grades of paper receive the final conditions in the finishing section. Table 7.16 presents some general data of the mill as well as summarises the gas consumption and power produced by its CHP-1 plant.

Table 7.16 Mill B General Data – 2006

GENERAL DATA MILL B		2002	2003	2004	2005	2006
Production	Paper produced, all types [t]	114.052	115.557	116.733	124.213	126.749
Raw materials	Pulp consumed [tones 100% dryness]	70.399	68.575	69.660	72.578	70.577
Chemicals and fillers	$CaCO_3$ and kaolin purchased [t]	48.231	57.574	56.975	65.320	63.519
Water	Fresh water intake [m^3]	1.600.566	1.595.363	1.559.093	1.579.928	1.580.023
Natural Gas	Consumption in the mill [MWh_{LHV}]	16.526	17.655	16.611	18.846	21.246
Electricity	Consumption [MWh_e]	86.295	86.432	84.281	79.673	84.352
GENERAL DATA CHP-1 PLANT		**2002**	**2003**	**2004**	**2005**	**2006**
Natural Gas	Consumption CHP-1 [MWh_{LHV}]	570.284	539.742	519.235	530.338	515.479
Electricity	Production [MWh_e]	186.128	189.847	183.925	185.340	179.397

Based on Table 7.16 data, Figure 7.15 shows the evolution of the specific energy consumption of the two main energy sources of Mill B.

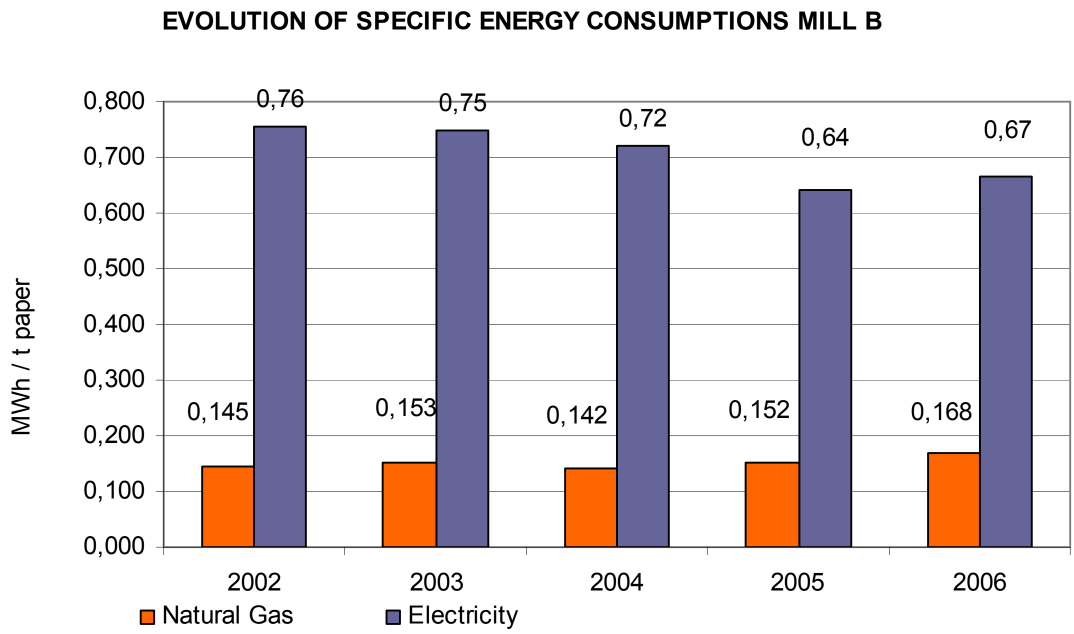


Figure 7.15 Evolution of specific energy consumption Mill B 2002-2006. The specific consumption is referred explicitly to Mill B, CHP-1 plant is not considered in this figure.

For later calculations, it is necessary to summarise the production profile of uncoated and coated paper production. Table 7.17 presents the shippable paper production in 2006.

Table 7.17 Shippable production 2006. Mill B

SHIPPABLE PRODUCTION 2006		
Paper grade	tones of paper	share %
Coated paper	108.592	86%
Uncoated paper	18.156	14%
Total	126.749	100%

The following lines exemplify the specific paper manufacturing process that takes place in Mill B using Figure 7.16 to overview its process diagram.

Stock preparation

Mill B uses dried pulp as main raw material. Specifically, this pulp contains a 20% of long fibre and 80% of short fibre. The paper web is formed with an additional 30% of own broke fibres.

The stock preparation system of Mill B is equipped with five pulpers to slush broke, two additional pulpers for long fibre and one pulper for short fibre. Seven refiners (2 of long fibre and 5 of short fibre) fibrillate and cut the fibres suspension. After refining, fibre suspension is derived to the approach flow circuit of each paper machine.

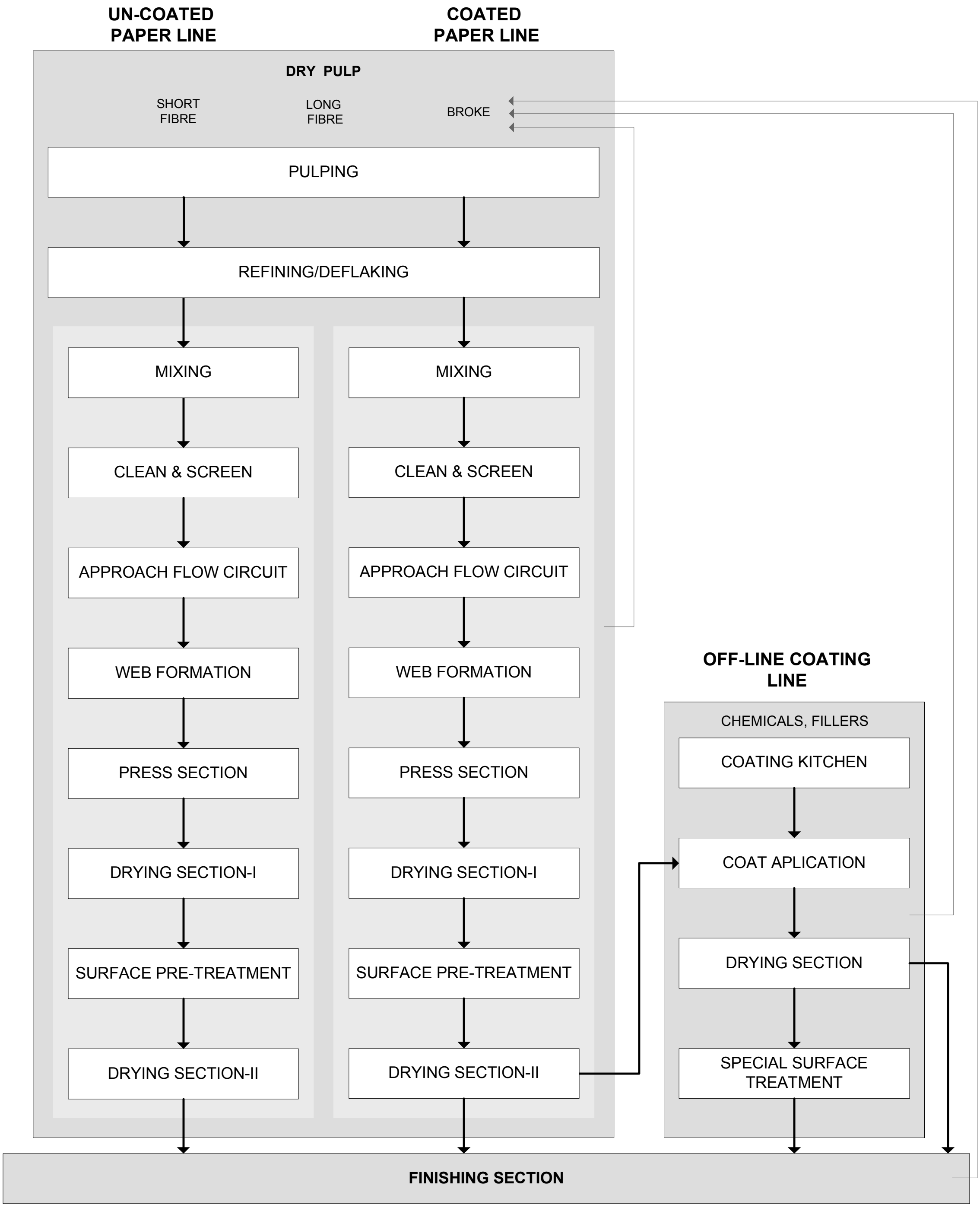


Figure 7.16 Mill B – Process diagram

Uncoated Paper line (UL)

The refined fibres move to a three stages of cyclone depuration, a fibre recovery system and a pressurised screener.

The uncoated paper line has a single side paper machine with a width of 2,06 m and a medium speed range of 160-320 m/min. This paper machine is assisted by three vacuum pumps to maintain the effectiveness of the wire drainage, the coach roll, the pick up roll and the suction boxes. The press section is composed of three press rolls. The drying section has 18 drying cylinders. A starch layer is applied with a size press. The drying section has an open hood.

Coated Paper line (CL)

Refined suspension follows a four-stage cyclone cleaning and a final pressurised screening. The coated paper line has a Fourdrinier paper machine of 3,29 m width and a speed range of 580-750 m/min. The vacuum system is equipped with seven vacuum pumps and the mechanical press section uses three conventional press rolls. The paper dryness out-presses rounds 42%. The drying section has 34 drying cylinders and an intermediate stage of pre-coating. A speed sizer and a group of IR dryers (fired with natural gas) complete this pre-coating section. The drying section has a closed hood with partial heat recovery for air systems.

Off-line coating machine

The off-line coating machine is a two-sided coating machine that incorporates 7 drying cylinders (steam), two hot air streams and IR dryers (fired with gas and electrical power) after each coating application point to ensure a perfect drying. The speed of this machine ranges 750-800 m/min. At the end of it, the paper web passes through a matt-on-line calender with 2 nips, to provide the desired surface level of brightness.

Finishing section

In the finishing section, paper produced in both lines is wound, cut, sized, wrapped, and prepared to be shipped.

7.3.2 Mill B energy-related issues and emission focus

As in the case of Mill A, Mill B main emissions can be allocated according to its final energy use.

- Mill B owns a cogeneration system, which supplies steam and electricity to its manufacturing process. The Combined gas cycle of Mill B uses natural gas. Chapter 6 has already described Mill B combined heat and power plant (named CHP-1 plant). Main energy data of Mill B cogeneration system has been presented in Figure 6.6 and in Table 6.1. CHP-1 plant produces enough steam to complete the requirements of Mill B and does not sell thermal energy to other out-site plants.

- CHP-1 plant produces a surplus of electricity, which is injected to national grid and sold to national pool.

- Mill B also uses natural gas in different groups of IR dryers to produce direct heat. These groups are installed in the drying sections of paper coated line (CL) and in the off-line coating machine.

Figure 7.17 graphically overviews the energy aspects mentioned in last paragraphs.

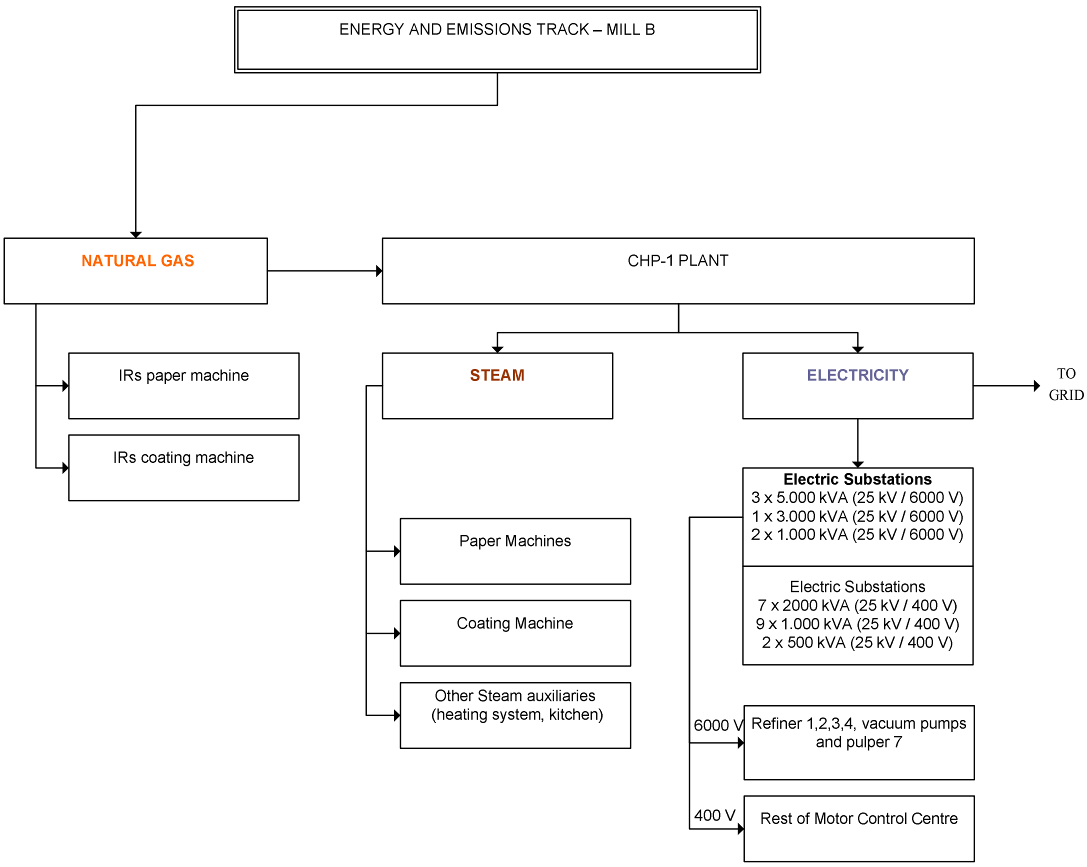


Figure 7.17 Energy and Emissions Track Mill B - Annual data (2006). The main energy source of Mill B is natural gas.

Moreover, collateral aspects can also become an additional source of GHG emissions:

- Mill B uses chemical pulp as main raw material. Neutral emissions are approached to pulp production, although it should be analysed pulp process deeply.

- Some of the workers of the mill use private transport to go to work although the rest use the bus service of the company.

- The paper manufactured in Mill B is sold to a wide market of countries. This fact implies a by-product logistic and distribution system, which again can have assigned a relevant amount of emissions.

- The waste paper –previous produced in the mill– can become part of landfills and it is there subjected to degradation under anaerobic conditions (methane emissions).

Considering the mentioned points, Mill B has associated the following emission scopes:

- Scope 1: Natural gas fired in stationary combustion (IR groups) and CHP-1 plant
- Scope 2: Electricity demand from peninsular grid in case of CHP-1 operation failures.
- Scope 3: Emissions assigned to the whole of paper life cycle, such as pulp production, transport of employees or carbonate production.

Setting Boundaries

All GHG emissions of Mill B are assumed as carbon dioxide emissions. The rest of the non-CO_2 gases are not taken into account according to the same considerations exposed in the case of Mill A (see paragraph 7.2.2). Actually, paragraph 3.4.2 has used, as a sample case, the same fossil fuel amount of Mill B to prove the lower materiality concept of CH_4 and N_2O emissions.

During 2006, CHP-1 plant had an availability factor of 98%. Consequently, Mill B purchased from the CHP facility the majority of its power requirements. Thereby, Mill B had to purchase from an external supplier a small quantity of megawatts. For this reason, the Scope 2 indirect-emissions that could be attributed to Mill B are not attended in this work, as the computation of the mentioned external power represents less than 0,6% of the total reported CO_2 emissions.

As mentioned in the introduction chapter of this work, emissions included in Scope 3 are not taken into consideration.

In conclusion, Mill B emissions allocation process comprises the complete range of direct emissions produced by the natural gas combustion, both in the IR groups and in the CHP-1 plant (Scope 1).

7.3.3 Estimating Emissions

According to the previous paragraph, Mill B emissions, which are focused on natural gas combustion, should have a first allocation into its final energy use. Figure 7.18 shows the main distribution track of natural gas emissions according to Mill B energy utilities.

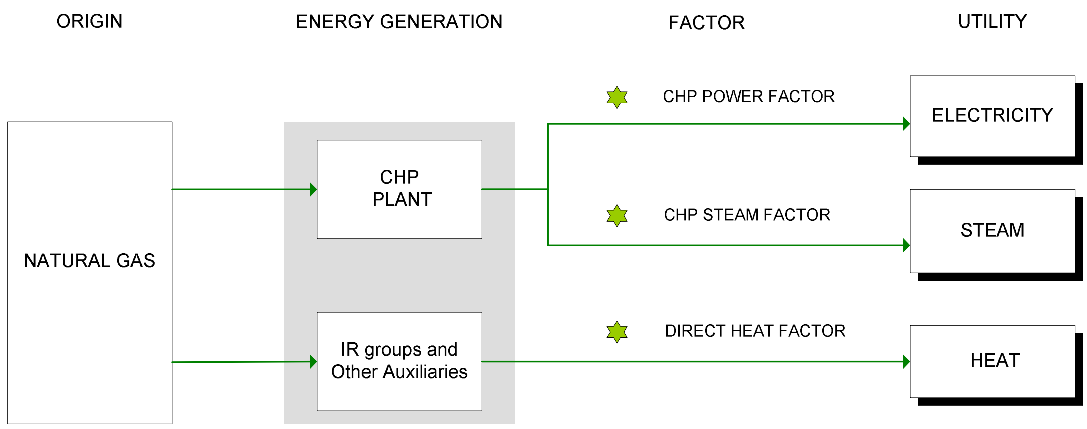


Figure 7.18 Mill B Main distribution map by source and energy final end-use

The CHP-1 plant sample case of paragraph 6.2 has already exposed the different methods to estimate emission factors assigned to power and steam generation. After evaluating all of them, Table 7.18 presents the emissions factors and the respective basis method used for emission's calculation purposes.

Table 7.18 CO_2 emission factors: Values and Calculation Method. 2006 Mill B

EMISSION FACTOR	tCO_2/MWh	CALCULATION METHOD
Natural Gas/Heat Emission Factor *	0,202	Factor according IPCC and Spanish NAP
Electricity Emission Factor	0,273	Calculations according to CHP-1 selected emission factor 2006 (detailed in paragraph 6.2.5)
Steam Emission Factor	0,269	Calculations according to CHP-1 emission Factor 2006 (detailed in paragraph 6.2.5)

* Emission factor is based on LHV units and includes oxidation factor

Steam and electricity emission factor is defined in accordance with results and concluding notes specified in paragraph 6.2.4 and 6.2.5. Note that power and steam factors correspond to the new proposed method (see Table 6.13).

Table 7.19 and Figure 7.19 present the total emissions produced by Mill B. This table distinguishes between emissions produced in CHP-1 and emissions produced in its manufacturing process.

Table 7.19 Total Emissions Mill B - 2006

ENERGY SOURCE	ANNUAL ENERGY MWh	ANNUAL EMISSIONS tCO_2
CHP-1 plant - Natural Gas	515.479	103.921
Mill B plant - Natural Gas	21.246	4.283
Total	536.725	108.204

Note that the emissions that are going to be allocated through paper process of Mill B are the emissions related to the mill energy use. Although Mill B produces an extra amount of electricity and CHP-1 is responsible for a high quantity of emissions associated, the emissions allocated through Mill B process are the emissions corresponding to Mill B specific energy use (electricity, steam and heat demand).

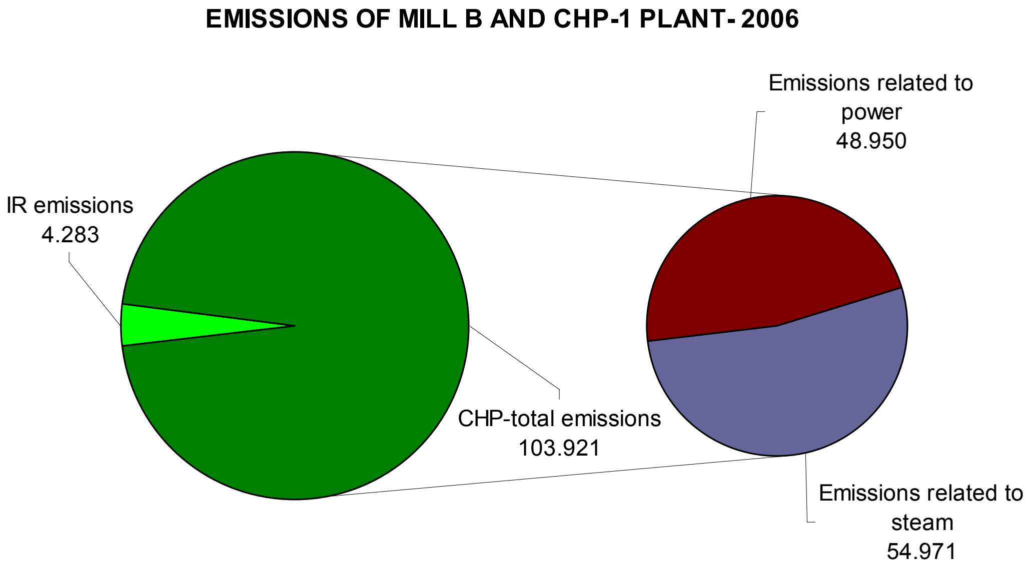
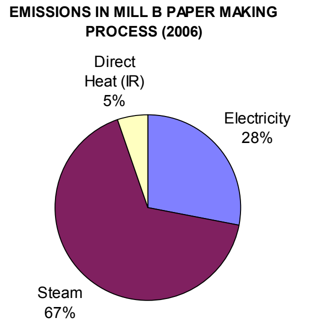


Figure 7.19 Total emissions of Mill B and its CHP plant (2006). Data expressed in tCO_2

Table 7.20 shows the annual electricity, steam and power consumptions of Mill B and its emissions associated according to emission factors detailed in Table 7.18 and calculated in Chapter 6.

