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Allowance Allocation and CO_2 intensity of the EU15 and Norwegian refineries

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Sammanfattning/Summary
On 1 January 2005 the European Union Emission Trading Scheme was launched. The launch was preceded by an allocation process in each of the Member States. The main objective of this study was to analyse the allocation in relation to CO_2 efficiency for the mineral oil refining sector.

A CO_2 intensity index for mineral oil refineries was defined and calculated for the refineries within the EU15 and Norway. The IVL CO_2 intensity index is based both on the Solomon Energy Intensity Index (EII), an assumed fuel mix and process-specific emissions. Due to uncertainties in input data, the determined values for the individual refineries are fairly uncertain, but the regional values can be used to identify trends.

It was concluded that there are substantial differences in the CO_2 intensity between refineries within different regions/countries in the EU and these differences have not been considered in the allocation process. However, there seems to be a correlation between allocation and CO_2 efficiency for refineries in different regions. With some exceptions countries where the mineral oil refining industry has a low CO_2 intensity index have allocated relatively more than countries with industries of high CO_2 intensities.

Only a few countries have mentioned energy efficiency or reduction potential due to CO_2 intensity of fuels used. Only one country (Denmark) has explicitly given a benchmark that will be used for allocation to new mineral oil refineries.

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Abstract

On 1 January 2005, the European Union Emission Trading Scheme (EU ETS) was launched. The launch has been preceded by an allocation process in each of the Member States. The main objective of this study was to analyse the allocation in relation to CO_2 efficiency for the mineral oil refining sector.

A CO_2 intensity index for mineral oil refineries has been defined and calculated for the refineries within the EU15 and Norway. The IVL CO_2 intensity index is based both on the Solomon Energy Intensity Index (EII), an assumed fuel mix, and process-specific emissions. Due to uncertainties in input data, the determined values for the individual refineries are quite uncertain. However, the regional values can be used to identify trends.

It was concluded that there are substantial differences in the CO_2 intensity between refineries within different regions/countries in the EU and these differences have not been considered in the allocation process. Only a few countries have mentioned energy efficiency or reduction potential due to CO_2 intensity of fuels used. Only one country (Denmark) has explicitly given a benchmark that will be used for allocation to new mineral oil refineries.

The allocation has generally been based on historic emissions, which will result in refineries with historically higher emissions being allocated larger amounts than refineries with historically lower emissions. This might be favourable for refineries that recently have performed emission-reducing measures but might be less favourable for refineries that during a long time period have implemented emission-reducing measures.

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1 Introduction

On 1 January 2005, the European Union launched an emission-trading scheme covering carbon dioxide emissions from the energy and some of the industry sectors (Directive 2003/87EC). Prior to the start of the trading scheme, every Member State was obliged to submit a national allocation plan describing how the initial amount of allowances would be allocated among the covered installations. The Commission, which was the authority to approve or reject the allocation plans, had given a list of criteria to be followed and guidelines to support the design of the national allocation plans. In the approval process, no harmonising between countries or sectors has been done other than making sure the principles do not violate any of the criteria listed in Annex III to the Directive 2003/87/EC (Zetterberg et al, 2004).

The European Union Emission Trading Scheme (EU ETS) approves of agreements with non-EU countries in order to provide for mutual recognition of emission allowances between the Community scheme and other emission allowance trading schemes. Norway has showed interest in such an agreement and since Norwegian refineries are competitors to not only the Swedish refineries but to most refineries within the EU, the Norwegian refineries were also included in this study.

2 Objective

The objective of this study was to:

- Quantify CO_2 emissions, production and "climate efficiency" for a selection of EU refineries. This included developing a new measure of the "climate efficiency" for fuel refineries.

- Assess the allocation methodologies and actual allocation for a selection of the EU refineries.

- Analyse the allocation in relation to the climate efficiency. Do refineries with low specific emissions benefit from the allocation methodology used or are the conditions reversed? How is the allocation correlated to emissions? How is the allocation correlated to the production? To determine how the allocations are related to the potential of reducing emissions and if the presence of energy-efficient technologies is considered when making the allocation.

The objective of this study was not to point out the exact differences between installations. However, the analysis points out differences in allocations to the oil refining sectors in different Member States. The aim was mainly to identify general trends in order to discover disadvantages for certain installations / types of installations or the whole sector in a country and thereby prevent those disadvantages from being overlooked in the national allocation plans, which would create biases in the competitive situation.

This report will mainly focus on the quantification of CO_2 emissions and CO_2 efficiency but will, to a certain extent also, analyse the results of the allocation process for the mineral oil refineries. A more complete assessment of the allocation methodologies has already been done in Zetterberg et al (2004).