Table 7.20 Emissions allocation due to power, steam and electricity demand – Mill B – 2006

ENERGY SOURCE	ENERGY CONSUMPTION MWh	EMISSIONS tCO_2
Electricity	84.352	23.016
Steam	204.173	54.971
Direct Heat (IR)	21.246	4.283
Total Mill B	309.771	82.270



To exemplify emissions and energy balance situation, Figure 7.20 presents a Sankey diagram with the main energy incomes and the corresponding emission focus due to the presented energy profile.

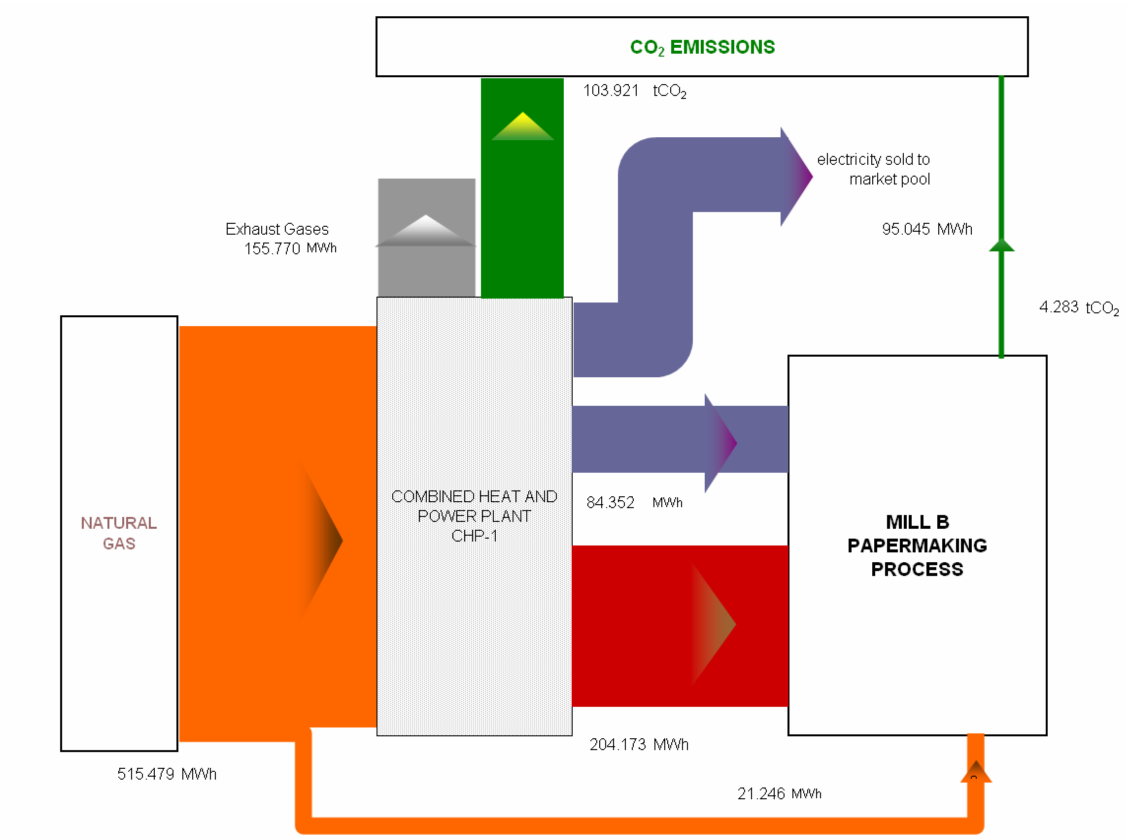


Figure 7.20 Emissions and energy balance – Mill B – 2006 data. Steam is coloured in red, electricity in blue, direct heat (natural gas) in orange and emissions in green.

As mentioned, all the emissions are defined as Scope 1 because energy use derives from natural gas combustion.

7.3.4 General emissions allocation according to energy use in Mill B

Mill B allocation method requires the same list of data-files and diagrams listed in paragraph 5.6.1, internal energy maintenance reports and some support information supplied by technicians of the mill.

Differing from Mill A, Mill B does not own a distributed control system, which supervises the consumption of the MCCs. Instead, Mill B has analogical power meters.

In addition, Mill B has steam meters to control steam demand and partial gas meters to quantify the gas consumed in the main units of the mill.

Figure 7.21 shows the energy allocation results that are going to be detailed in next paragraphs.

7.3.5 Allocating emissions due to electricity demand

According to the allocation method, energy utilities are allocated into the different process lines (CL and UL), and afterwards distributed along the rest of defined levels (by sections, unit operation or/and devices).

Mill B registers power readings of two main substations and multiple MCCs provided with analogical power meters. Each month, operators note down each meter reading.

The low-voltage grid system of Mill B has two main substations (named A and L). Each substation feeds a variety of motor control centres, each of them with an analogical power meter. At the same time, MCCs feed different electrical units and these last ones feed both CL and UL devices.

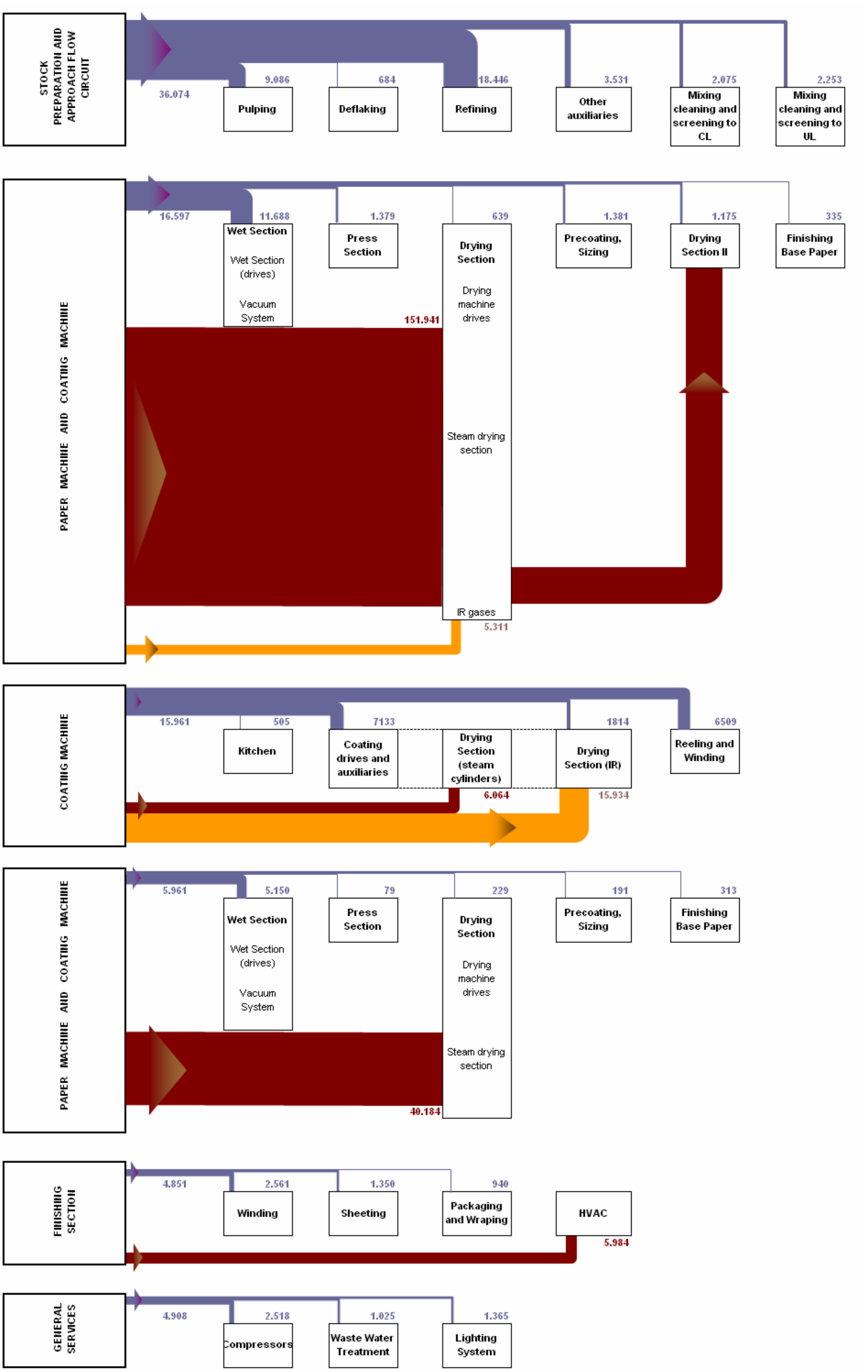


Figure 7.21 Allocation of power, gas and direct heat through out the paper process of Mill B (2006). Steam is coloured in red, electricity in blue and direct heat in orange. Data units are expressed on MWh

Figure 7.22 compiles and simplifies the available power units and the devices connected to each of them.

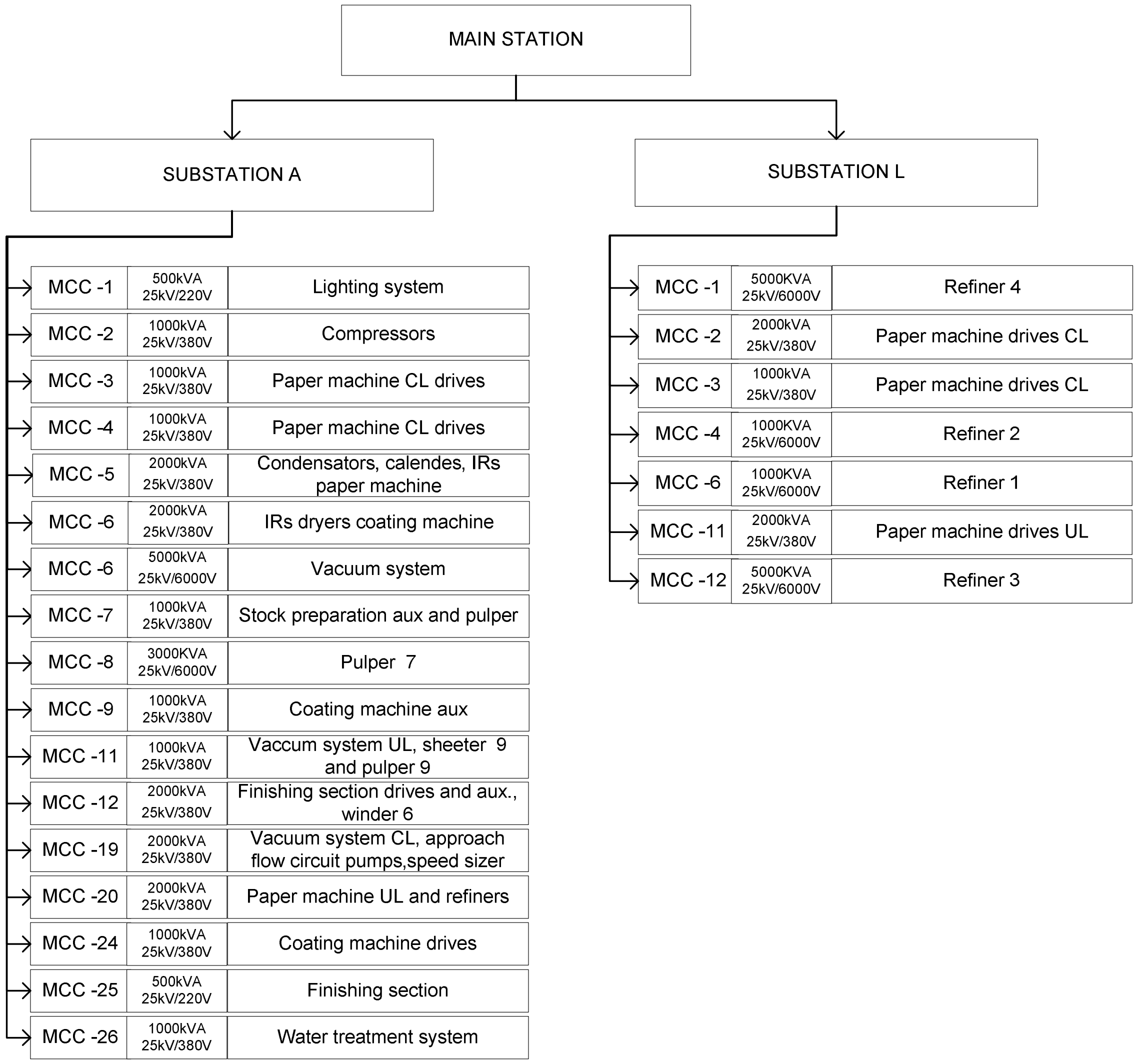


Figure 7.22 Electricity substations and motor control centres of Mill B (2006). Main devices connected to each of them. CL abbreviates coated line and UL uncoated line.

It has been taken into account an availability factor of some devices according to criteria of technicians. Despite the mentioned assumptions and estimations of electricity consumption, the allocation method proposed in Figure 5.4 cannot be completed as desired. Figure 7.23 presents the electricity distribution map according to the electricity metering boundaries of the mill.

POWER RELATED EMISSIONS	ELECTRICITY	EMISSIONS	SHARE
SECTION / UNIT OPERATION / DEVICES	kWh/t	kg CO_2/t	%
STOCK PREPARATION			
Pulping			
Pulpers (SF)			
Pulpers (LF)			
Pulpers (Broke)			
Pulpers (Other fibre)			
Deflaking			
Deflakers (broke)			
Deflakers (other fibre)			
Refining			
Refiners (SF)			
Refiners (LF)			
Refiners (other fibre)			
Other auxiliaries			
Pumps, agitators, other			
Other significant facilities			
APPROACH FLOW CIRCUIT			
Mixing, dilluting, cleaning, screening			
Pumps, agitators, other			
PAPER PRODUCTION LINE 1			
Wet section Operations			
Drives (Wet section)			
Vacuum pumps (LP)			
Vacuum pumps (HP)			
Press section Operations			
Press section drives			
Predrying section			
Predrying section drives			
Sizing or precoating			
Precoating section drives			
Kitchen pumps and auxiliaries			
Postdrying section			
Postdrying section drives			
Finishing Base paper			
Calendering and reeling drives			
Off-line or on-line coating			
Kitchen pumps and auxiliaries			
Coating machine drives			
IRs (electricity)			
Reeling drives			
PAPER PRODUCTION LINE 2			
Wet section Operations			
Drives (Wet section)			
Vacuum pumps (LP)			
Vacuum pumps (HP)			
Press section Operations			
Press section drives			
Predrying section			
Predrying section drives			
Sizing or precoating			
Precoating section drives			
Kitchen pumps and auxiliaries			
Postdrying section			
Postdrying section drives			
Finishing Base paper			
Calendering and reeling drives			
Off-line or on-line coating			
Kitchen pumps and auxiliaries			
Coating machine drives			
IRs (electricity)			
Reeling drives			
FINISHING SECTION			
Surface finishing			
Matt-on-line drives			
Supercalenders drives			
Embossing drives			
Other significant devices			
Final Treatings			
Winding drives			
Sheeting drives			
Shiping			
Packaging drives			
Retractile Oven			
GENERAL SERVICES			
Compressed Air system			
Compressors			
Lighting system			
Lights			
Waste water treatment			
Pumps and agitators			
HVAC			
Heating,Ventilating and Air Cooling (HVAC) systems			
Other auxiliaries			
Other significant devices			

Figure 7.23 Mill B – Emissions allocation by electricity consumption, the method adjusted to Mill B case. Green colour denotes the available data, and grey colour denotes data is not applicable to the mill case.

Following paragraphs present the results of the power emissions allocation, according to data availability.

General view of electricity consumption

Figure 7.24 shows graphically the electricity-use profile of the main section of the paper mill. Stock preparation and paper machines followed by off-line coating machine are the sections with higher grade of energy use.

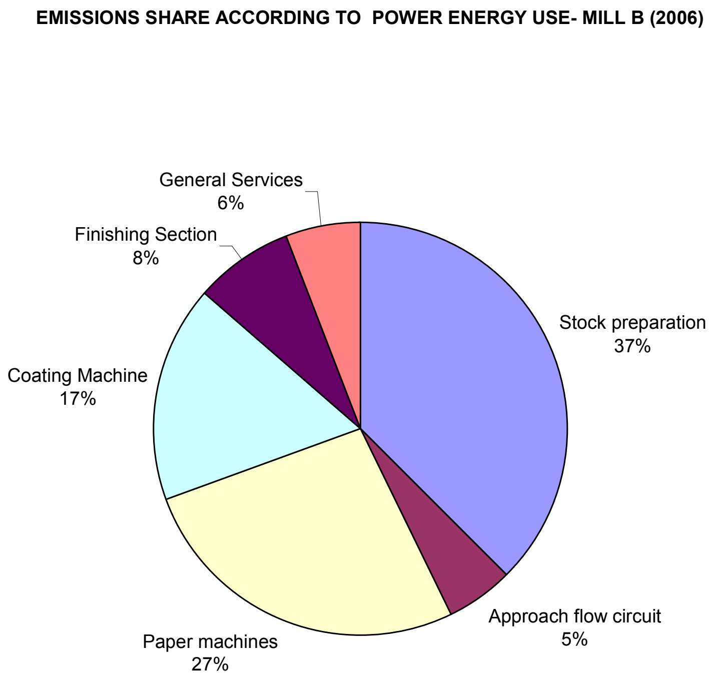


Figure 7.24 Electricity emission shares by main section 2006. (*) Approach flow circuit and Paper machine include both paper machines and devices of the two paper production lines together.

7.3.5.1 Stock preparation and approach flow circuit section

Table 7.21 presents the results obtained when distributing power emissions through out the stock preparation section. Refining and pulping are the major consumers of this section.

Table 4.5 defined some specific energy ratios on fibre refining. According to this table, long fibre refining usually implies a consumption of 100-200 kWh/t_{ref} (tones of refined pulp), meanwhile short fibre refining consumption ranges 50-100 kWh/t_{ref}. Mill B uses 20% of long fibre and 80% of short fibre. For Mill B, these values would be equivalent to 10-20 kWh/t (for long fibre) and 20-40 kWh/t for short fibre. In short fibres ranges, it seems that Mill B refining system is consuming more than the expected, although it should be taken into account that Mill B produces at lower substances; this fact entails a higher grade of refining.

Table 7.21 Specific power consumption and emissions. Stock Preparation (2006)

SECTION	UNIT OPERATION	FACILITIES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
STOCK PREPARATION CL + UL	Pulping	Pulpers (LF)	16	4	6
		Pulpers (SF)	26	7	10
		Pulpers (broke)	30	8	12
	Deflaking	Deflaker (broke)	5	1	2
	Refining	Refiners (SF)	135	37	54
		Refiners (LF)	11	3	4
	Other auxiliaries	Pumps, agitators, other	28	8	11
		Total	250	68	100

Moreover, pulping unit operation (long and short fibre) also entails a high electrical demand. This fact can be explained from different points of view. From one hand, long fibre pulp is received in bales of 90% dryness, and such grade of dryness requires major energy consumption for hydration, separation and pulping. From the other hand, broke represents the 30% of the web pulp. Such average of broke fibre needs pumping power to return broke to the approach flow circuit.

Paper machine lines

Coated paper line

The process structure of paper machine (CL) is similar to Mill A paper machine. In energy terms, they differ from IR groups. Mill B has one group fired with natural gas and another one with power.

Table 7.22 outstands that the vacuum circuit and the wet section drives are the main power consumers and together constitute up to the 70% of the power consumption of the paper machine section.

Table 7.22 Specific power consumption and emissions. Coated paper line (per tone of coated paper produced)

SECTION	UNIT OPERATION	FACILITIES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
APPROACH FLOW CIRCUIT CL	Mixing, dilluting, cleaning, screening	Pumps, agitators, other	19	5	100
PAPER MACHINE CL	Wet Section	Wet Section Drives	51	14	33
		Vacuum Pumps	57	15	37
	Press Section	Press Section Drives	13	3	8
	Drying Section	Drying Section Drives	6	2	4
	Precoating, Sizing	Precoating Kitchen	13	3	8
	Drying Section II	IRs	11	3	7
	Finishing Base Paper	Calendering and Reeling drives	3	1	2
		Total paper machine	153	42	100

According to Table 4.11 (BREF) the vacuum system of a slow speed paper machine should consume between 80-120 kWh/t. This reference energy range tallies with the vacuum system of the CL machine.

Uncoated paper machine line

The uncoated paper machine line has been in service since 1953. The process line is simple and along decades has received little investments. The vacuum level is controlled by throttling valves. The fibre web receives a starch layer with a size press. Table 7.23 shows the results of the power allocation method. Vacuum system of this machine has a relevant consumption, according to BREF reference values (Table 4.11).

Comparing Table 7.22 and Table 7.23, the paper machine section of the uncoated paper line consumes 2/3 more than the coated paper line, in terms of specific energy. In conclusion, UL is an inefficient system and needs urgent investment.

Table 7.23 Specific power Consumption and emissions. Uncoated paper line (per tone of uncoated paper produced)

SECTION	UNIT OPERATION	FACILITIES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
APPROACH FLOW CIRCUIT UL	Mixing, dilluting, cleaning, screening	Pumps, agitators, other	124	34	100
PAPER MACHINE UL	Wet Section	Wet Section Drives	125	34	38
		Vacuum Pumps	159	43	48
	Press Section	Press Section Drives	4	1	1
	Drying Section	Drying Section Drives	13	3	4
	Precoating, Sizing	Precoating Kitchen	11	3	3
	Finishing Base Paper	Calendering and Reeling Drives	17	5	5
		Total paper machine	328	90	100

Off line coating machine

The two-sided coating machine supplies a coating layer to the web (CL). As in the paper machine, the coating machine has two groups of IRs installed. One of them is fired with power (in order to control paper caliper) and the other uses natural gas.

Table 7.24 highlights how IR dryers tally with coating machine drives in terms of energy use.

Table 7.24 Specific power consumption and emissions. Coating Machine Section – Mill B

SECTION	UNIT OPERATION	FACILITIES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
OFF-LINE COATING MACHINE	Coating	Pumps, agitators and auxiliaries	5	1	3
		Coating Machine Drives	66	18	45
		IRs	60	16	41
Additional treatment		Calendering	17	5	11
		Total	147	40	100

Finishing Section

Finishing section of Mill B provides service to the two paper lines (UL and CL). Table 7.25 presents the power consumption of its main units, considering both coated and uncoated paper production. As Mill B is not supplying a special end surface treatment, electricity in the finishing sections is consumed by basic equipment, such as winding, sheeting and wrapping units. Mill B uses an electric oven for retractile wrapping.

Table 7.25 Specific power consumption and emissions. Finishing Section – Mill B (per tone of total shippable production)

SECTION	UNIT OPERATION	DEVICES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
FINISHING SECTION	Winding	Winding machine drives	20	6	53
	Sheeting	Sheeting drives and auxiliaries	11	3	28
	Packaging and Wraping	Packaging and Wraping machine drives	7	2	19
		Total	38	11	100

Compressors, water treatment and the lighting system are considered general services of Mill B. Table 7.26 presents the specific allocation power results.

Table 7.26 Specific power consumption and emissions. General Services – Mill B (per tone of total shippable production)

SECTION	UNIT OPERATION	DEVICES	ELECTRICITY kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
GENERAL SERVICES	Air compressors	Compressors and air treatment	20	6	51
	Waste Water Treatment	Pumps, agitators and auxiliaries	8	2	21
	Lighting System	Lights	11	3	28
		Total	39	11	100

The consumption of Mill B air compressing system is quite relevant as well as the lighting system.

Compressing system has received little investment for the last decades and technicians agree that air demand profile and the regulation of the compressor units should be analysed and reviewed.

Lighting system consumption is also relevant. Mill B has still installed several vapour mercury lamps, which have a lower efficiency ratio.

7.3.6 Steam allocation coated paper and uncoated paper lines

CHP-1 plant derives four output steam streams to mill process. One of them is sent to uncoated paper machine (at 3,5 bar) and the rest to the coated paper line. Two of these last ones feed the coated paper machine (at 3,5 and 5 bar) and the other one is the income stream of the uncoated machine line (3,5 bar). Figure 7.25 presents a steam distribution basic diagram of Mill B.

As mentioned, the mill has reliable steam flow meters. However, these are not enough to provide the allocation purposes proposed in Figure 5.5. The information obtained just complies with the same steam allocation results of Mill A (see Figure 7.12).

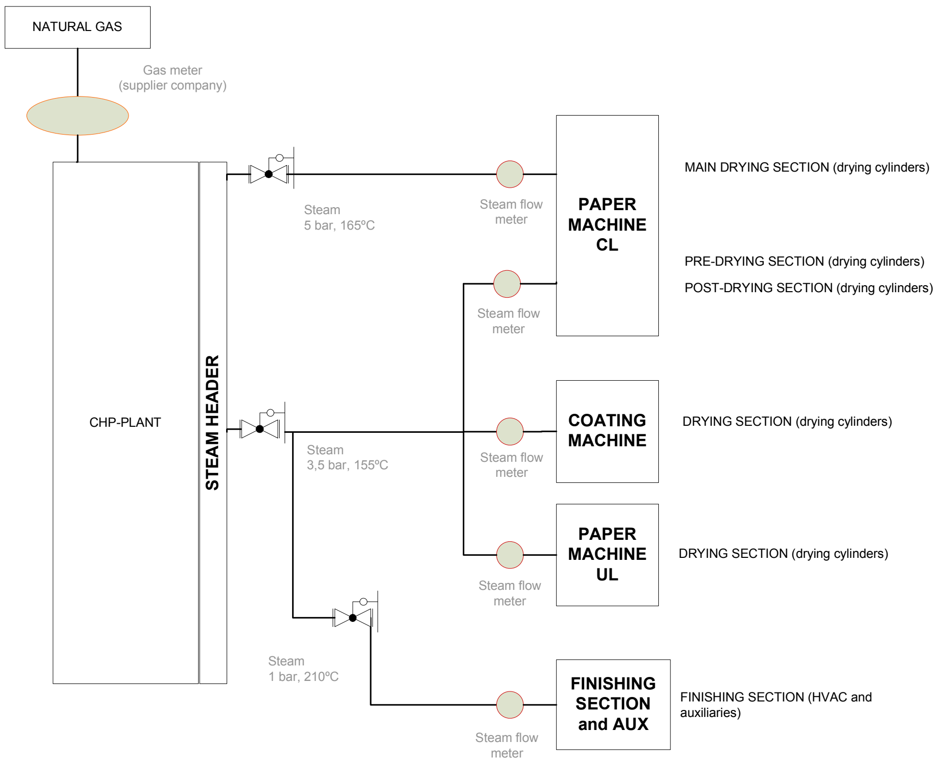


Figure 7.25 Steam distribution through out Mill B

Table 7.27 summarises steam distribution (metered by reliable steam flow meters). Obviously, the main steam consumers are paper machine lines, and particularly the UL paper machine line.

Table 7.27 Steam Distribution – Mill B

SECTION	STEAM kWh/t*	EMISSIONS $kgCO_2/t$	SHARE %
Drying Section Paper Machine CL (3,5 bar)	650	175	35
Drying Section Paper Machine CL (5 bar)	749	202	40
Drying section Coating Machine (3,5 bar)	56	15	3
Drying Section Paper Machine UL (3,5 bar)	2213	596	20
Finishing Section (1 bar)	47	13	3
Total	1611	434	100

* t of paper refers to the shippable paper production of respective line, according to Table 7.17. Share has been evaluated according to absolute steam values

The drying section of the uncoated line consumes –in specific energy terms– up to the double of steam than the drying section of the coated paper machine. UL paper machine has deficiencies in its steam recovery system. Its open hood is not recovering enough heat from the drying process and the conditioning of the income air is carried out by an extra amount of steam. The drying cylinders efficiency should also be examined.

Even though the UL machine had the same efficiency of the coated paper line, it has to be taken into account that the paper produced has a high basis weight; the basis weight is due to fibre as there is no coating layer. Fibre drying requires higher steam transference than coating layer drying. For that reason in this particular case, the steam consumption would provably be higher, although not the double.

As in Mill A, the profile of flash steam has been analysed at the drying system of both paper machines. Moreover, to calculate the thermal losses of both drying systems using data of flash steam not recovered, it has been used the specific cooling power of each of the steam condensers located at the end of the flash tanks line. Technicians noted inlet and outlet temperatures of the condensers as well as the water volume flow and the production rate. With this data it is achieved the cooling power, which can be translated into thermal losses (see Table 7.28).

Table 7.28 Steam condensers. Thermal Losses estimations in drying section of paper machines

RELATED-CONDENSERS	INLET TEMPERATURE ºC	OUTLET TEMPERATURE ºC	FLOW m^3/h	COOLING POWER kW	PRODUCTION RATE t/h	SPECIFIC LOSSES kWh/t
UL	27	38	33	402	2	201
CL	30	37	125	1.001	15	67

According to Table 7.28, specific thermal losses of UL are reaching 200 kWh/t. Meanwhile at the CL the losses are 67 kWh/t. Both specific losses are higher than the reference value 20 kWh/t, which has been provided by the supplier of the steam control system [3]. Thus, steam regulation should be reviewed and adjusted, as steam is misused in the drying section of each paper machine.

7.3.7 Allocating emissions due to other thermal energy (heat demand)

An additional input of natural gas is used in the IR dryers. This input stream is classified as other thermal energy. As in the case of Mill A, Mill B disposes of internal gas meters, which enable to complete the Other Thermal Allocation method proposed in Figure 5.6.

Table 7.29 presents the allocation of heat demand through out the paper and coating machines. The IR dryers of the coating machine undertake the higher share of this consumption. The main reason is that the coating layer needs to be dried quickly and efficiently, to allow a second coating application.

Table 7.29 Direct Heat Allocation – Mill B

SECTION	DIRECT HEAT kWh/t	EMISSIONS $kgCO_2/t$	SHARE %
Drying Section Paper Machine CL	49	10	25
Drying section Coating Machine	147	30	75
Total	196	39	100

Table 7.30 presents the energy consumption profile of the IR dryers installed in the paper and coating process, comparing both gas and power ratios.

Table 7.30 Comparing IRs energy consumption and emissions - Mill B

IR TYPE / MACHINE	ENERGY CONSUMPTION kWh/t	EMISSIONS $kgCO_2/t$	ENERGY SHARE %
PAPER MACHINE (POWER)	11	3	4
PAPER MACHINE (GAS)	49	10	18
COATING MACHINE (POWER)	60	16	22
COATING MACHINE (GAS)	147	30	55
Total	266	59	100

Up to 75% of both power and heat is consumed in the coating machine.

7.3.8 Uncertainties related to emission results of allocation method

The results of Mill B allocation method should be presented with the corresponding grade of uncertainty. Mill B emissions are focused on direct emissions of natural gas combustion. Such emissions are related to the specific emission factor and to the level of accuracy of the gas meter, its converter and the net calorific value of the supplier company. In this sense, formulas expressed in Table 7.12 are also applicable in Mill B.

Table 7.31 presents the main features of gas meter and converter of the plant, as these instruments are measuring the unitary focus of Mill B emissions. Uncertainties are certified with less than 0,34% [4]. The cogeneration plant is compliyimg with metering legislation.

Table 7.31 Main gas meter of Mill B. Main features and uncertainties

COUNTER METER	MEASURE METERED	RANGE	CALIBRATING NORM	UNCERTAINTY
Gas Counter: Elster ETM	volume m^3	13-250	PT-08	<0,34%
Conversor: Elster EK 88	bar abs	1,4-3,5	UNE 60-520-88	<0,33%

As in the case of Mill A, according to definitions of formulas 5.4 and simplified formula 5.5 (see Table 7.12), direct emissions can be presented with an approaching grade of accuracy of 7%, including uncertainty of emission factor and metering.

Steam flow meters of Mill B have been audited and the certifying company defines its metering accuracy in a 4% for each of them [7]. Partial gas meters operate with a 2% of accuracy, according to the supplier catalogue [6].

Results concerning uncertainties of power allocation method can reach up to 7% of uncertainty, regarding the same assumptions of paragraphs 7.2.9.

Concluding, again, this work recommends qualifying uncertainties according to the same reasons exposed in 7.2.9. Considering the qualifications of Table 5.1, the results of the allocation method could receive a “good” qualification according to its uncertainty.

7.3.9 Concluding points of emissions allocation method in Mill B

As in the case of Mill A, the allocation method proposed in Chapter 5 has been put into practice with some limitations and arrangements. Figure 7.23, Figure 7.12 and Figure 7.14, denoted these limitations, particularly in steam and electricity allocation. The mill should install additional power meters and steam flow meters, in order to differentiate energy and emissions addressed to the two paper machine production lines.

Although emissions allocation results are not as accurate as expected, summary tables of each section presented in previous paragraphs provide some useful information. Steam generation is the main cause of Mill B emissions, followed by electricity consumption. Thus, the uncoated paper machine drying section, the approach flow circuit, the vacuum systems and the short fibre refiners should be followed and studied continuously and deeply.

Table 7.32 summarises the specific energy consumption of the main sections of Mill B process. It has to be underlined that in this case, the specific values (tones of product) are referring to both lines of productions, UL and CL.

Table 7.32 Mill B energy intensities by main sections (per tones of total shippable production)

ENERGY USE ALLOCATION MAIN SECTION	ELECTRICITY kWh/t	STEAM kWh/t	DIRECT HEAT kWh/t	TOTAL kWh/t	SHARE %
Stock preparation	250	-	-	250	10
Approach flow circuit	34	-	-	34	1
Paper machine	178	1516	42	1736	71
Coating Machine	112	48	126	285	12
Finishing Section	53	47	-	100	4
General Services	39	-	-	39	2
Total	666	1611	168	2.444	
Share %	27	66	7		100

Paper machine sections of the two lines involve the larger purchase of both power and steam-based utilities. Steam demand is responsible for the 67% of the total energy consumed in Mill B. Therefore, drying section of the two paper machine lines should be audited specifically in order to evaluate potential savings and investment parameters.
To conclude, Table 7.33 compiles the specific emission focus according to main sections of the mill.

Table 7.33 Mill B Emission intensities by main sections

EMISSION ALLOCATION MAIN SECTION	ELECTRICITY $kgCO_2/t$	STEAM $kgCO_2/t$	DIRECT HEAT $kgCO_2/t$	TOTAL $kgCO_2/t$	SHARE %
Stock preparation	68	-	-	68	11
Approach flow circuit	9	-	-	9	1
Paper machine	49	408	8	465	72
Coating Machine	30	13	25	69	11
Finishing Section	14	13	-	27	4
General Services	11	-	-	11	2
Total	182	434	34	649	
Share %	28	67	5		100

Again, Table 7.33 shows how steam-based operations are the largest responsible for emissions, followed by power-based devices.

Considering above exposed results, regulation of drying section and the heat recovery (close-hood and heat recovery units) of the UL production line should be the first reduction targets concerning thermal energy. In the case of power reduction targets, refiners and the vacuum systems of UL paper machine should be, according to this work, the first priorities of the mill.

7.4 BENCHMARKING ON EMISSION AND ENERGY RATIOS: MILL A AND MILL B

7.4.1 Introduction

Table 7.34 summarises the emission factor, energy and emission intensities generated by the two paper manufacturing processes. Specific data is defined per tone of total shippable paper. The information of this table excludes the CHP-plant analysis, although it references to the plant by means of its emission factors.

Table 7.34 concludes that Mill A has lower emission ratios than Mill B, despite its power emission factor is higher.

Table 7.34 Mill A and Mill B. Emission factors, energy consumption and emissions (2006)

MAIN ENERGY USE	MILL A			MILL B		
	EMISSION FACTOR tCO_2/MWh	ENERGY CONSUMED kWh/t	EMISSIONS GENERATED $kgCO_2/t$	EMISSION FACTOR tCO_2/MWh	ENERGY CONSUMED kWh/t	EMISSIONS GENERATED $kgCO_2/t$
Electricity	0,396	482	191	0,273	666	182
Steam	0,220	1.204	264	0,269	1.611	434
Direct Heat	0,202	171	35	0,202	168	34
Total	-	1.857	490	-	2.444	649

Regarding steam generation, Mill A uses gas boilers with an average of 91% of efficiency. The steam factor is in this case lower than Mill B, although the point of the comparison has to be done globally. This fact highlights that CHP plant ensures environmental attractive results towards a SHP system.

Moreover, Figure 7.26 compares energy intensities of the two mills according to energy end-use.

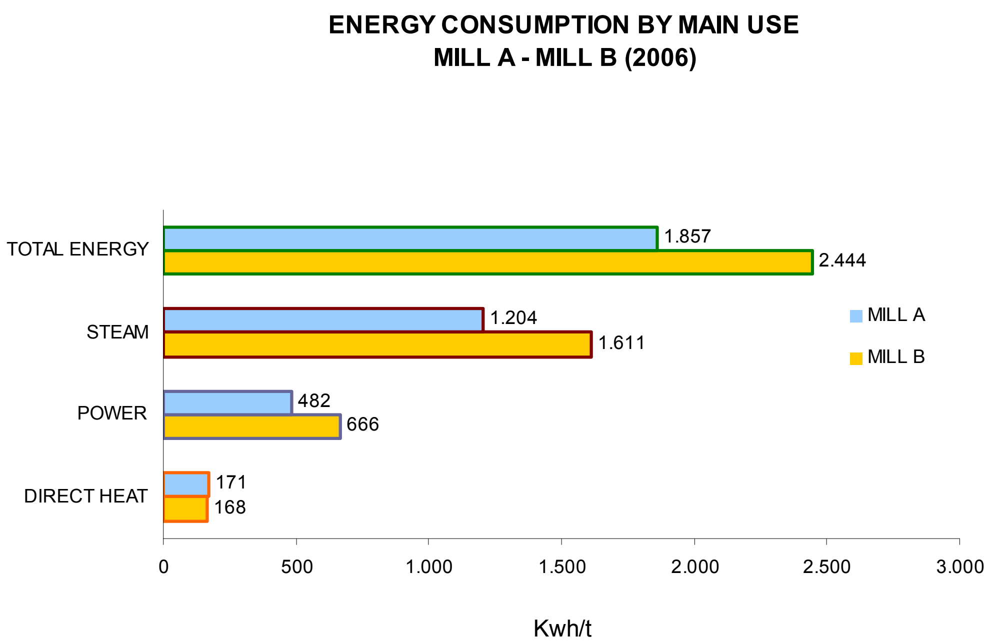


Figure 7.26 Mill A and Mill B specific energy use according to its final energy demand. Mill A denotes its efficiency, in both steam and power systems.

Mill A has higher efficient-based unit operations, concerning power and steam use. Direct heat is mostly used by IR dryers, and in both mills they have a similar demand.

Despite Mill B has a CHP plant and power emission factor is lower than the Spanish grid system, the energy inefficiencies of Mill B derive to a high assignment of emissions.

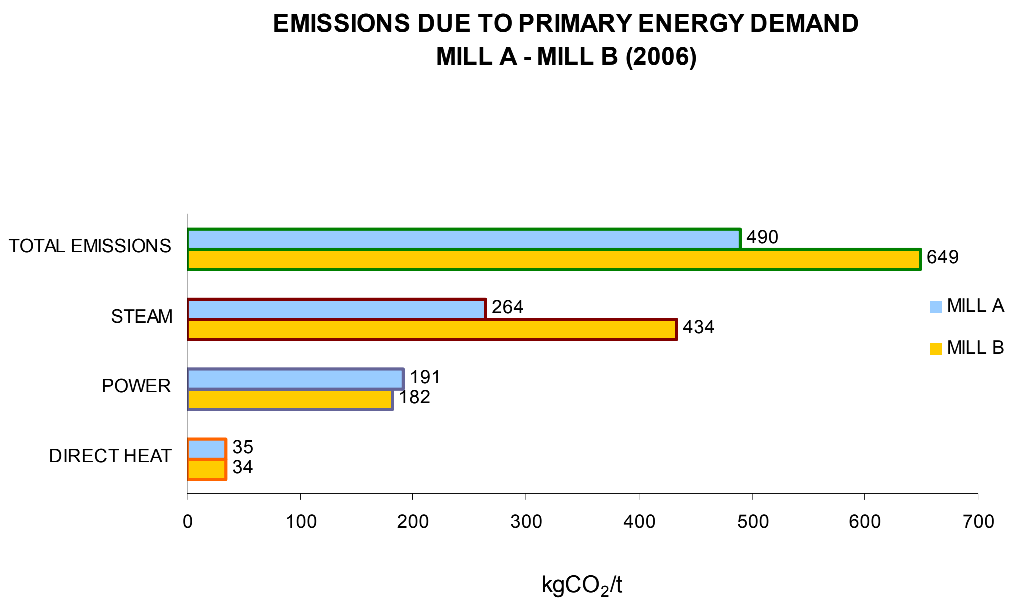


Figure 7.27 Mill A and Mill B specific emission ratios according to energy-use

Following paragraphs present energy efficiency and emission benchmarking ratios assigned to different sections and unit operations, according to the allocation method results of the two mills.

7.4.2 Energy and emission benchmarking of Mill A and Mill B coating lines

First of all, to evaluate and compare consistent ratios, this work considers that Mill A needs to be benchmarked to Mill B coating line process, otherwise the uncoated line of Mill B would interfere in each of the distribution parameters.

Table 7.35 compares the specific electricity consumption of the two mills by main section. Results outstand that Mill B overpasses energy demand in stock preparation and general services section, meanwhile Mill A paper machine section is larger electricity demander than Mill B (CL).

Table 7.35 Mill A and Mill B (CL). Power consumption by main sections (per tone of coated paper production line)

ENERGY USE BY MAIN SECTION	MILL A ELECTRICITY kWh/t	MILL B (CL) ELECTRICITY kWh/t
Stock preparation	116	250
Approach flow circuit	50	19
Paper machine	192	134
Coating Machine	44	147
Finishing Section	56	38
General Services	24	39
Total	482	627

Moreover, Table 7.36 denotes that pulping and refining unit operations of Mill B bring in higher energy intensity. Mill B produces a low basis weight paper and uses a 20% of long fibre pulp. Thus, a higher Schopper-Riegler grade is needed. In addition, refiners of Mill B are not as energy efficient as in Mill A refining section.

Table 7.36 Mill A and Mill B (CL). Power consumption of Stock preparation unit operations

SECTION	UNIT OPERATION	FACILITIES	MILL A Electricity kWh/t	MILL B (CL) Electricity kWh/t
STOCK PREPARATION	Pulping	Pulper (LF)	3	16
		Pulpers (SF)	15	26
		Pulpers (broke)	6	30
	Deflaking	Deflaker (broke)	6	5
	Refining	Refiners (LF)	4	135
		Refiners (SF)	50	11
	Other auxiliaries	Pumps, agitators, other	33	28
APPROACH FLOW CIRCUIT	Mixing, dilluting, cleaning, screening	Pumps, agitators, other	50	19
		Total	166	270

Furthermore, Table 7.37 compiles specific electricity consumption of both paper machine sections. Vacuum system and drying section drives of the paper machine have a relevant consumption in Mill A. In this case, paper produced in Mill A has a higher basis weight, which could lead to a higher vacuum demand to favour water drainage. Nevertheless, the mill previews specific energy audits to determine the state of the vacuum pumps.

Table 7.37 Mill A and Mill B (CL). Power consumption of Paper machine section

SECTION	UNIT OPERATION	FACILITIES	MILL A kWh/t	MILL B (CL) kWh/t
PAPER MACHINE	Wet Section	Wet section drives	52	51
		Vacuum Pumps	70	57
	Press Section	Press section drives	12	13
	Drying Section I	Drying section drives	14	6
	Precoating, Sizing	Precoating Kitchen	9	13
		Precoating drives + speed sizer	6	
	Drying Section II	Drying drives and IR dryers	18	11
	Finishing Base Paper	Calendering and reeling drives	12	3
		Total	192	153

According to Table 7.38, Mill B has a specific consumption, which is roughly three-times higher than Mill A. Indeed, Mill B has an extra drying operation due to its IRs electrical units.

Table 7.38 Mill A and Mill B (CL). Power consumption of Paper machine section

SECTION	UNIT OPERATION	FACILITIES	MILL A kWh/t	MILL B (CL) kWh/t
OFF-LINE COATING MACHINE	Coating	Pumps, agitators and auxiliaries	17	5
		Coating Machine Drives (all)	23	66
		IR dryers	4	60
		Total	44	130

Moreover, Table 7.39 shows how common finishing unit operations of both mills remain fairly closer in terms of energy intensities. However, embossing and calendering unit operations of Mill A denote an additional consumption.

Table 7.39 Mill A and Mill B. Power consumption of finishing section

SECTION	UNIT OPERATION	FACILITIES	MILL A kWh/t	MILL B (CL) kWh/t
FINISHING SECTION	Calendering	Calender drives and auxiliaries	18	17
	Embossing	Embossing calender drives and auxiliaries	1	
	Winding	Winding machine drives	11	20
	Sheeting	Sheeting drives and auxiliaries	16	11
	Packaging and Wraping	Packaging and Wraping machine drives	10	7
		Total	56	55

Finally, Table 7.40 denotes that compressor system of Mill B has a relevant power intensity ratio. For this reason, Mill B plans to review its compressor system, after detecting it is working under designed conditions.

Table 7.40 Mill A and Mill B. Power consumption of General Services

SECTION	UNIT OPERATION	DEVICES	MILL A kWh/t	MILL B (CL) kWh/t
GENERAL SERVICES	Air Compressors	Compressors and air treatment	5	20
	Waste Water Treatment	Pumps, agitators and auxiliaries	8	8
	Steam Generation	Pumps and auxiliaries	10	
	Lighting System	lights (all mill)		11
		Total	24	39

Mill A equates the same specific power consumption of Mill B in both water treatment systems.

7.4.3 Steam and heat-based benchmarking

In a benchmarking of steam-based operations (Table 7.41), it is detected that steam intensities of Mill B roughly overpass a 20% of Mill A intensities.

In both cases, the main demand of this steam takes place in the paper machine section.

Both lines should inspect accurately its drying section. Moreover, both mills have similar direct heat consumptions.

Table 7.41 Mill A and Mill B. Steam and direct heat consumption, by main section

ENERGY USE BY MAIN SECTION	Mill A		MILL B (CL)	
	STEAM	DIRECT HEAT	STEAM	DIRECT HEAT
	kWh/t	kWh/t	kWh/t	kWh/t
Stock preparation				
Approach flow circuit				
Paper machine	806	58	1.399	49
Coating Machine	174	99	56	147
Finishing Section	224	14	47	
General Services				
Total	1.204	171	1.502	196

7.4.4 Concluding points on benchmarking results

A benchmarking based on energy efficiency ratios might not lead to the same results with an emission ratio basis, obviously, because mills can use different facilities to product or purchase basic energy utilities.

Mill A power emissions (Scope 2) depend on the Spanish national grid. Therefore, Mill A emissions can fluctuate according to climate conditions and to government energy policies; if hydro power facilities are under operating, power emission factor increases, whereas if policy makers support renewable energies (in decrement of thermal coal plants) the CO_2 power factor diminishes. Actually, the CHP plant of Mill B nearly ensures a constant emission factor.

7.5 GENERAL CONCLUSIONS OF CHAPTER 7

Emissions allocation methodology is projected to assist paper mills with establishing the outstanding points on emission reductions as well as defining efficiency and emission ratios for a benchmarking basis.

When approaching the allocation method, it has been examined the energy profile of the mill as much accurately as possible. The application boundaries of the allocation have been delimited by the control systems and the energy metering points.

In the case of assigning emissions to power-use, the distributed control system of Mill A has provided the electric data compilation. Moreover, the physical structure of its electric system has been helpful to match unit operations with its corresponding MCC (and power measures). This fact has simplified the distribution of consumptions into the main sections of the process. On the contrary, power system profile of Mill B has not been easy to implement. Devices from different production lines are switched to the same MCC or electric unit.

According to these metering boundaries, the power allocation method (designed in Chapter 5) has not been completely respected. Despite this fact, the results obtained are accurate enough to establish an emissions benchmarking through out the process, at least at main section or unit operation levels.

Furthermore, steam is the main energy utility demanded by both mills. However, this utility is the less controlled variable, in comparison with gas and power. Although steam boilers or CHP plants are submitted to regular tests, steam production is merely controlled by fuel input computation. CHP-1 plant has a correct control of steam production, until it is derived to unit operations and specific devices. Obviously, both mills control steam flow rigorously in the drying sections of the paper machines. However, steam demand remains in a closed loop control (Scada system). The control loop directs its aim to quality parameters, but does not focus on energy regulation.

A benchmarking of emissions can become the first milestone to achieve an energy and emissions management system. Although an estimative energy ratio supplies a reference value for a benchmarking strategy, it is not useful in internal energy control terms, as it is not expressing real consumption. For that purpose, the only solution is to have energy meters switched to a control system in order to have available on-line which devices or mill units are not working properly.

If a mill targets an emission reduction performance, it is important to enforce its energy efficiency, but also to evaluate its primary energy sources. Next chapter compiles some general key issues while considering reducing emissions from different origins.

7.6 REFERENCES

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8 THE OPTIMISED MILL – ZERO EMISSIONS

8.1 INTRODUCTION

The aim of this chapter is to highlight some possible reduction areas in order to drive a mill towards zero CO_2 emissions. This is the result of the analysis and work achieved in the previous chapters. Once the amount of GHG emissions and their allocation in papermaking process has been assigned, it is necessary to set targets and define a GHG reduction program.

For that purpose, this chapter provides a description of different strategies to reduce emissions, such as reducing emissions in origin, reducing emissions by improving the energy efficiency of the process or promoting a CO_2 label.

It also overviews advanced possibilities that could match with the emission reduction targets of a standard paper mill. Some of the possibilities are not easy to introduce because they need accurate feasibility studies before investment. However, other possibilities either require little investment or little modifications of standard operations. Moreover, awareness of employees and good working practices can lead to potential saving-emissions actions.

As expressed in previous chapter, the most important sources of GHG emissions in a papermaking process are related to energy use. Because of that, this chapter focuses on energy-related aspects.

To exemplify the variety of alternatives for emission-reducing actions, this chapter uses Mill A and Mill B, as sample cases to expose some reduction measures. Mill A and Mill B represent the majority of non-integrated paper plants of Europe, regarding emission focus. One of them uses a conventional boiler and is switched to national grid meanwhile the other has a cogeneration system with natural gas.

Some of the measures exposed could seem not economically viable. For that reason, a simplified economic balance is exposed to denote the general viability of the actions proposed.

Finally, it proposes a GHG eco-label to incentive energy and emission savings in a green environmental market.

8.2 OUTSTANDING POINTS FOR EMISSION REDUCTIONS

Figure 8.1 presents some possible emission-reducing focus. All of them can be summarised in three key-issues:

- To reduce in origin.
  To introduce green heat and power by means of replacing fossil fuels in energy production fields by fuels with less GHG potential or bio fuels. To promote other renewable energy installations.
- To reduce in process.
  To set an emissions management system, this is to develop and implant energy efficiency measures in energy generation and in papermaking process.
- To promote a GHG eco-label in order to enhance energy efficiency and GHG reduction policies by marketing-related targets.

Following paragraphs describe briefly the possibilities presented in Figure 8.1

Some of the mentioned issues are developed within this chapter in terms of general targets and measures to be applied in an ideal scenario (Table 8.1).

8.3 REDUCTION OF EMISSIONS ACCORDING TO THEIR ORIGIN

As mentioned along this work, the most important focus of emissions in a paper mill is the energy consumption. Therefore, the first point to turn to should be the origin of energy sources. During last decades, environmental and technological market has developed and adapted new bio-fuels to substitute fossil fuels. In addition, the inside-electricity production does not necessarily have to be supported by fossil fuel combustion (usually cogeneration systems). Even though, a biomass cogeneration system can be posed. Moreover, some other power generating systems could be considered, such as wind power, hydro power or solar photovoltaic. Although it has to be noted that the mentioned renewable energies have neither a continuous regime nor are prepared for high power capacities and need to be thought as support systems.

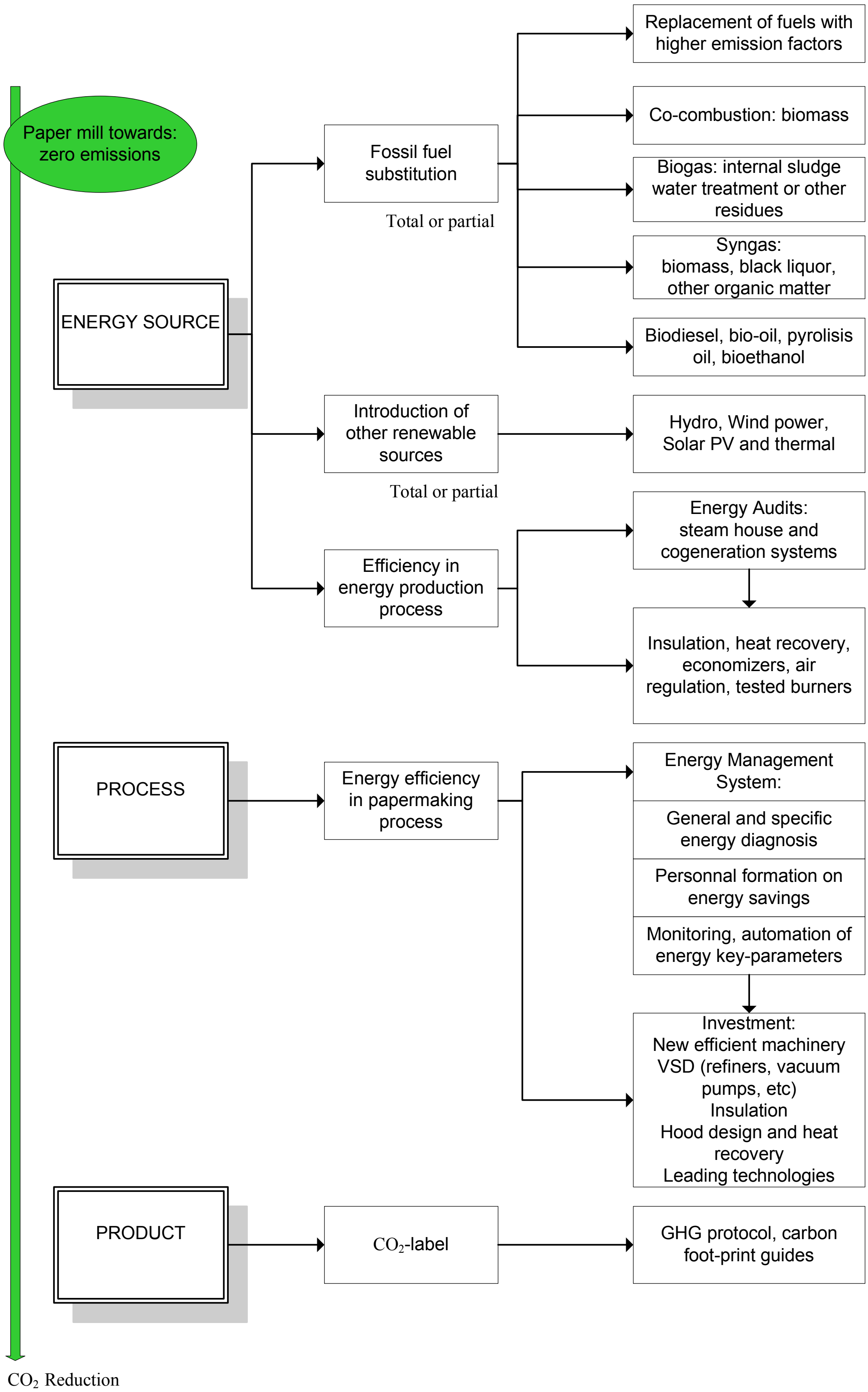

Figure 8.1 Some key points to drive a paper mill towards Zero CO2 emissions scenario. The reduction is based on energy source, process efficiency and environmental policy targets.

Table 8.1 Potential savings concerning measures and targets of zero-emission scenario

MEASURES AND TARGETS TOWARDS ZERO CO_2 EMISSION SCENARIO	
ENERGY GENERATION ACTIVITIES	**SAVING POTENTIAL**
Origin	
Replacement of fossil fuel by fuel with fewer impact	★ ★
Replace of fossil fuel by biomass source	★ ★ ★
Introduction of renewable energy systems	★ ★ ★
Efficiency measures	
General: CHP plant instead of SHP	★ ★ ★
Boilers/engines: Combustion - Air regulation	★ ★
Boilers: Raise Temp. of air input. Economizers	★ ★
Steam System: Recovery of condensates	★ ★
Steam System: Maintaining Insulation	★
Steam System: Repairing steam leaks	★
Steam System: Steam holding tanks	★ ★
Steam System: Correct sizing and routing of pipes	★
Steam System: Boiler sequence of operation	★ ★
PAPERMAKING ACTIVITIES	
Management	
Energy and emissions management system	★ ★ ★
Efficiency measures	
General: Correct dimension of pumps capacity	★
General: Revision of continuous operation-mode of pumps	★ ★
General: No-load energy consumption in refiners	★ ★
Press section: Dewatering improvements	★ ★
Steam section: spoiler bars	★
Steam section: monitoring and control of syphons water removal	★
Steam section: heat recovery/hood	★ ★
General services: vacuum pumps operation	★ ★
General services: compressed-air system operation	★ ★
General services: Lighting system efficiency	★
General services: Power factor (reactive energy)	★
COMMERCIAL MEASURES	
Eco-labeling papermaking process	★

8.3.1 Replacement of fossil fuels

Figure 8.2 pictures emission factors published by IPCC (Table 3.4). According to the graphic results, paper mills –as well as the rest of industries– should replace coal or fuel oil by other fuels less aggressive to climate change, such as natural gas or biomass.

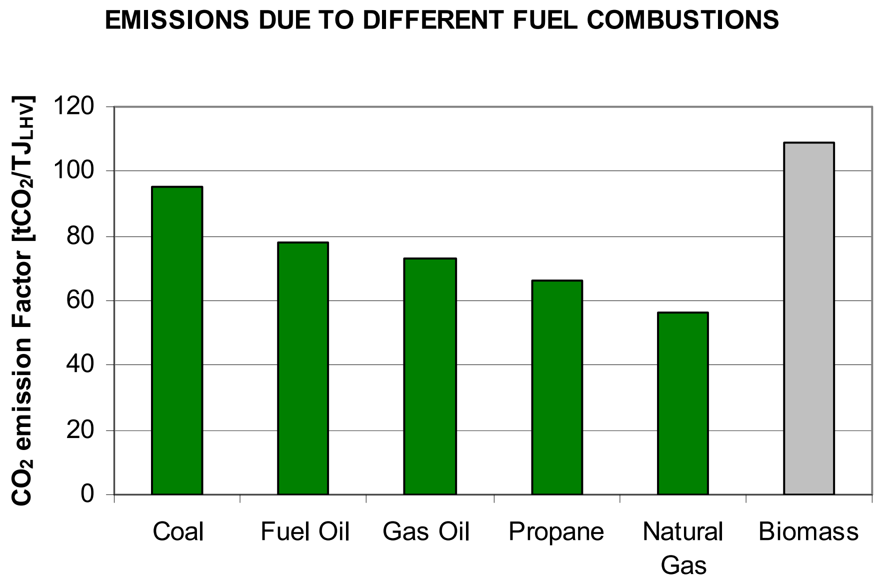

Figure 8.2 Comparing emissions according to different type of fuel combustion. Source: IPCC [1] Biomass is considered neutral, meanwhile coal followed by fuel oil are the fuels with a major green house potential.

Paper mills already tend to supplant fuels, gas oil or coal for natural gas. However, it could be thought to include environmentally friendly fuels, such as bio diesel, pyrolysis oil, black liquor (in the case of integrated mills), biogas or other fuels with fewer impact on the green house effect.

Figure 8.3 presents the multiple options to produce energy or bio fuels by thermo chemical, biochemical conversion or direct extraction of biomass. This figure outstands that industries have a huge variety of options to obtain electricity, heat and steam by using biomass.

The wide range of possibilities presented in Figure 8.3, conceive biomass as an alternative source to generate neutral emissions.

In some cases, the obtaining of bio fuels by biomass sources presented in Figure 8.3 comprises some disadvantages. For instance, the biomass product enters in competition with food product. Another example of controversy, the life cycle of the bio fuel obtained emits more emissions than the equivalent fossil fuel.

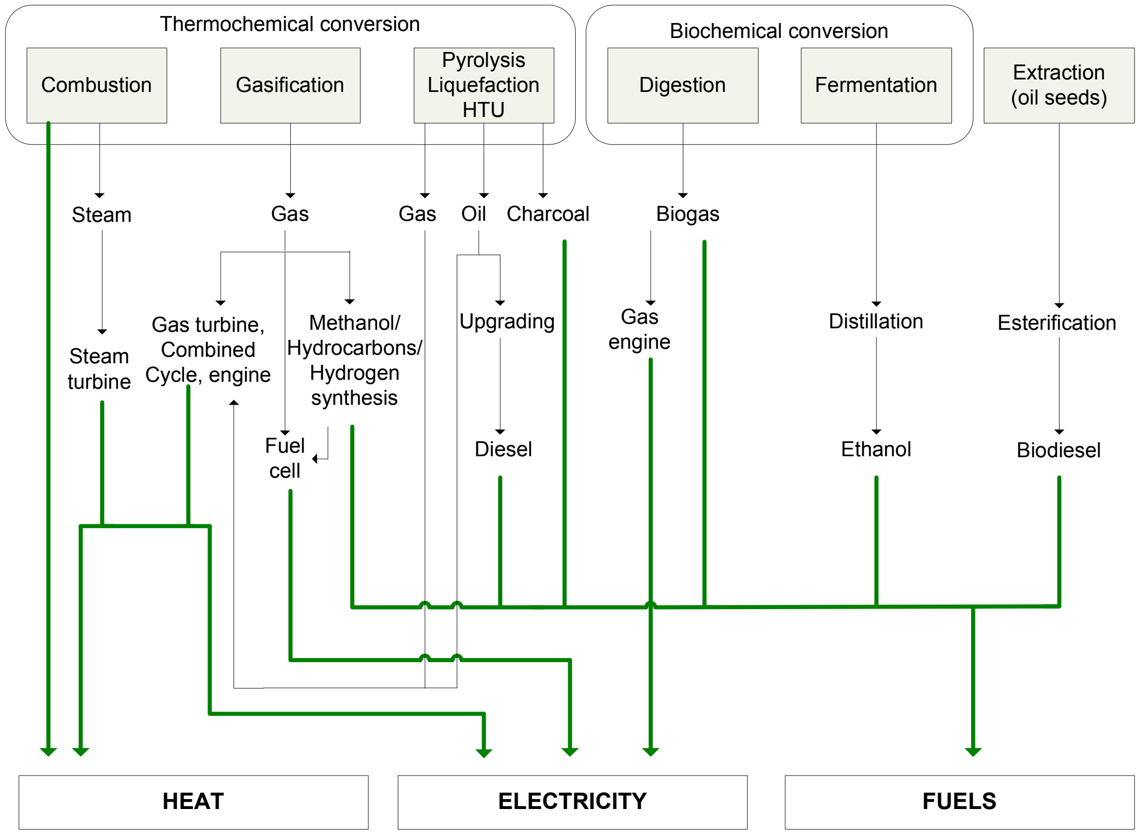

Figure 8.3 Biomass and its energy conversion routes. HTU abbreviates hydrothermal upgrading process. Based on Brown publication [2]

The definition of biomass entails different possibilities, such as forestry residues, energy crops or industrial residues with a biomass origin, such as the black liquor from the pulp sector. Figure 8.4 pictures the different types of biomass according to its origin.

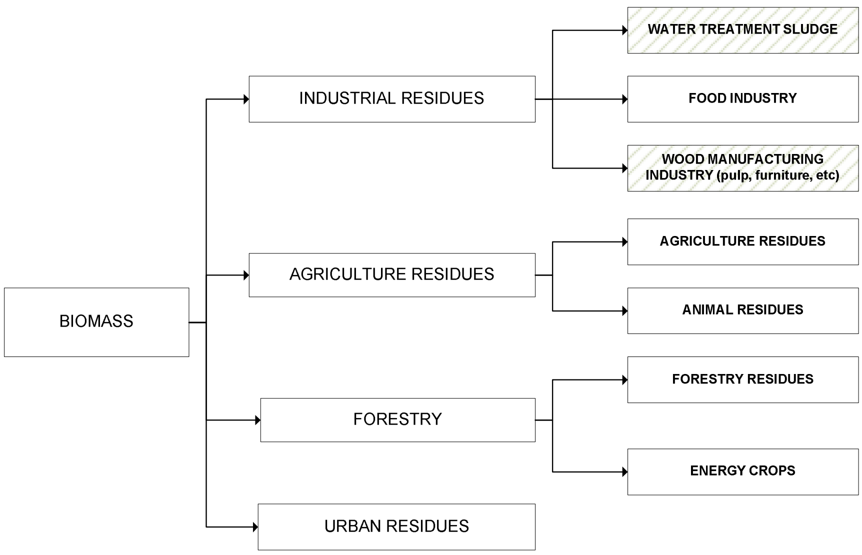

Figure 8.4 Types and origin of biomass. In grey colour, the biomass directly related to paper mills.

To solve some of the mentioned problems, biomass research on biochemical conversion has lately focused on second generation bio fuels. Such bio fuels have a high content of lignocellulosic material which unable sugars to be easily fermented. Despite this disadvantage, the fermentation is possible after thermal and enzymatic hydrolysis. Lignin is undertaken as a by-product because it can be combusted to produce thermal energy.
Furthermore, some of the technological possibilities expressed in Figure 8.3 are still on development, and its scale-up is not yet established [3].

Pulp and paper industry is a leader sector in CHP plants. Most of the Spanish CHP plants use natural gas or fuel oil [4]. Government rates for kilowatt-hour produced in CHP modality favour financial plant profits. Currently, Spanish government promotes in major grade [5] cogeneration systems that use biomass or biogas rather than cogenerations operating with conventional fuels.

8.3.2 Introduction of some renewable energies

As mentioned in the introduction of this chapter, renewable energies should be understood as support energy. Hydro, wind power or solar can be thought as an auxiliary system of power demand. However, the consolidation of these energies depends on the location and features of the paper mill environment.

8.3.2.1 Small hydro power plants

Paper mills (as the same word indicates) have been historically located next to rivers. In some occasions, mills had installed some small turbines for own-consumption, but as the production of mill grown up, the electricity supplied by these turbines became completely irrelevant. Most of these turbines fell into disuse. This is the case of Mill A, which used to have a hydro turbine; in a water flow in 1960, the turbine and the entire mill were flooded. The mill was restored some meters far from the initial location; meanwhile the turbine was not recovered.

For environmental purposes, it could be planned to reacquire such technologies. Feasibility studies might bring an objective approach of the investments and payback period.

Moreover, it is difficult to project new hydro-plants, especially in Spain and with climate change favouring climate dryness. Not all the rivers are prepared for hydro plants. The installation of such plant is characterised by the following parameters:

- River flow and season cycle
- Water Drop

One of the main disadvantages of small hydro power plants is the high maintenance costs and the low power capacity.

8.3.2.2 Solar Energy

Both, photovoltaic and thermal solar plants are featured by its low specific energy capacity. Thermal solar panels could pre-heat water for some mill services. However, this alternative system does not have much sense because paper plants have a high potential of hot water recovery in the form of condensates of the steam system. Mills should firstly invest in heat efficiency measures and heat recovery systems.

Solar photovoltaic energy

Sun is one of the most democratic energy sources. Photovoltaic solar power is one of the hottest areas in energy investment right now in Spain. Photovoltaic panels provide electricity according to solar radiation. Figure 8.5 presents the medium annual average of solar radiation of Spain in horizontal surface.

MEDIUM AVERAGE SOLAR RADIATION	
Zone Category	kWh/m^2
Zone I	< 3,8
Zone II	3,8-4,2
Zone III	4,2-4,6
Zone IV	4,6-5,0
Zone V	> 5,0

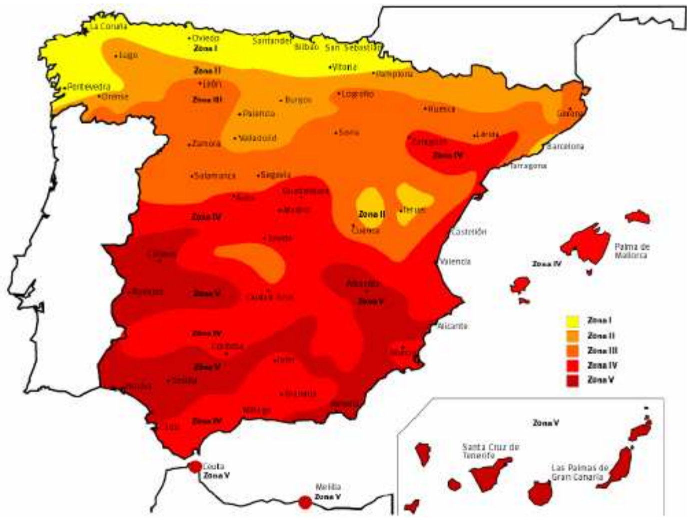

Figure 8.5 Medium annual average solar radiation in Spain. Based on map of Instituto nacional de meteorología [6]

Solar panels are becoming more competitive in terms of price and their efficiency is rapidly improving.

Spanish government incentives reward on interesting selling rate for kilowatt-hour produced. The free available area of a paper mill can be used for a large-scale solar power installation.

However, such systems have a considerable initial investment; consequently, previous and accurate feasibility studies are recommended.

8.3.2.3 Wind power

It can be suggested to install an aero generator, although it is still difficult to sort out the voltage stability during the loading periods. Obviously, this type of investment also depends on mills location and the wind intensity profile of the area as well as public administration permissions.

8.3.3 Improving efficiency of energy production facilities

A system improvement is commonly achieved by investment in efficient technologies or modifications of historic habitudes in order to maximise the efficiency of the process. However, to distinguish which the best and the first actions to consolidate are, it is necessary to examine deeply the process and to evaluate the profit benefits after the investment. Energy audits or energy assessment projects embed these tasks.

Companies can face on three types of energy diagnosis: preliminary, general and specific audits or diagnosis. The first ones offer a quick review on the energy situation of the paper mill, the second ones contribute with a general (but more detailed) analysis of the plant, meanwhile the specific energy assessment projects focus on some devices of the mill and evaluate specific measures with a certain grade of accuracy.

Referring to energy production facilities, periodical checking on deviation of the efficiency from the initial project design should help to detect major problems of steam boilers and cogeneration systems. In addition, well-planed system maintenance assists the mill on energy savings.

As steam generators o cogeneration systems are not specific units of a pulp and paper mills, this chapter does not extend largely on them. Despite of that, following lines outstand some key strategies to manage some of their potential savings [7]:

- To control the proper amount of air (oxygen) for combustion in either boilers or prime-mover engines. The regulation of the air input flow becomes a difficult equilibrium to achieve. A low oxygen level can drive towards CO emissions formation and soot releases. On the contrary, the excess of air leads to a reduction of efficiency. A meaningful solution might lead to a regulation of inlet air flow by the analysis of the combusted gases.

- To check the flue gas temperature of the boilers and install economisers to recover the maximum amount of heat. For example, a standard boiler with a combustion efficiency of 89,5% can reach a 95,5% of efficiency by installing an economiser system to recover heat content of flue gases and preheat the inlet feed water of the boiler. In this particular sample, such efficiency is assumed with a 93% of condensate return.

- To recover the condensates. The quantity and the quality of the condensate returned to the boiler reduce energy and consumption of chemicals. The returning enthalpy of the condensates is going to lower the extra amount of energy for steam production. For example, 15% of condensates losses in a steam system fed by a gas steam boiler unit (steam at 6 t/h 6 bar) represents and extra amount of natural gas of 700 kW and an additional emission flow of 140 kgCO_2/h.

- To maintain the insulation of pipes, steam lines, deaerators, vessels, valves, boilers and other steam system units. Deteriorated or wet insulation materials produce great misuse of energy. Figure 8.6 details a termographic photo of a steam pipe with some insulation failures.

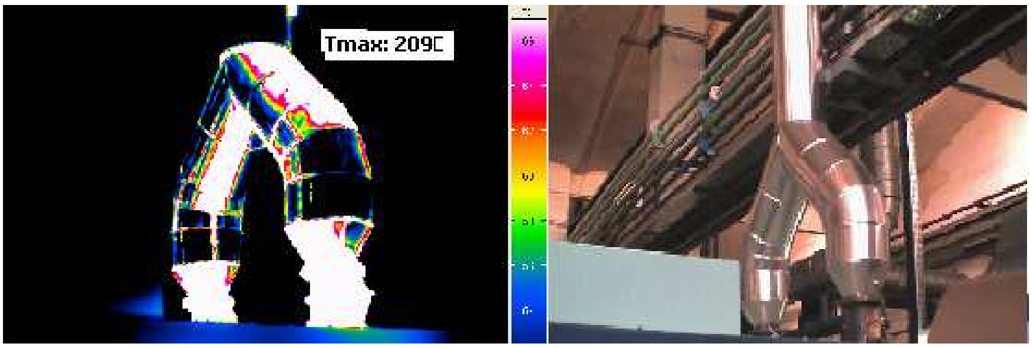

Figure 8.6 Failures of heat insulation in a steam pipe. On the left side, thermographic photograph of a steam pipe. Right side, the same photo taken in the visible.

- To repair steam leaks. Each hole or leak at the steam line represents a pressure drop, looses of treated water (and chemicals) and a hazardous risk for operators [8].

- To install steam holding tanks. In case of paper machine downtimes, steam boilers need to stop and restart, with a consequent extra amount of fuel consumed in the restarting process.

- To correct sizing and routing of pipes to minimise losses. This fact can avoid load pressure drops and heat losses by means of reducing steam track.
- To analyse boiler sequences of operation. Frequently, mills (as Mill A) are prepared with different steam boilers in order to supply pick demands or to supplant a boiler in downtimes. Experts recommend analysing the best sequence of boilers. Setting an automatic loop control is another relevant measure to consider.

8.4 REDUCING EMISSIONS IN PAPERMAKING PROCESS

A reduction of emissions in the papermaking process calls for a proper use of energy at all levels of the mill.

BREF on Energy Efficiency [9] recommends an energy efficiency management system. The mentioned system promotes detailed measuring and control of some energy parameters. Additionally, it sets the targets to implement reducing measures. Some reducing measures are also common for a variety of mills. According to energy BREF, an energy management system should firstly be approached before investing in specific measures associated with unit operations. Figure 8.7 diagrams some of the stages included in an energy and emissions management system (EEMS).

8.4.1 Energy Efficiency and emissions management system

Energy efficiency management system (EMS) is defined as a systematic control of some parameters that can have a significant impact in the process of purchase, transformation or consumption of energy [10]. An EMS should form part of the management system of the mill. The experience achieved along compilation of operational data for both paper mills (Mill A and Mill B, detailed in Chapter 7 and its annex), states that an emissions and energy management system should be the starting point of any specific energy-saving investment.

Furthermore, two types of investments are necessary to consolidate an EEMS: capital and human investments.

Capital investments have a relative economic low-cost. Capital investment focuses on a proper energy register system that consists of electricity analysers, power meters, steam, gas meters, etc. For example, plants should install, calibrate or repair power meters and water and steam flow meters in order to have a major control of its major consumption centres.

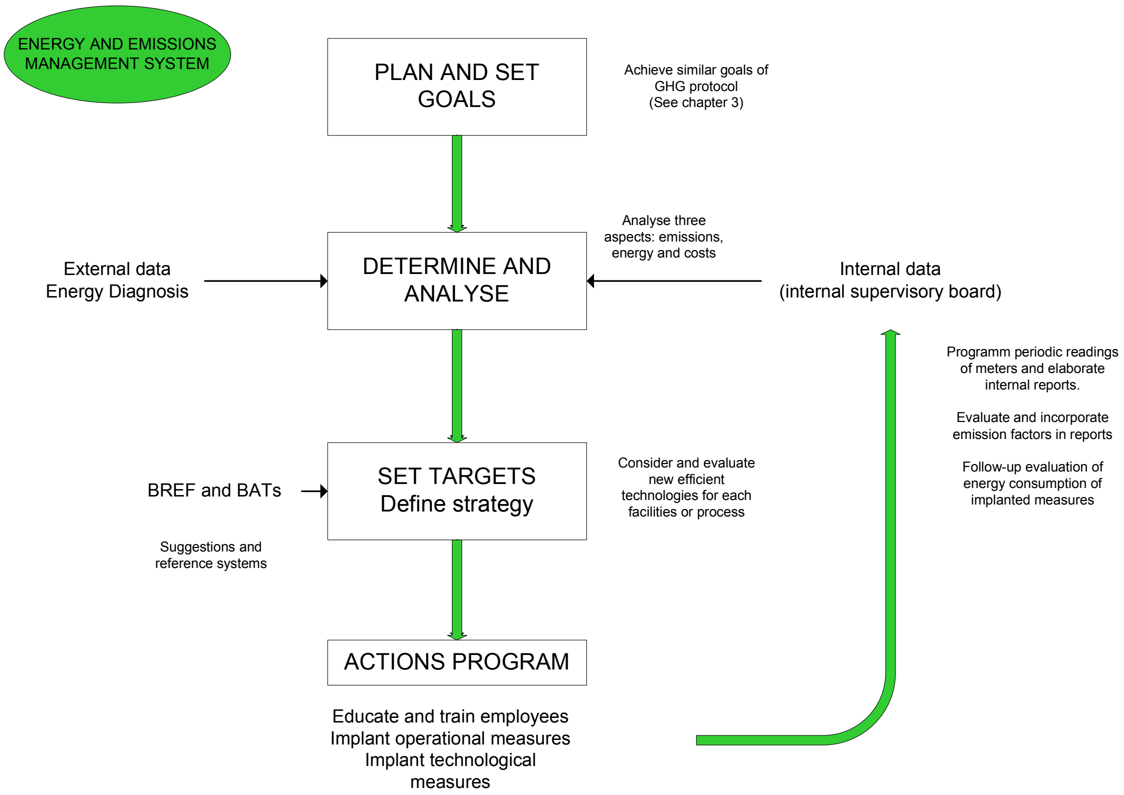

Figure 8.7 Diagram of Energy and Emissions Management System (EEMS)

Human investments imply education and training programmes on energy savings. The incorporation of energy efficiency culture in the mill daily operation framework entails:

- Awareness of what energy saving means at all levels (management, technical and productive)
- Training possibilities on energy management or particular areas concerning energy efficiency

Finally, EEMS should structure a maintenance program and take care of determining of emissions, energy-use, and metering equipment.

8.4.2 General energy saving key-strategies in papermaking process

In chapter 7, it has been structured an emissions allocation system using energy and emission data of Mill A and Mill B. Simultaneously, experiences of technicians regarding energy efficiency measures and alternative potential savings were collected.

This work encountered that the energy red points of both mills can be faced as general problems related to most of the paper mills.

For this reason, following lines summarise some suggestions dealing with energy efficiency measures. Some of the energy potential savings have been completed using bibliography, technical journeys and courses.

- Over-sizing of pumps, motors and fans should be minimised and energy efficient pumps and fans introduced. An over-sizing range of 10% is considered adequate at a design stage (for pumps and fans) and a 2% for motors.
- The operational of individual pumps should be checked and evaluated. According to Blum [11], pumping saving potentials can derive towards process modification (shut down of the pump), variable speed drives (VSD) by inverters, use of smaller impellers or pumps, motor efficiency and transmission. Blum estimates 20-70% of savings for individual pumps.
- Energy efficient refiners should have the minimum no-load energy consumption. This fact should be a decision criterion when investing in new refiners. For that purpose, workload can be increased by operating in batch mode. Blum estimates power savings for singulars refiners up to 30% [11]. In addition, traditional refiners can be replaced with double cylinders or double cone refiners.
- Pressing process is more important than what is usually considered. In order to save steam consumption and reduce emissions, paper web should not be over dried by evaporation; efficient pressing should dry the web at maximum level. Extended nip press or shoe press can achieve an off-press dryness up to 50% [12].
- Siphons installed in the drying cylinders are in charge of removing condensates. Modern high speed paper machines use stationary siphons and their working conditions are regulated by differential pressure [13]. The lower the differential pressure achieved, the lower the blow through steam and the higher the overall thermal efficiencies.
- Breaking the condensate rim using spoiler bars [14] can significantly improve thermal efficiencies in the drying cylinders.
- A better control on the moisture of the web in the drying system avoids over drying, saves steam and increases the production.

- A correct-designed hood system reduces the thermal demand at the drying section [15]. An automatic hood control system can be installed at the suction of the exhaust fan to improve heat recoveries. In addition, totally closed hoods can be prepared with an operation dew point as high as 65 ºC [16]. Consequently, exhaust air and supply air volume flows experience an important reduction, with subsequent energy savings on the fans [17].

- The number of vacuum pumps should be limited and its dimensioned nominal power should be analysed and corrected. In the case of liquid ring pumps, it can be studied the reduction of transmission ratio of motor to pump. VFD can also optimise the vacuum system. VFDs are recommended in speed variation is required from 50 to 100% range. Centrifugal exhausters have a higher energy efficient (30% more) than water ring vacuum pumps [18]. The mill should consider the separation of low vacuum and high vacuum levels. Blum has experienced and quantified power savings for the vacuum system improvement from 10% to 15% [11].

- The lighting system should be checked. The replacement of mercury vapour lamps for methaloide lamps can lead to a 40% of power reduction, maintaining the same luminance capacity.

- To review leaks from compressed air system. As a general service, compressed air system is responsible for a significant amount of power energy consumption. Identification, repair, maintenance and control of compressed air line might become a preventive energy measure. Table 8.2 estimates the energy losses in a particular compressed air line.

Table 8.2 Energy analysis of leaks in air compressed system. Source: Leeksystem [19]

LEAK TYPE	SIZE mm	AIR LOSSES Nm^3/year	ENERGY LOSSES kWh/year
Small	0,1-0,3	1.314	210
Medium	0,3-1	7.709	1.233
Large	>1	38.544	6.167

*data is based on a compressor of 7,5 bar, 0.16 kWh/m^3 and 8.760 working hours

- The power factor in the industry should be 0,95 or better. Some advantages appear by means of economic benefits from the supplier company and additionally the capacity of the electrical equipment in mills is utilised better with a higher power factor.

8.5 REDUCING EMISSIONS BY PRODUCT: ECO-LABELING ON CO_2

As happened in other sectors, eco-labelling has become an important fact of decision when purchasing products.

As climate change is such a global concern, a carbon footprint label could motivate industries to strength their energy and emissions saving policies. CEPI has prepared a carbon footprint guide [20]. This guide could prepare in a future, the basis for a carbon-footprint-label. CEPI's guide is for the moment comprising the whole lifecycle of the paper.

- Carbon sequestration in forests
- Carbon stored in forest products
- Greenhouse gas emissions from forest product manufacturing facilities
- Greenhouse gas emissions associated with producing fibre
- Greenhouse gas emissions associated with producing other raw materials or fuels
- Greenhouse gas emissions associated with purchased electricity, steam and heat and hot and cold water
- Transport-related greenhouse gas emissions
- Emissions associated with product use
- Emissions associated with product end-of-life
- Avoided emissions and offsets

However, customers require a simple statement to guarantee that the product reflects the best available technologies on emissions reduction, and there is a still much work to be done to normalise such carbon foot print procedures.

8.6 GENERAL MEASURES APPLIED TO MILLS REALITY

Some of the energy saving measures summarised in lasts paragraphs are applied to Mill A and Mill B realities. Part of the mentioned energy and emission saving potentials derived from results achieved in chapter 7, meanwhile some others –such as fuel replacement– arise from the situation and features of the mill. Multiple zero-emissions scenarios could be analysed and further discussed, although accurate feasibility studies should be done before any investment. Nevertheless, to prove the meaningful of results and solutions exposed in these paragraphs, a simplified financial balance follows the general description of each measure. This financial balance exposes gross investment numbers as well as a payback value as a general indicator. Different suppliers of each technology have provided the initial investment cost of each proposed measure. A more accurate financial cash flow should also consider the cost of the CO_2 tone in the European pool. However, the market is fluctuant and a medium price is difficult to fix. Actually, fluctuant energy and emissions costs are not considered.

8.6.1 Mill A towards zero emissions strategy

Mill A could approach a zero emissions scenario projecting some energy efficiency principles or achieving a replacement of fuels.

Regarding a reduction in origin, Mill A could focus on a wide range of possibilities. For example, it can be analysed the exchange of natural gas boiler for biomass boiler. Another possibility is covering part of the mill's electrical power demand by introducing a simple cogeneration system. In addition, it can be evaluated a CHP facility operating with biomass. Reduction of emissions can be additionally achieved by process efficiency measures. For example, Mill A could either invest in corrective measures of its lighting system and its vacuum system. Overall, measures should be implemented within the scope of a EEMS.

8.6.1.1 Replacement of natural gas for biomass

According to Figure 7.5, in 2006 Mill A required 166 GWh of process steam and consequently emitted 36.630 tones of CO_2. In addition, a reduction of emissions in origin could arise from the exchange of the main natural gas boiler for a biomass boiler. Several types of biomass with a specific gross calorific value and moisture can be used to feed the boiler. Therefore, biomass power income might vary according to its dryness and its specific heat. Table 8.3 presents some possible biomass inputs to cover steam production of the main boiler of Mill A; the same table attaches an approach of unitary cost of each type of biomass.

Table 8.3 Annual quantity of biomass estimated to replace the main gas boiler. Mill A. Based on Abertis [21] and IDAE [22]

TYPE OF BIOMASS	HEAT VALUE kWh/kg	QUANTITY TO COVER STEAM DEMAND t	UNITARY COST €/t
Almond nuts (13% WC)	4,44	42.414	90
Pine woodchips (20% WC)	4,27	44.109	50
Eucaliptus stumps (20% WC)	4,20	44.827	35
Grape residues (30% WC)	4,96	37.990	35
Forestry residues (35% WC)	2,96	63.655	110

* WC, water content. Calculations are based on a 85% of biomass boiler efficiency . Prices are own source

To analyse the proposal from an economic point of view, this works undertakes the energy reference values expressed in Table 8.4. These unitary costs are based on the Spanish market prices, medium average of 2007.

Table 8.4 Unitary energy cost –Spain 2007

ENERGY COST	€/MWh
Natural Gas	27
Electricity	85

Using the aforementioned reference values, the biomass boiler proposal is financially evaluated in Table 8.5. Pine woodchips have been selected as the raw material for the boiler input. The main reason of this decision is that pine wood chips are available in the nearby area of Mill A as some sawmills are operating there. Pine price has an interesting price/energy ratio (11 €/MWh) and a low content of ashes.

Table 8.5 General payback analysis of a biomass boiler facility

GENERAL FINANCIAL BALANCE	€
Annual cost of gas	4.325.427
Annual cost of biomass	2.205.437
Benefits by fuel replacement	2.119.990
Initial investment biomass boiler	6.000.000
Payback (year)	2,83

* It has been chosen pine woodchips as biomass source. Energy costs based on Table 8.4

At today's surging energy costs, the biomass boiler installation in Mill A has an interesting cash-flow result. However, it can not all be regarded in economical terms. In this case, the major problem is neither the cost of biomass nor the initial investment rather than the availability of biomass itself. Biomass boilers require maintenance stops and guarantee a maximum average of 8.000 operating hours/year. Thereby, another support boiler needs to be kept to supply steam in maintenance periods. In addition, the mill needs to have enough space for biomass feedstock.

Afterwards, a feasibility study should be requested to prove and guarantee the supply and cost stability of such amounts of biomass, although if the project success, Mill A could reduce annually 32.297 tones of CO_2.

8.6.1.2 Energy efficiency in the steam boiler house

Main steam boiler of Mill A (gas) was supposed to be connected to a steam turbine. For this purpose, this boiler produces 28 t/h of steam at 420 ºC and 40 bar. However, by historical company decision, the steam turbine system was never installed. Instead, a spray type cooling valve reduces steam pressure to 15 bar, and later a pressure-reducing valve reduces it to 6 bar.

Figure 8.8 exemplifies a project diagram of steam back pressure turbine assembled to Mill A steam boiler.

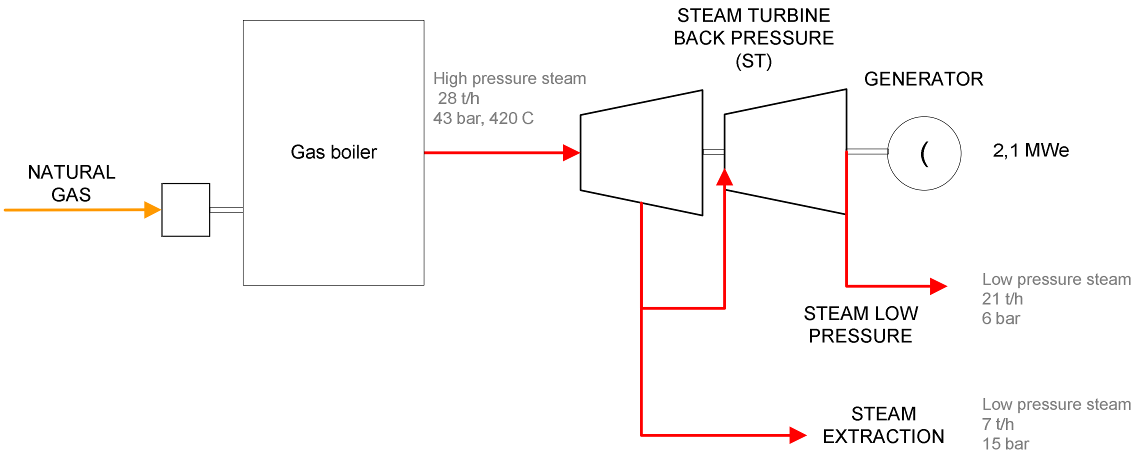

Figure 8.8 Steam back pressure installation in Mill A

The main pressure-reducing valve could be replaced by a backpressure steam turbine. After consulting a steam turbine supplier, a backpressure steam turbine with such steam income could hold a power capacity of 2,1 MWe and a production of 21 t/h of saturated steam at 6 bar. If the steam turbine achieves 8.400 operating hours, energy generated in that period could reach the values expressed in Table 8.6. At the same time, energy savings can be translated as emission savings emitted in the Spanish national grid.

Table 8.6 Steam turbine production and emission savings per year

BACK PRESSURE STEAM TURBINE INSTALLATION	
Electricity production steam turbine [MWh]	17.640
Emission Savings [t CO_2]	6.985

*Emission savings are based on the grid power factor calculated in Chapter 6

Moreover, this general proposal has an attractive payback (see Table 8.7).

Table 8.7 Simple payback analysis of steam turbine installation

GENERAL FINANCIAL BALANCE	€
Cost savings (electricity)	1.499.400
Initial Investment	1.600.000
Payback (years)	1,07

* Energy costs based on Table 8.4

Power savings have been evaluated according to the same electricity cost (market reference) of 85 €/MWh, presented in Table 8.4. It should be remarked that Table 8.7 does not take into account the maintenance cost of the steam turbine. However, the first payback period is enough attractive to develop an accurate proposal.

Regarding these last two emission-reduction proposals (biomass boiler and steam turbine), Mill A could analyse complementing both of them and installing a biomass CHP plant. The plant could consist of a biomass boiler that generates a high pressure steam and an assembled steam turbine. In this case, the suitable biomass boiler has a higher economical cost, around 10 M€. Thus, the project is subjected to a larger payback period despite the benefits of power and gas savings (see Table 8.8).

Table 8.8 General payback analysis of simple cogeneration system with biomass

GENERAL FINANCIAL BALANCE	€
Annual cost of gas	4.325.427
Annual cost of biomass	2.205.437
Benefits by fuel replacement	2.119.990
Power savings	1.499.400
Initial investment Biomass CHP plant	11.600.000
Payback (year)	3,20

* Energy costs based on Table 8.4

Nevertheless, it has to be taken into account this measure achieves greater goals in environmental-related targets. Concluding, a biomass cogeneration system saves CO_2 emissions both by fuel replacement and by grid power savings.

8.6.1.3 Energy and emissions management system

It has already been underlined the importance of the consolidation of an energy and emission management system. In a first stage, Mill A should review its metering system and evaluate most attractive energy potential strategies.

As expressed in chapter 7, Mill A has a friendly-power structure and its DCS facilitates the control of the main sections of the mill. However, some extra power meters should be installed to enlarge the approach of power allocation. Specifically, compressors, pulpers, and the paper machine main sections should have internal power meters.

In the case of steam control -as described in chapter 7-, steam allocation method has been difficult to apply because steam flow meters where missing or not working properly. Steam flow meters should be repaired or reviewed and a steam control system established. Quality and quantity of condensates should be reviewed periodically.

In a second stage, targets should be defined and scheduled. Finally, a management commission should follow the energy consumption and the evolution profile of the investments in both energy and emissions benefits.

Management commission should also dedicate great efforts on educational campaigns for all employees of the mill.

8.6.1.4 Investing in energy measures of the paper process

As recommended in paragraph 7.2.10, the first investments of Mill A should focus on the vacuum system.

Vacuum system

A mill has different possibilities to reduce vacuum system consumption. One of them is to consider and revise the power capacity of the vacuum pumps. The vacuum system might be over or under dimensioned.

Vacuum system is usually a service with energy saving potentials. Frequently, companies tend to over-dimension vacuum systems, to avoid peak loads. In other occasions, the mill adds or changes some parts of the process and the vacuum system becomes over or under-exploited.

In 2007, Mill A already analysed this issue and invest in its vacuum system. Two of the main vacuum pumps where running at maximum power meanwhile their strength valves were overworking during a high average of working hours. Managers decided to install two variable frequency drives to both vacuum pumps. Moreover, a third VFD was installed in the vacuum pump of the water circuit-sealing. A pressure control loop regulates the speed of the vacuum pumps. Energy savings have already been proved. The vacuum system has reduced up to 10% of its consumption. According to this fact, Table 8.9 summarises the power and emission savings.

Table 8.9 Annual emission savings by investment in vacuum system

VACUUM SYSTEM IMPROVEMENTS	
Electricity savings [MWh]	972
Emission Savings [t CO_2]	385

The installation of VFD in pumps with fluctuating levels of demand has been in this case economically and environmentally profitable. Table 8.10 shows the financial payback of the already applied measure.

Table 8.10 General payback analysis of VFD at the vacuum system pumps

GENERAL FINANCIAL BALANCE	€
Power Savings	82.642
Initial Investment	35.000
Payback (years)	0,4

* Energy costs based on Table 8.4

According to results of Table 8.10, it might be interesting to check other devices of the mill operating in continuous at maximum power and with fluctuating demand.

Lighting system Improvements

Part of the lighting system is composed of vapour mercury lights, 400 W each. Metal halide lights of 250 W each could replace the luminance capacity of mercury ones. Thus, up to a 37% reduction could be achieved with this investment. Considering that it could be replaced 100 units of vapour mercury lights, Table 8.11 shows the potential energy and emission savings.

Table 8.11 Annual emissions and energy savings by improvement on Lighting System

LIGHTING SYSTEM SAVINGS	
Energy savings [MWh]	130
Emission Savings [tCO_2]	51

The profit of this measure is estimated in Table 8.12. It has been considered that the lighting system runs in continuous mode during 360 days/year.

Table 8.12 General payback analysis. Lighting system modifications

GENERAL FINANCIAL BALANCE	€
Annual cost of power saved	11.016
Initial investement	7.000
Payback (years)	0,64

Due to the high range of operability of the lighting system, lighting measures usually result profitable in a short period.

8.6.1.5 Concluding points towards a zero emissions scenario in Mill A

The variety of estimations expressed in last paragraphs can be summarised in Table 8.13. Obviously, saving keys expressed in this table aim to assess and should be submitted to further studies.

Table 8.13 Emission saving keys – Mill A

TYPE OF REDUCTION	EMISSION SAVING KEYS	ANNUAL EMISSIONS SAVINGS tCO_2
Reduction in origin	Replacement of natural gas boiler	32.297
Reduction in origin	Assembling steam turbine to boiler	6.985
Reduction in origin	Biomass cogeneration system	39.282
Reduction in process	VFD in vacuum system	385
Reduction in process	Lighting system improvement	51
	Total (biomass cogeneration + VFD + lighting)	39.718
	% saving vs 2006 emissions	59%

In conclusion, Mill A should further study the replacement of natural gas for biomass. Guarantee agreements on availability and cost of biomass could lead to the success of this project. Moreover, measures regarding fuel replacement in on-site energy production facilities have a higher impact in terms of emission reduction. Despite the general impression on renewable-based systems, environmental and financial profits have appeared to be relevant.

In addition, energy saving proposals should be analysed, applied and further monitored and followed.

8.6.2 Mill B towards zero emissions

8.6.2.1 Reduction in origin

As Mill B has already a CHP plant, it has been considered the exchange of natural gas for other GHG-neutral fuel, such as biogas.

Biogas

In general terms, biogas is usually composed of 60% methane and 40% of CO_2. Biogas could replace natural gas with fewer problems in a gas-fired engine or turbine, although it has to be ensured that biogas composition ups to 50% of methane and sulphur content has been minimised to desired levels. Actually, biogas obtained has to be upgraded in order to remove pollutants and make it competitive for this final end-use. One of the available input residues in Mil B nearby area is animal manure, majorly pig manure. In addition, an optimized mixture with co-ferments containing carbohydrates could improve the biogas production yield. Indeed, the biogas production depends on the solid volatile content of the ferment and the correct proportion carbon-nitrogen.

However, the retention time and volume of residues necessary for biogas production are limitant factors. In this context, to substitute the 515 GWh of natural gas fired in the CHP plant during 2006, the amounts of organic waste to produce such quantity of biogas are excessive to replace the totality of natural gas.

Figure 8.9 Biogas plant in Ethern Austria. On the left side, a view of the two digestor tanks. On the right side, a biogas engine of 1 MWe.

Consequently, due to the limitation of raw material, it would be fair to replace partially the natural gas produced in the CHP plant. Table 8.14 shows some general calculations to exchange small part of natural gas for biogas.

Table 8.14 General calculations to exchange natural gas used in CHP-1 plant for biogas (annual basis). Based on ICAEN publication [23]

REPLACING PART OF NATURAL GAS USED IN CHP-1 BY BIOGAS	
Pig manure [m^3/year]	91.741
Organic residues (urban, paper sludge) [m^3/year]	23.272
Biogas [m^3/year]	3.281.000
Low Heat value Biogas [kWh/m^3]	6,5
Natural Gas to substitute [MWh/year]	21.327
Emission Savings [tCO_2]	4.299

*Calculations based on 2006 gas consumption and specifications of a real experience Thorso. Retention time: 15 days, digestor volume: 4600 m^3

Moreover, it should be taken into consideration technical problems that biogas technologies entail; the huge volume of organic residues that should be treated, the gas cleaning systems, the stability of the bacteria or the guarantee of a fixed composition of the raw material are key points to consider.

Table 8.15 exposes a general financial analysis of this particular biogas plant proposal. In this balance, it has been considered the green-power electricity incentive. That means biogas electricity generation is paid 25% higher than natural gas power (according to the Spanish fixed rate RD/661/2007 [5]).

Table 8.15 General payback analysis of a biogas plant

GENERAL FINANCIAL BALANCE	€
Annual cost of replaced gas	575.816
Annual cost of organic residues	23.272
Selling power to grid (extra benefits)	161.740
Annual benefits	714.284
Initial Investment Biogas plant	2.500.000
Payback (years)	3,50

* Energy costs based on Table 8.4. Investment excludes turbine or engine. Annual costs of raw material is supposed 1€/m^3 (transport purposes). The sludge should come to the biogas plant, the animal manure is supposed to be generated next to biogas plant; the mill is supposed to be located to a minimum distance of the animal farming.

B) Solar photovoltaic panels

Mill B has 17.000 m^2 (free area and roof) available for installing photovoltaic panels. Spanish government incentive for an installation of 100 kW was in 2007 of 0,44 €/kWh the first 25 years and 0,35 €/kWh afterwards.

If Mill B is situated in Zone II, it has an expected electricity consumption up to 4,2 kWh/m^2.

Table 8.16 presents an approach of annual power production of a solar photovoltaic system with a power capacity of 100 kW. It also describes the potential of emissions reduction on electricity savings. A supplier of photovoltaic panels has provided the mentioned information.

Table 8.16 Energy benefits of solar panels in Mill B

SOLAR PHOTOVOLTAIC SYSTEM (100 kW) - Mill B	
Expected energy production [kWh]	115.870
Emission Savings [tCO_2]	32

As advanced earlier in this chapter, the initial investment is significant. Table 8.17 supplies a general financial balance for this specific installation.

Table 8.17 General payback analysis. Solar panels

GENERAL FINANCIAL BALANCE	€
Annual benefits of electricity sold	52.736
Initial investement	650.000
Payback (years)	12,33

The payback is high although, it might be of interest to consider the TIR and the VNA for such analysis. On the other hand, it should also be considered environmental targets.

8.6.2.2 Energy and emissions management system

As expressed in chapter 7, it has been difficult to apply the allocation method in Mill B, especially in the case of uncoated paper line. An energy and emission management system is strongly recommended before any investment in energy savings is applied. Indeed, it would be interesting to have meters separating both production lines, either for power and steam measurements. Meters should be installed at the main devices of both lines in order to complete the allocation method proposed in chapter 5. In addition, meters should be controlled by a centralised system in order to enable the consequent registration and analysis of the consumption data. As mentioned in Mill A, energy efficiency campaigns should promote energy savings at all levels of employees.

8.6.2.3 Investing in energy measures

As denoted on paragraph 7.3.6, drying section of the non-coated paper machine is working below energy efficiency criterion. Investment could consist of a closed hood, followed by heat recovery system to condition the income supply air. Technicians have already consulted a commercial supplier.

Table 8.18 estimates the energy and emission savings by considering such potentiality.

Table 8.18 UL paper machine hood improvements

CLOSED HOOD FOR UL PAPER MACHINE	
% Saving potential	21%
Steam energy Savings [MWh]	8.318
Power energy benefits Steam turbine [MWh]	998
Emission Savings [t CO_2]	2.240

In this case, the steam saved could be introduced and exhausted in the steam turbine of the CHP plant, generating an electricity surplus. The steam turbine power efficiency is supposed 12%. Table 8.19 presents the payback analysis of this measure. It is underlined the relevant effect on emission and steam savings towards financial profit.

Table 8.19General payback analysis of hood improvements

GENERAL FINANCIAL BALANCE	€
Annual cost of benefit of extra power	915.033
Initial investment	85.000
Payback (years)	0,09

* the power sold to grid has been fixed at 110 €/MWh

In this particular case, it is denoted the relevance on heat recovery systems. The potential saving is significant meanwhile the investment is relatively low and quickly recovered.

Improving the press section: extended nip press

As expressed in chapter 7, drying sections of the two production lines of Mill B are the largest focus of emissions. To reduce the drying section consumption it can be enhanced the efficiency of the web previous stage, the press section. As advanced in paragraph 8.4.2, a minor grade of water content in the web, entails a lower specific steam demand in the posterior drying section. In addition, the higher dewatering capacity allows a higher speed on the paper machine.

Mill B uses conventional roll nip press in its paper machines. It could be interesting to introduce higher efficient systems in the press section of its paper machine.

During last decade, the market has developed and patented numerous models on extended nip press. The extended nip press term embeds the common known shoe press.

The main advantage of a shoe press is that it can transfer a higher linear loading to the web in comparison with a conventional roll press. This fact is translated in a higher dewatering capacity.

Concerning the particular case of Mill B coated paper line, Table 8.20 expresses a comparison of a conventional roll system with an extended nip press system according to the expected steam energy savings.

Table 8.20 Analysis shoe press installation in Mill B

PRESS SECTION - MILL B	
Basis weight (average) [g/m^2]	100
Paper machine speed [m/min]	750
Dryness out presses (conventional system) [%]	42
Dryness out presses (shoe press) [%]	47
Steam savings [%]	22
Annual steam savings [MWh]	15.310
Annual steam savings [tCO_2]	4.127

*steam savings are based on a closer experience of a paper machine with the same grade and paper weight

Initial investment of a shoe press system is high, despite the steam saving advantages. Payback analysis of Table 8.21 denotes that the benefits of such modification in the press system are not that significant.

Table 8.21 General financial balance. Shoe press

GENERAL FINANCIAL BALANCE	**€**
Annual benefit of extra power production	202.097
Initial investement	5.000.000
Payback (years)	25

* Energy costs based on Table 8.4, again is suposed steam savings are translated on power benefits due to steam tubine over-operation. The power sold to grid has been fixed at 110€/MWh

Actually, the shoe press investment might not be such interesting in terms of steam and energy savings; however, it should be underlined that an extended nip press enables a higher speed operability in the paper machine. This fact must be also considered in terms of payback and financial profits.

Compressed air system

Another general service to be evaluated is the compressed air system. Technicians have detected that by reducing the pressure level from 8 bar to 6,5 bar, electricity savings up to 6% could be reached. The maintenance in the distribution network, tools and equipment could eliminate leakages (valves, tools, switches), electricity savings up to 10% could also be achieved, according to compressed air maintenance experts. Table 8.22 presents the emission and energy savings according to the aforementioned assumptions (10% energy savings) and the estimated compressors system consumption of Figure 7.21.

Table 8.22 Emissions and energy savings by improvement on compressed air system (per year)

COMPRESSED AIR SYSTEM IMPROVEMENT	
Energy savings [MWh]	252
Emission Savings [tCO_2]	58
Economic benefit [€]	21.403

In this case, the measure can be put into practice with little initial investment, as the improvement is based on maintenance and set point variation.

8.6.2.4 Concluding points towards zero emissions - Mill B

Estimations expressed in last paragraphs can be summarised in Table 8.23. To reduce emissions in origin, it is thought to replace part of natural gas demand with biogas and install photovoltaic solar panels. On the other hand, energy potential savings can be focused on new strategies such as shoe press installation, compressed air system improvement or hood repairs.

Table 8.23 Emission saving keys Mill B

TYPE OF REDUCTION	EMISSION SAVING STRATEGIES	Annual emission savings tCO_2
Reduction in origin	Introduction of biogas	4.299
Reduction in origin	Photovoltaic Panels	32
Reduction in process	Shoe press	4.122
Reduction in process	Heat recovery in drying section	2.240
Reduction in process	Compressed Air system revision	58
	Total	10.693
	% saving vs 2006 emissions	13%

Concluding, energy savings and renewable sources can reduce emissions and drive Mill B towards a zero emission stage.

As mentioned, the feasibility of new fuels such as biogas is subjected to raw material availability. In addition, as Mill B has already a CHP plant, it could be interesting to invest in energy diagnosis of this particular facility.

8.7 CONCLUSIONS

This chapter could further extend on energy related measures and GHG origin-reducing strategies. However, the exposed sample cases meant to highlight the several potential savings regarding emission-reducing fields.

Actions concerning renewable-based energies and best efficient technologies consolidation, will primary imply a specific support of energy policy from government and from the same company of the paper mill.

Emission-reducing measures should be planned as an environmental solve to anthropogenic GHG focus as well as a financial opportunity for industries, which enforce leading technologies implementation.

Finally, a consolidation of an EEMS should become the first investment before any reducing project is executed, as this system settles the tools to monitor and control the environmental and energy performance of each particular project.

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9 CONCLUSIONS AND FUTURE WORK

9.1 CONCLUSIONS

This project has developed and appraised a new methodology of emissions allocation in the paper manufacturing process with the aim of highlighting the potential keys to minimise emissions. This objective has been implemented in different stages.

In a first stage, a conceptual methodology has been composed and designed. Emissions have been identified, determined and distributed according to its final end-use. This task is mainly underlining energy-facilities, as energy generation is the main responsible for emissions in paper mills. In this context, emissions concerning each of the selected end-uses (power, steam and other thermal applications) have been allocated gradually through operational levels of the paper process, such as production lines, sections, unit operations and devices. Results are expressed as particular ratio indicators and set the base for benchmarking purposes. This conceptual distribution has focused on printing paper manufacturing. Despite this fact, it has been tried to generalise the scope to the rest of paper manufacturing profiles.

The second stage has evaluated emission factor methodologies concerning results of the first method. Energy supplying systems –both CHP and SHP facilities– have been visualized as the two common configurations for case studies. In the case of CHP plants, no methodology to allocate GHG emissions of a CHP plant into its energy output streams has been yet standardised. Thereby, three published methods have been considered and applied to a particular CHP facility. These methods have in common an allocation base of emissions into the utile output streams of the CHP plant. Nevertheless, after the analysis of the results, this work considers that inefficiencies –concerning both intrinsic to the system and the operational ones– should be weighted in the allocation method proposal. For this reason, an alternative method of CHP emissions allocation based on the aforementioned considerations has been composed and developed. The proposed methodology is formulated according to efficiency indicators concerning BATs of different CHP components. However, at current date, there are no published best available efficiency ratios concerning the main units of a CHP system. To normalise this new methodology such ratios should be available as a standard data source.

Moreover, a method to calculate a grid power emission factor enclosing an interconnected system of power generators has been defined and evaluated. The Spanish electricity system has been used as a sample case. The information concerning power and emissions from the facilities of generation mix has been complex to compile. The power factor obtained still embeds the thermal factor of combined cycle and rest of the cogeneration facilities. In this context, a power and heat allocation method –as well as additional information– is required to delimit the definition of electricity factor. With the available information, a monthly power factor has been delivered. Such factor experiences a continuous fluctuation as it depends on the operative plants profile, which is simultaneously influenced by water reservoirs and peak-loads of the market demand. This variability should be taken into consideration when determining power emissions within a short-period scope.

Furthermore, the allocation method proposed has not only been conformed in a conceptual mode but also has been translated into an excel worksheet. This calculation tool illustrates the conceived methodology and provides to the user a friendly and versatile application to manage an inventory of emissions, set indicators and monitor milestones and targets.

In a third stage, the proposed allocation method has been applied to the reality of two non-integrated paper mills. The allocation method has not been fully completed, due to the limited metering capacity of the mills. Assumptions and estimations during the allocation process have led to an approach of energy and emission ratios. Indeed, the determined energy and emission intensities have been essential to detect system weak-points and to characterise SHP and CHP systems.

The emission benchmarking applied to the two paper mills has concluded that CHP facilities are an efficient system of power and steam production. However, an investment in efficient energy technologies is not worth if energy is misused along the manufacturing process. Mill B is the clear example of this fact, as it has a correct CHP facility but steam and power use is not optimised enough. For example, the drying sections of the paper machines require extended investment in heat recovery and steam regulations. Moreover, power indicators of different sections of this mill have denoted that technical audits in compressed-air system, refiners and vacuum system should be carried on. The last two critical points should be also improved in Mill A.

As a general benchmarking conclusion, it should be stated that the amount of emissions produced by a specific mill is subjected to size effect, productivity and the introduction of the best available technologies. For that purpose, such parameters have to be visualised in a benchmarking procedure, including both the origin and efficiency of the primary energy sources.

The allocation method results have additionally clarified some key-strategies associated with a zero-emission scenario in a paper mill. Measures concerning reduction in origin (by fuel replacement or introduction of renewable energy projects) as well as during the process (energy efficiency measures) have been overviewed. The most interesting ones have been exemplified using the two paper mills case-studies. A simplified cash flow has been presented in order to prove the financial viability of the measures exposed. In this sense, renewable energy-based plants pose some challenging potentials of emission reductions to the paper mills. In the case of solar, hydro or wind power energy, the physical location of the mill is a limiting factor. However, the regionability is not the only disadvantage; such renewable sources do not produce energy in a continuous mode. In the case of biomass, the limiting factor is the biomass itself. Contractual guarantee supplies of biomass might be the key factor for the sucess of this neutral emission generation source.

According to this work, both renewable energy generation and energy efficiency concepts should be jointly implemented in order to achieve the optimum emission reduction targets.

Finally, factor methodologies, calculation of activity emissions and parameters concerning energy and emission efficiency must be puzzled together in an integrated structure. For this reason, an EEMS, which comprises the allocation method proposed in this work, is strongly recommended before the investment in energy or emission-reducing fields. Thereby, an EEMS will ensure a larger profitability of the implemented measures.

9.2 FUTURE WORK

This research work could be continued or derived in several topics. Further research topics that have been conceived with the aim of extending and improving this work are exposed below.

- To prove all paper ratings in the allocation method

As stated in conclusions paragraph, the new developed allocation method has a printing paper manufacturing-base. Although this work has attempted to generalise this base to the rest of paper manufacturing rates, the scope of the method framework should be proved in future research. It is proposed to implement the allocation method to different case studies such as tissue paper, board paper or special paper manufacturers.

- To extend this work to pulp manufacturing

It should be underlined that this work has particularly centred on emission allocation among paper manufacturing processes. It could be of interest, to extend the methodology towards the lifecycle of the paper itself, specially the production of pulp, as raw material. Further research could focus on pulp manufacturers, working out the set of emissions of black liquor or biomass by-product within different types of pulp producers. An allocation method enclosing the pulp making process should be designed and proved.

- To generalise the emission factor method and produce a BATs database

The new methodology proposed to determine an emission factor of a CHP plant has been proved for a particular CHP plant configuration. It could be relevant to exemplify this method with other cogeneration configurations. In addition, it is of interest, to collaborate in a general database containing the best available efficiency ratios of primary engines and of main components of cogeneration plants.

- To evaluate renewable-based projects in pulp and paper industry

It is proposed to explore environmental and financial performance of leading projects that are based on energy renewable sources or energy efficiency measures. They should be evaluated and adapted to the paper sector profile.

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ANNEX 1

WORKSHEET TOOL ILLUSTRATION

This annex contains some screen-prints concerning the tools that the user have available within the emissions allocation worksheet tool. The aim of these illustrations is to highlight the friendly-user tool that has been designed and to picture some of the main worksheet contains.

As explained in chapter 5, the worksheet contains the index of sheets illustrated in Figure A.1.1.

INDEX OF WORKSHEETS

NAME OF THE WORKSHEETS		CONTENT
INTRODUCTION	0	Presentation of this worksheet tool
GENERAL DATA	1	General information of the mill, focused on emissions and energy-related issues
EMISSION SOURCES AND FACTORS	2	Emissions and factors of the main energy-related issues as well as other factors related to mobility, raw material, water treatment, etc
MAIN FOCUS OF EMISSIONS	3	Emissions assigned to each main focus. Power and steam systems. Calculations of direct heat, steam and power factors.
MAIN FOCUS DIAGRAM	4	Sankey diagram tool to produce a general sankey diagram related to emission focus of the mill and related end-use
POWER-RELATED EMISSIONS	5	Allocation of power-related emissions through out the specific paper process, taking into account production lines and general services
STEAM-RELATED EMISSIONS	6	Allocation of steam-related emissions through out the specific paper process, taking into account production lines and general services
OTHER -RELATED EMISSIONS	7	Allocation of other thermal-related emissions through out the specific paper process, taking into account production lines and general services
GENERAL COMMENTS	8	General comments to be noted, after results obtained
SUPPORT DATA	9	Default emission factors, net energy heating values and unit conversion factors to achieve unit consistency.

Figure A.1.1 Worksheets contain of the Allocation Tool

In the following screen-displays are presented some of the main worksheets contents. This is the case of General data sheet (Figure A.1.2), Emissions Sources and factors (Figure A.1.3), Main focus of Emissions and Main focus diagram (Figure A.1.4). Power, steam and other related- emissions sheets have already been presented in Chapter 5.

GENERAL DATA

This worksheet should contain relevant information about production, emission and energy issues of the paper mill.
Historical data should be introduced in order to set the base for specific indicators regarding energy or emission issues.
The spreadsheet is prepared for an anual base period, although shorter base periods (monthly, daily basis) might be introduced.
Optional variables and main features can be added to General Data table. Mill's reality must determine which are relevant features to manage and control.

CELLS COLOUR DETAILS

Notemarks, suggestions or default values
User entries, cells to be filled
Calculation results

MILL NAME	*Mill C - offset paper mill*
User	*Name and position in the company*

PAPER MILL GENERAL DESCRIPTION

for example, Mill A is an offset printing paper mill that manufacturers uncoated paper in Catalunya. During last year the company has invest in new refiners. A new quality and energy policy is consolidating production.

Mill C - offset paper mill GENERAL DATA

MAIN FEATURE	DESCRIPTION	UNIT	2002	2003	2004	2005	2006	2007
General production data								
Production	Paper produced, all types	[t]						
	Paper produced, specific type A	[t]						
	Paper produced, specific type B	[t]						
Raw materials	Pulp supplied by a group pulp mill	[t $_{100\%\ dryness}$]						
	$CaCO_3$ and kaolin purchased	[t]						
	Other significant Raw materials	[t]						
Water	Fresh water intake	[m^3]						
Other								
Energy-related issues								
Electricity	Quantity of power purchased	[MWh_e]						
Natural Gas	Quantity of fuel burned	[MWh_{LHV}]						
Gas oil	Quantity of fuel burned	[MWh_{LHV}]						
Fuel oil	Quantity of fuel burned	[MWh_{LHV}]						
Other	Quantity of fuel burned	[MWh_{LHV}]						

Figure A.1.2 General Data Sheet. This worksheet should include general data to perform allocation method for a particular mill.

EMISSION SOURCES AND FACTORS

EMISSION SOURCES OF Mill C - offset paper mill

CELLS COLOUR DETAILS

Notemarks, suggestions or default values. Some default values are available at the worksheet 9 Support Data
User entries, cells to be filled
Calculation results

INVENTORY BOUNDARIES

This worksheet should contemplate the total amount of emissions that the company wants to manage or control. Not all the emissions specified in this worksheet can be of application in each mill. Use the following table to set the inventory boundaries.
Use the following marks to set the correct inventory boundaries
X: considered
N.A: not applicable
-: not considered

FOCUS OF EMISSIONS		GENERAL REMARKS
Energy-related emissions (direct)	X	
Energy-related emissions (indirect)	X	
Mobile and transportation sources	-	ex. Not available
Waste management	N.A	ex. Not applicable because there is not methane landfill/waste water treatment potential
Direct make-up chemicals	N.A	ex. Not considered because the chemicals are made out-side mill
Biomass	N.A	ex. Not applicable because the mill does not combust any biomass type
Other significant emission sources	N.A	

EMISSION SOURCES

Next table should contain the sources of emissions defined in the inventory. General main sources are already specified, although it might be necessary to add new ones. Some information regarding unit conversion, specific energy values or emission factors can be encountered in "Support data" sheet.

EMISSION SOURCES		AMOUNT	LHV	Energy content	EMISSION FACTOR	CO_2 EMISSIONS	EMISSION FACTOR	CH_4 EMISSIONS	EMISSION FACTOR	N_2O EMISSIONS	TOTAL EMISSIONS	EMISSION FACTOR eq.
	Units	Quantity	MWh/m3,t,l	MWh_{LHV}	tCO_2/MWh	tCO_2	tCH_4/MWh	tCH_4	tN_2O/MWh	tN_2O	tCO_{2eq}	tCO_2/MWh or tCO_2/t
Energy-related focus												
Natural gas	m3	*47.063.481*	0,011	508.286	0,201	102.287	5,04E-06	3	3,60E-07	0	102396	0,201
Fuel Oil	l or t	*8.000*	0,011	88	0,276	24	1,08E-05	0	1,08E-06	0	24	0,276
Gas Oil	l	*3.000*	0,010	31	0,264	8	7,20E-07	0	1,44E-06	0	8	0,265
Coal	t			0	0,347	0	3,60E-05	0	5,04E-06	0	0	0,000
Power *	MWh			1.300.000	0,396	514.800		0		0	514800	0,396
Other				0	*0,400*	0		0		0	0	0,000
Mobile and transportation focus												
Gasoline	l			0	0,247	0	1,80E-04	0	7,20E-06	0	0	0,000
Gas oil	l			0	0,264	0	7,20E-07	0		0	0	0,000
Other	l			0	*0,230*	0		0		0	0	0,000
Waste Management												
Sludge 1	m3 (dry)						2,30E-01	0			0	0,000
Sludge 2	m3 (dry)						2,30E-01	0			0	0,000
Direct Make-up chemicals												
Sodium Carbonate production	t				0,415	0					0	0,000
Calcium Carbonate production	t				0,440	0					0	0,000
Biomass												
Type of biomass	t			0	0,392	0		0		0	0	0
Black Liquor				0	0,342	0		0		0	0	0
Other												
Other				0		0		0		0	0	0
Total											617229	

*energy consumption related to power from grid, CHP or other cogeneration treatment

Figure A.1.3. Emission sources and factors. This worksheet is prepared for quantifying the emissions from a particular activity source.

MAIN FOCUS OF EMISSIONS

CELLS COLOUR DETAILS

Notemarks, suggestions or default values

User entries, cells to be filled

Calculation results

Regarding emission sources of the previous sheets, allocate the main emission focus of each of this sources. Detail the energy use or the specific variable to attribute emissions to focus. Complete the rest of the form using the display grouping bar

GENERAL ALLOCATION OF EMISSIONS					
EMISSION SOURCES	Amount			Emissions	Share
Units/facilities	MWh	t	m^3	t CO_{2eq}	%
Energy-related focus					
Natural gas	471.942.129			94.973.634	100%
CHP					
Boiler 1	1.111.000			223.578	0,2%
Boiler 2	7.000.000			1.408.680	1,5%
Boiler 3	463.831.129			93.341.376	98,3%
IR					
Other					
Fuel Oil	88.244			24.334	100%
CHP					
Boiler 1	80.000			22.061	90,7%
Boiler 2	8.244			2.273	9,3%
Boiler 3					
Other					
Gas Oil	30.875			8.158	100%

SANKEY DIAGRAM - ENERGY AND EMISSIONS

Sankey diagram is a particular type of flow diagram,wherein the width of the arrows is visualised proportionally to the flow quantity.
These diagrams aremainly used to depict energy or material transfers between processes.

This Sankey diagram tool is based on a Sankey Excel macro, which has been designed by Gabor Doka ©

Some modifications has been made in order to adapt it to pulp and paper allocation worksheet

Bellow some short guidelines are expressed in order to built your own Sankey diagram for your particular paper mill

For further information or extended guidelines, please, download ---> http://www.doka.ch/sankey.htm#sample

DIAGRAM STEPS

Identify and built the respective diagram

You can reuse, modify or start a new diagram

Add new arrows or forms by using Microsoft Excel Draw bar

To assign to each arrow a corresponding value, select the cell where the value is allocated

Select immediately the arrow or form to be modelled

Run de **Macro a_assig or press ctrl+A**

To assign the appropiate width modify the Scaling factor. Scaling factor cell and its value cell can not be deleted or withdrawn.

Repeat the process for each arrow or form to assign a specific value

To recalculate and refresh values Run Macro d_sizeAll or press Control+D

For other secondary functions, display this form   Display Form   Hide Form

Macro Name	Function	Shortcut Key
a_assig	Assigns the currently selected shape(s) to the activated table cell	Option+Shift+a
d_SizeAll	Adjusts all line widths and shape heights of assigned Sankey shapes, using the current scaling factor	Option+Shift+d
y_slantarrow	This gives all Sankey chevrons ( ) and pentagons ( ) an arrowhead angle of 26.6° (1:2).	Option+Shift+y
c_dessignCellToShape()	Disconnects the link between a text box (label) an a cell containing label text.	Option+Shift+c
p_ShowPrecedents	Shows which shapes are connected to which table cells (blue arrows)	Option+Shift+p
l_DeletePrecedents	Deletes all blue arrows created by the above macro	Option+Shift+ (L)
m_toggleDrawingtoolsMenu	Shows/Hides toolbars with useful built-in Excel drawing tools	Option+Shift+m
g_SaveCollectionAsGIF	Exports selected shape(s) as a GIF picture to the hard drive (shared filter for GIF Export needs to be present. Extended from Ed Ferrero's Chart Export).	Option+Shift+g

* Source: Sankey Helper 2.1

Figure A.1.4. Screen displays of two different sheets. The first one, Main Focus of Emissions, contains a first assignation of emission-activities according to end-use. The second screen comprises some of the first guidelines to assist the user with a Sankey diagram production.

ANNEX 2

DETERMINING EMISSION FACTORS

Below is presented some of the information used to evaluate grid power factors of Spain electricity system.

To evaluate the emission factor of the main fossil fuels related to power generation, it has been compiled the verified CO_2 emissions of this facilities as well as the reported power produced that has been injected to the Spanish grid system. Regarding verified emissions, Spanish Ministry of Industry has published these data in order to report in transparent mode the annual emissions of the installations subjected to legislation. The generated power data has been gathered from REE Annual report.

Table A.2.1 presents the certified emissions and the power generated of thermal plants using coal, as raw material.

Table A.2.1 Coal-fired plants, CO_2 emissions and power Spain 2006

COAL-FIRED PLANTS	CERTIFIED TONES 2006	POWER GENERATED 2006 GWh
Viesgo Generación - Serchs	1.022.993	1.103
Iberdrola Generación, S.A.U. - Pasajes	1.123.589	1.256
Viesgo Generación - Puente Nuevo	1.407.854	1.589
Iberdrola Generación, S.A.U. - Lada 3	1.806.590	1.806
C.T. Anllares	2.112.535	2.266
Unión Fenosa Generación. S.A - Narcea 1	2.677.815	2.808
Endesa Generación - Los Barrios	3.340.822	3.691
Unión Fenosa Generación, S.A - La Robla	3.554.304	3.896
Hidrocantábrico S.A - Soto Ribera 1	3.751.284	4.108
Unión Fenosa Generación. S.A - Meirama	3.847.539	3.292
Endesa Generación, S.A. - Compostilla	6.119.184	6.563
Endesa Generación, S.A. - Litoral	6.326.518	7.180
Endesa Generación - Teruel	6.347.323	6.540
Hidrocantábrico S.A - Aboño 1	6.960.496	6.342
Endesa Generación, S.A. - Puentes	9.122.201	9.534
Total	59.521.047	61.974

The same information has been processed for combined-cycle plants and fuel-fired plants. Table A.2.2 and A.2.3 depict the mentioned results.

Table A.2.2. Combined-cycle plants, CO_2 emissions and power Spain 2006

COMBINED CYCLE PLANTS	CERTIFIED TONES 2006	POWER GENERATED 2006 GWh
Iberdrola Generación, S.A.U. - Aceca 3	449.243	1.231
Iberdrola Generación, S.A.U. - Santurce (grupo 4)	461.360	1.247
Iberdrola Generación, S.A.U. - Arcos de la Frontera -1	462.816	1.235
Iberdrola Generación, S.A.U. - Arcos de la Frontera -2	503.372	1.348
Castelnou Energía, S.L.	610.644	1.790
Eléctrica de la Ribera del Ebro. S.A - Castejón I-	635.370	1.724
Endesa Ciclos Combinados, S.L. - San Roque 2	787.348	2.164
Gas Natural, S.D.G., S.A. - San Roque 1	846.600	2.356
Endesa Ciclos Combinados, S.L. - Besos 3	879.605	2.403
Gas Natural, S.D.G., S.A. - Besos 4	910.434	2.567
Iberdrola Generación, S.A.U. - Arcos de la Frontera -3	912.336	2.774
Bizkaia Energía, S.L. - Amorebieta	1.154.104	3.150
Bahía Bizkaia Electricidad - BBE	1.623.067	4.413
Gas Natural, S.D.G., S.A. - Arrubal	1.635.897	4.651
Unión Fenosa Generación, S.A. - Palos de la Frontera	2.536.246	7.179
Total	14.408.442	40.232

Table A.2.3 Fuel-fired plants, CO_2 emissions and power Spain 2006

FUEL-FIRED PLANTS	CERTIFIED TONES 2006	POWER GENERATED 2006 GWh
Endesa Generación, S.A. - Cristóbal Colón	23.692	35
Iberdrola Generación, S.A.U. - Escombreras fuel	167.396	204
Endesa Generación S.A. - Sant Adrià del Besòs	178.158	279
Viesgo Generación - C.T. Bahía de Algeciras	211.016	277
C.T. de Aceca C.B. IB y UF - Aceca 2	683.603	917
Unión Fenosa Generación, S.A. - Sabón	310.591	382
Endesa Generación - Foix	428.285	938
Iberdrola Generación, S.A.U. - Santurce	458.691	655
Iberdrola Generación, S.A.U. - Castellón fuel	600.245	762
Total	3.061.677	4449

This information enables the extrapolation of emission factors (Chapter 6). Additionally, the emission factor evolution of the period 2004-2006 can be analysed by means of the market electricity balance of the same period. Table A.2.4, Table A.2.5 and Table A.2.6 synthesise the mentioned information.

Table A.2.4 Annual balance of Spanish electricity system 2004

Electricity Balance (GWh)	jan-04	feb-04	march-04	abr-04	may-04	june-04	july-04	aug-04	sep-04	oct-04	nov-04	des-04	TOTAL 2004
Ordinary Regime													
Hydroelectric	3.524	3.197	2.962	2.753	3.100	2.682	2.097	1.802	1.636	1.822	2.336	1.865	29.777
Nuclear	5.692	5.347	5.151	5.328	5.040	5.376	5.759	5.644	4.917	4.673	5.294	5.386	63.606
Thermal Conventional													
Carbon	5.993	6.215	6.728	5.449	5.629	6.237	6.927	6.709	6.611	6.564	6.316	6.980	76.358
Fuel-Gas	473	380	660	201	349	800	1.172	773	1.013	633	512	729	7.697
Combined Cycle	1.578	1.985	2.322	1.867	2.063	2.370	2.782	2.390	2.987	2.914	2.828	2.888	28.974
Consumption in generation	-690	-672	-717	-591	-651	-758	-806	-774	-748	-746	-735	-760	-8.649
Special Regime													
Thermal Special	1.953	1.871	2.024	1.894	1.862	1.744	1.864	1.718	1.766	1.849	1.932	2.005	22.481
Minihidroelectric	572	415	493	529	555	400	324	242	192	237	322	314	4.596
Other Renewable energy	1.962	1.321	1.544	1.783	1.269	1.278	1.185	1.324	1.366	1.931	1.811	2.017	18.791
Net Generation	**21.057**	**20.058**	**21.167**	**19.213**	**19.216**	**20.131**	**21.303**	**19.828**	**19.741**	**19.878**	**20.616**	**21.424**	**243.631**
Consumption in pumping	-405	-276	-339	-329	-393	-426	-408	-386	-388	-411	-359	-484	-4.605
Brute Generation	*21.462*	*20.334*	*21.506*	*19.542*	*19.609*	*20.556*	*21.712*	*20.214*	*20.129*	*20.289*	*20.975*	*21.908*	248.236
International Exchanges	-318	-300	-234	-621	-304	-321	-241	-455	-54	-331	-46	198	-3.027
Inputs	667	588	725	494	630	591	740	477	660	686	777	1.077	8.112
Outputs	-985	-888	-959	-1.115	-933	-912	-982	-932	-714	-1.017	-823	-879	-11.139
Transport Demand	**20.334**	**19.482**	**20.594**	**18.262**	**18.519**	**19.384**	**20.653**	**18.987**	**19.300**	**19.135**	**20.212**	**21.138**	**235.999**
Grid Power Factor	0,354	0,385	0,405	0,355	0,372	0,403	0,433	0,431	0,448	0,430	0,399	0,423	**0,403**

Table A.2.5 Annual balance of Spanish electricity system 2005

Electricity Balance (GWh)	jan-05	feb-05	march-05	abr-05	may-05	june-05	july-05	aug-05	sep-05	oct-05	nov-05	des-05	TOTAL 2005
Ordinary Regime													
Hydroelectric	1.623	1.570	1.793	1.983	2.228	1.994	1.570	1.269	1.045	998	1.369	1.727	19.169
Nuclear	5.820	5.102	4.617	3.956	3.801	3.972	4.089	4.741	5.363	4.934	5.420	5.723	57.539
Thermal Conventional													
Carbon	7.209	6.451	6.548	5.838	6.020	6.113	6.647	6.107	6.266	6.511	6.710	6.975	77.393
Fuel-Gas	978	1.173	1.455	406	573	1.228	1.446	445	570	399	466	874	10.013
Combined Cycle	3.420	3.436	3.415	3.311	3.598	4.740	5.290	4.519	4.525	4.164	4.263	4.204	48.885
Consumption in generation	-806	-759	-783	-656	-695	-732	-804	-708	-763	-745	-795	-836	-9.082
Special Regime													
Thermal Special	2.012	1.904	2.012	1.940	1.948	1.882	1.850	1.719	1.830	1.792	1.791	1.780	22.460
Minihidroelectric	343	283	369	447	420	282	231	173	140	208	365	391	3.653
Other Renewable energy	2.190	2.026	2.119	2.257	1.832	1.543	1.915	1.939	1.578	2.162	2.258	2.675	24.494
Net Generation	22.788	21.186	21.545	19.482	19.724	21.021	22.234	20.205	20.554	20.423	21.847	23.515	254.524
Consumption in pumping	-553	-433	-493	-451	-644	-635	-693	-446	-520	-483	-455	-554	-6.358
Brute Generation	23.341	21.619	22.038	19.932	20.368	21.655	22.928	20.651	21.074	20.906	22.301	24.068	260.882
International Exchanges	296	300	51	69	176	176	32	-175	-495	-663	-690	-420	-1.343
Inputs	1.368	1.091	939	844	985	949	950	701	552	577	479	777	10.212
Outputs	-1.073	-791	-888	-775	-809	-772	-919	-876	-1048	-1239	-1168	-1197	-11.555
Transport Demand	22.530	21.053	21.104	19.100	19.256	20.563	21.573	19.584	19.539	19.278	20.703	22.541	246.822
Grid Power Factor	0,423	0,425	0,433	0,404	0,419	0,437	0,451	0,420	0,427	0,428	0,413	0,405	0,424

Table A.2.6 Annual balance of Spanish electricity system 2006

Electricity Balance (GWh)	jan-06	feb-06	march-06	abr-06	may-06	june-06	july-06	aug-06	sep-06	oct-06	nov-06	des-06	2006-tot
Ordinary Regime													
Hydroelectric	1.679	1.277	2.748	2.464	2.020	1.538	1.666	1.158	1.313	1.726	3.002	4.737	25.330
Nuclear	5.661	5.105	5.304	3.714	4.506	5.078	5.023	5.420	4.523	4.857	5.313	5.622	60.126
Thermal Conventional													
Carbon	7.296	6.138	5.071	3.722	5.391	5.909	6.895	5.619	5.754	5.108	4.537	4.566	66.006
Fuel-Gas	824	677	331	323	249	571	1.082	377	821	376	148	126	5.905
Combined Cycle	5.663	5.592	4.811	4.755	5.040	5.591	6.809	4.943	6.459	5.167	4.357	4.317	63.506
Consumption in generation	-861	-778	-725	-585	-671	-776	-881	-764	-785	-712	-676	-693	-8.907
Special Regime													
Thermal Special	1.759	1.688	1.781	1.643	1.697	1.563	1.541	1.450	1.548	1.622	1.642	1.653	19.587
Minihidroelectric	388	308	546	486	344	236	216	169	155	298	365	459	3.971
Other Renewable energy	1.869	2.232	3.121	2.299	1.995	1.711	1.501	2.504	1.782	2.636	2.560	2.469	26.680
Net Generation	24.280	22.239	22.989	18.822	20.572	21.421	23.852	20.878	21.570	21.077	21.247	23.257	262.204
Consumption in pumping	-575	-520	-368	-300	-306	-360	-497	-388	-487	-542	-542	-377	-5.261
Brute Generation	24.854	22.759	23.357	19.122	20.878	21.781	24.349	21.266	22.057	21.619	21.788	23.634	267.465
International Exchanges	-365	-584	-799	42	19	-262	-378	63	-311	-237	-285	-182	-3.280
Inputs	809	590	498	800	894	730	684	984	783	855	683	783	9.093
Outputs	-1175	-1173	-1297	-758	-875	-992	-1062	-921	-1093	-1092	-969	-965	-12.373
Transport Demand	23.340	21.135	21.822	18.564	20.284	20.799	22.977	20.554	20.773	20.299	20.420	22.697	253.664
Grid Power Factor	0,425	0,407	0,328	0,328	0,381	0,406	0,437	0,384	0,419	0,364	0,315	0,288	0,373

Moreover, for further regional calculations, the power generation profile of each Spanish autonomous region has been evaluated. For that purpose, information configured in Table A.2.7 (a and b) has been taken into consideration.

Table A.2.7 a) Power system profile of the Spanish autonomous regions

ELECTRICITY GENERATION 2006 GWh	Andalucía	Aragón	Asturias	Baleares	C. Valenciana	Canarias	Cantabria	Castilla-La Mancha	Castilla y León	Catalunya	Ceuta
Hydro	843	2.296	1.484	0	1.026	0	682	521	6.470	2.716	0
Nuclear	0	0	0	0	9.219	0	0	8.660	3.837	23.470	0
Coal	12.460	7.538	15.064	3.320	0	0	0	664	15.094	1.103	0
Fuel/gas	312	0	0	1.335	762	6.803	0	2.373	0	1.218	211
Combined Cycle	21.492	1.790	0	1.442	3.239	2.064	0	2.789	0	8.767	0
Ordinary Regime	35.107	11.623	16.548	6.097	14.247	8.867	682	15.007	25.402	37.274	211
Internal consumption	-1.060	-605	-946	-358	-488	-486	-11	-998	-1.278	-1.538	-9
Renewables	1.879	4.192	1.175	138	350	288	245	4.265	4.704	1.133	0
Hydro	103	777	196	0	15	0	193	189	490	507	0
Wind power	1.042	3.342	357	5	266	288	0	3.935	3.840	301	0
Other Renwables	733	72	621	133	69	0	52	141	374	325	0
Biomass	728	63	221	0	55	0	11	99	274	77	0
Industrial Residues	0	8	400	0	0	0	34	34	0	10	0
Urban Residues	0	0	0	133	0	0	7	0	87	231	0
Solar	5	1	0	0	13	0	0	8	14	7	0
Non renewables	3.457	1.638	325	0	1.376	217	1.535	946	1.837	4.146	0
Residual Heat	61	0	110	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	748	0	0	0	0
Fuel-gasoil	203	54	124	0	54	217	4	286	106	326	0
Refinery Gas	286	0	0	0	0	0	0	0	0	0	0
Natural Gas	2.908	1.584	91	0	1.322	0	783	660	1.731	3.820	0
Total Special Regime	5.336	5.830	1.500	138	1.726	505	1.781	5.211	6.541	5.279	0
Net Generation	39.383	16.849	17.102	5.877	15.486	8.886	2.452	19.220	30.665	41.015	202
Pumping consumption	-692	-423	-171	0	-883	0	-871	-280	-1.082	-518	0
Exchanges	294	-5.569	-5.657	0	11.695	0	3.230	-7.532	-16.150	5.945	0
Bus bars demand	38.985	10.857	11.274	5.877	26.297	8.886	4.811	11.408	13.433	46.442	202
POWER FACTOR tCO_2/MWh	0,535	0,504	0,853	0,787	0,142	0,627	0,408	0,193	0,495	0,162	0,719

Table A.2.7 b) Power system profile of the Spanish autonomous regions

ELECTRICITY GENERATION 2006 GWh	Extremadura	Galícia	La Rioja	Madrid	Melilla	Murcia	Navarra	Euskadi	total PENINSULA	TOTAL SPAIN
Hydro	2.215	6.594	69	39	0	45	97	232	24.955	24.955
Nuclear	14.939	0	0	0	0	0	0	0	60.125	60.125
Coal	0	12.826	0	0	0	0	0	1.256	64.749	68.069
Fuel/gas	0	382	0	0	178	204	0	655	4.869	13.396
Combined Cycle	0	0	4.651	0	0	8.914	3.053	8.810	42.728	46.234
Ordinary Regime	17.155	19.802	4.720	39	178	9.163	3.151	10.953	197.428	212.781
Internal consumption	-592	-794	-99	0	-10	-193	-69	-238	-8.399	-9.262
Renewables	30	7.497	958	440	2	131	2.827	826	26.866	27.294
Hydro	29	967	55	44	0	20	282	104	3.565	3.565
Wind power	0	5.970	897	0	0	93	2.248	339	19.950	20.243
Other Renwables	1	560	6	396	2	17	297	384	3.348	3.483
Biomass	0	242	3	58	0	12	269	55	1.831	1.831
Industrial Residues	0	317	0	0	2	0	0	17	801	803
Urban Residues	0	0	2	330	0	0	0	309	657	790
Solar	1	1	1	8	0	6	28	3	59	59
Non renewables	36	1.409	86	890	0	706	343	856	17.681	17.898
Residual Heat	0	0	0	0	0	0	0	90	171	171
Coal	0	0	0	0	0	0	0	0	748	748
Fuel-gasoil	0	757	3	34	0	64	1	28	1.951	2.168
Refinery Gas	0	0	0	0	0	0	0	8	286	286
Natural Gas	36	651	83	856	2	642	341	730	14.523	14.525
Total Special Regime	66	8.905	1.044	1.330	6	836	3.170	1.682	44.543	45.192
Net Generation	16.628	27.914	5.666	1.369	170	9.807	6.251	12.398	233.579	248.714
Pumping consumption	-53	-286	0	0	0	0	0	0	-5.259	-5.259
Exchanges	-12.144	-8.429	-3.905	29.229	0	-1.666	-920	8.298	-8.993	-8.993
Bus bars demand	4.431	19.199	1.761	30.598	170	8.141	5.332	20.696	219.326	234.461
POWER FACTOR tCO_2/MWh	**0,001**	**0,478**	**0,300**	**0,241**	**0,725**	**0,368**	**0,195**	**0,411**	**0,377**	**0,396**

The power system structure of the islands or isolated regions favours the fuel-fired plants role and entails a consequent higher power factor for each particular case.

ANNEX 3

DATA OVERVIEW FOR APPLICATION OF THE POWER ALLOCATION METHOD IN MILL A AND MILL B

Chapter 7 describes the difficulties to apply a theoretical method into a mill operation reality. This annex presents some of the information and structured data that has been used along this work in order to obtain allocation method final results.

In this context, multiple worksheets concerning electrical parameters and MCC metering consumptions have been puzzled together to achieve the conceptual paper manufacturing distribution.

As the mentioned working worksheets would not provide further information, Figure A.2.1 and Figure A.2.2 illustrate the main distribution worksheets of each mill and indicate with a worksheet icon the multiple relations corresponding to each variable.

In the case of electricity distribution, a nominal installed power or operational power has been assigned to a particular device. Each device corresponds to a particular unit operation and is switched to a MCC which at the same time has allocated a periodic energy consumption. The relation between the mentioned parameters enables an assignment of an energy consumption value to each device. It should be highlighted that nominal installed power has been used as default value for calculations. However, when reviewing data with electricity technician of each mill case-study, some additional punctual measures have been taken with the ammeter in order to contrast the first results. When obtaining a relevant discrepancy, the punctual current measures have been used for calculations. In other calculations, the working hours registration of some devices and the working nominal power, have been used for assignment approaches. In this last case, it has been taking into account the power consumption stability of the corresponding device.

RELATED MCC	UNIT OPERATION/SECTION/DEVICE	Total installed power kW	MCC Share	Estimated annual consumption kWh
MCC1	Sizing and sheeting drives U1	24,43	2%	81.599
	Packing drives	318	25%	1.062.494
	Winding drives U4	474,85	37%	1.586.058
	Sizing and sheeting drives U3	354,76	28%	1.184.942
	Sizing and sheeting drives U4	0	0%	0
	Packing machine	77,37	6%	258.425
	Embossing	27,6	2%	92.187
	TOTAL CCM1	1277,11	100%	4.265.706
MCC2	Predrying drivers (PM)	3	1%	66.011
	Predrying drivers (PM)	2,98	1%	65.571
	Predrying drivers (PM)	9,17	3%	201.773
	Postdrying (PM)	3,3	1%	72.612
	Pre coating kitchen (PM)	54	20%	1.198.094
	Precoating drivers (PM)	11	4%	242.039
	Wet section drivers (PM)	30	11%	660.107
MCC2 (BIS)	Post drying (PM)	107,44	39%	2.364.062
	Reeling (PM)	22	8%	484.078
	Precoating dirvers (speed sizer)	11,5	4%	253.041
	Reeling (PM)	20,045	7%	441.061
	Total CC	274,885	100%	6.048.448
MCC3	Pulpers	314,4	12%	1.000.038
	Refiners	616	23%	1.959.362
	Deflakers	350	13%	1.113.274
	Stock aux. others	1160,15	44%	3.690.184
	Blending	225,14	8%	716.121
	Total CCM3	2665,69	100%	8.478.979
MCC4	Stock others	17,33	1%	75.723
	Wet section	1127,29	50%	4.925.644
	Blending	1.095	49%	4.786.215
	Total CCM4	2.240	100%	9.787.582
MCC5	CM drivers	944,04	63%	2.768.832
	CM kitchen	346	23%	1.015.684
	Reeling CM	69,18	5%	202.902
	Reeling CM	142,6	9%	418.240
	Total CCM5	1502,12	100%	4.405.658
MCC6	Calenders U3	448,91	18%	938.764
	Calenders U5	717,67	29%	1.500.797
	Sizing and sheeting U5	467,52	19%	977.681
	Auxiliaries	16,53	1%	34.568
MCC6 (BIS)	Pulpers	392	16%	819.753
	CM drivers	206,16	8%	431.123
	Waste Water Treatment	203	8%	424.515
	Total CCM6	2451,79	100%	5.127.201
MCC7	Gas Boiler Unit	0	0%	0
	Gas Boiler Unit	386,59	49%	1.414.680
	Waste Water Treatment	204,52	26%	748.416
	Air compressed system	193,5	25%	708.090
	Total CCM7	784,61	100%	2.871.186
MCC8	CM kitchen	809,992	100%	1.286.368
MCC9	Wet section drives	862,2	23%	1.674.596
	Press section drives	854,2	23%	1.659.058
	Drying drives	831	22%	1.613.998
	Blending	710	19%	1.378.987
	Precoating drives	154	4%	299.104
	Reeling PM	356	9%	691.436
	Total CCM9	3767,4	100%	7.317.179
MCC10	Refiner U3	650	27%	2.010.763
	Refiner U4	650	27%	2.010.763
	Refiner U5	650	27%	2.010.763
	Pulper U2	460	19%	1.423.002
	Total CCM10	2410	100%	7.455.291
MCC11	Vacuum pumps	1708,5	100%	9.722.623

POWER STATION	2006 kWh annual
MCC1	4.265.706
MCC2 MCC2-BIS	6.048.448
MCC3	8.478.979
MCC4	9.787.582
MCC5	4.405.658
MCC6 MCC6 BIS	5.127.201
MCC7	2.871.186
MCC8	1.286.368
MCC9	7.317.179
TE10	7.455.291
MCC11	9.722.623
Total	66.766.221

Figure A.2.1 Calculation-base for power allocation method. Mill A.

		UNIT OPERATION/SECTION/DEVICE	Total installed power kW/ working hours	MCC Share	Estimated annual consumption kWh
	Kitchen - Coating machine	20,4	0,67*L4	3%	43.860
	Stock preparation UL	37,0	0,67*L4	6%	79.434
U1	Kitchen - CL machine	31,0	0,67*L4	5%	66.553
	Venting - CL	14,6	0,67*L4	2%	31.344
	Stock preparation CL	538,0	0,67*L4	84%	1.155.015
	Total	641,0	0,67*L4	100%	1.376.206
	Stock preparation CL	391,6	L3+0,33L4	33%	1.784.592
	17.828.634	160,0	L3+0,33L5	13%	729.224
	Deflaker 2	150,0	L3+0,33L6	13%	683.647
	616.984	48,7	L3+0,33L7	4%	221.957
	Pulper 2, 3, 5	445,8	L3+0,33L8	37%	2.031.571
	Total	1196,0	L3+0,33L9	100%	5.450.992
	Wet section CL machine	1260,1	L11+A3	30%	2.648.013
	Drying section CL machine	289,2	L11+A3	7%	607.744
	Speed sizer CL	211,0	L11+A3	5%	443.409
	reeling winding CL	159,4	L11+A3	4%	334.973
U3	Screening pumps CL	1217,0	L11+A3	29%	2.557.482
	Pulper 1, 4	302,0	L11+A3	7%	634.642
	Press section CL	656,0	L11+A3	16%	1.378.561
	Other auxiliaries CL	61,1	L11+A3	4%	128.420
	Total	4155,8	L11+A3	100%	8.733.245
U4	Rewinder 3				out of order
	Rewinder off-line coating machine	48,0	A25	89%	1.114.318
U10	Auxiliars off-line coating	6,1	A25	11%	141.611
	Total	54,1	A25	100%	1.255.929
	Auxiliars off-line coating	747,3	A11	89%	4.413.065
U11	Pulper 6 broke	93,5	A11	11%	552.135
	Total	840,8	A11	100%	4.965.200
U13	Compressed Air system	905,7	A2	100%	2.517.646
	Stock preparation CL	125,4	A8	12%	361.592
	Stock preparation UL	52,0	A8	5%	149.978
	Pulper 7	463,5	A8	46%	1.336.740
U14	Screening system UL	294,7	A8	29%	849.974
	Screening system UL	75,0	A8	7%	216.315
	Total	1010,5	A8	100%	2.914.600
	Refiner 2	315,0	A20	18%	1.505.772
	Refiner 3	161,4	A20	9%	771.577
	Wet section drives UL	296,7	A20	17%	1.418.294
	Size press UL	15,8	A20	1%	75.528
	Pulper UL	147,0	A20	8%	702.694
	Vaccum System UL	22,0	A20	1%	105.165
14	Stock preparation UL Aux.,	120,5	A20	7%	576.018
	Refiner 1	161,4	A20	9%	771.529
	Press section drives UL	16,6	A20	1%	79.113
	Head box system UL	471,4	A20	27%	2.253.161
	Press section drives UL	48,0	A20	3%	229.451
	Rewinder 5	40,0	6000		240.000
	Total	1775,7	A20	100%	8.728.300
U18	Water treatment system and pump	554,8	A26	100%	1.024.890
U24	Water treatment pumps	280,5			
	Winder 1	135,0		56%	1.511.100
U27	Power IR	105,0		44%	1.175.300
	Total	240,0		100%	2.686.400
	Screening pumps CL	366,0	A19	22%	1.853.090
	Vaccum System CL	807,1	A19	48%	4.086.519
U28	Kitchen coating machine, aux	171,9	A19	10%	870.547
	Pulper 8	341,5	A19	20%	1.729.044
	Total	1686,6	A19	100%	8.539.200
	Pulper 9	30,0		5000	150.000
U32	Vacuum pumps UL	310,0	A12	90%	2.776.194
	Rewinder	34,9	A12	10%	312.546
	Total	344,9	A12	100%	3.238.740
	Finishing sections U15+U 31		A13		4.914.200
	Winder 6	135,0		6000	810.000
A13	Sizing machine drives	225,0		6000	1.350.000
U15	Reker oven	100,0		7000	700.000
	Packaging machine	40,0		6000	240.000
	Other finishing aux.				1.814.200
A1	Lighting system		A1	100%	1.365.093
A6	IR coating machine		A6	100%	6.509.100
A7	Vacuum pumps Nash		A7	100%	2.051.483
A9	Pulper 7		A9	100%	1.949.200
L2	Refiner 4		L2	100%	2.503.389
L6	Refiner 1		L6	100%	2.693.389
L7	Refiner 3*		L7	100%	616.984
L10	Refiner 2		L10	100%	8.853.754

Figure A.2.2 Calculation-base for power allocation method. Mill B.