3 CO_2 intensity for mineral oil refineries

The main objectives of this study were first, to define a measure of climate efficiency for mineral oil refineries in order to see if this has been considered in the allocation process and then, to assess if highly climate-efficient refineries have been treated more favourably than less CO_2-efficient refineries. Since only carbon dioxide is included in the EU ETS during the first period (2005-2007), it was decided that 'climate efficiency' would only reflect the CO_2 efficiency and not efficiency with respect to other greenhouse gases such as CH_4 or N_2O. For practical reasons, an intensity index instead of an efficiency index was determined. A description of the developed CO_2 intensity index for mineral oil refineries is given below.

3.1 Sources of CO_2 emissions at mineral oil refineries

The CO_2 emissions from a mineral oil refinery are affected by many sources:

- The complexity of the refinery (number of different processes)
- Process-related fuels that have to be burned
- Quality of product slate delivered (e.g., low sulphur fuels)
- Quality of crudes and other raw materials used in the refining process

Shires and Loughran (2004) have, on the behalf of the American Petroleum Institute, put together a compendium on methodologies on how to estimate greenhouse gas emissions from the oil and gas industry. According to this compendium, the CO_2 emissions from mineral oil refineries can be divided into the following source categories:

Combustion sources – Stationary Devices
– Boilers, process heaters, turbines, engines, flares, catalytic and thermal oxidisers, coke calcining kilns, incinerators.
Point sources – Process vents
– catalytic cracking, catalytic reforming, catalyst regeneration, thermal cracking, coking, hydrogen production, sulphur recovery units, asphalt production.

Point sources - other venting
– Storage tanks, pneumatic devices, loading racks
Non-point sources – fugitive emissions
– Fuel gas system leaks, other process equipment leaks
Non-point sources – other non-point sources
– Waste water collection and treating, sludge/solids handling, cooling towers.
Non-routine activities – other releases
– Pressure relief valves (PRV), emergency shut downs (ESD).
Indirects
– Electricity usage/production, steam generation/import

In this study the sources of CO_2 emissions from refineries were divided into five categories:

- combustion sources
- point sources - process vents
- point sources - other vents
- non-point sources and
- indirects

According to the Guidelines for monitoring and reporting of greenhouse gas emissions from installations included in the EU ETS (2004/156/EC), the monitoring of greenhouse gas emissions from a mineral oil refinery shall include all emissions from combustion and production processes as occurring in refineries. In the guidelines, a list of potential sources of CO_2 emissions is given. The sources are divided into two categories:

1. Energy-related combustion:
   - Boilers, Process heaters / treaters, Internal combustion engines / turbines, Catalytic and thermal oxidisers, Coke calcining kilns, Emergency/ standby generators, Flares, Incinerators and Crackers.

2. Processes:
   - Hydrogen production installations, Catalytic regeneration (from catalytic cracking and other catalytic processes) and Cokers (flexi-coking, delayed coking).

Below is a closer description of the categories used in this study.

3.1.1 Combustion sources – stationary devices

The main source of CO_2 emissions in refineries is the combustion of fuels for production of steam, heat and electricity. Most of the processes in a refinery require heating and, therefore, combustion of fuels is necessary. The operation of the refinery also requires some use of electricity and many processes are dependent on steam access.

Shires and Loughran (2004) also mention flaring as a part of this source category. Flaring is a process where surplus gas is burned. This combustion is not input to any other process but is only performed in order to eliminate surplus gas. Emissions resulting from combustion in transport devices (i.e., vehicles, ships, etc.) should also be included in this category (Shires & Loughran, 2004). Comparing the definition made by Shires and Loughran (2004) and the European Commission in 2004/156/EC, one can conclude that the combustion source categories are quite similar. The Commission does not, however, include emissions resulting from combustion in transport devices such as vehicles and ships. The Commission includes emergency generators, which Shires and Loughran (2004) included in non-point sources.

3.1.2 Point sources – process vents

According to Shires and Loughran (2004), there are a few different processes that give rise to CO_2 emissions other than the combustion of fossil fuels as an energy source for the process. These processes are:

- Hydrogen production
- Regeneration of catalytic cracker catalyst and regeneration of other catalysts
- Cokers
- Other process vents

The potential sources of process-related CO_2 emissions at mineral oil refineries listed by the European Commission (2004/156/EC) are the same (see the beginning of this chapter).

Hydrogen production
The hydrogen plant produces a significant quantity of CO_2, which may be further processed for other uses or may be vented to the atmosphere. The quantity of CO_2 vented depends on the carbon to hydrogen rate of the feed gas. Most refineries use a process (steam reforming) where H_2 is produced from CH_4, but there are some plants that operate with other feedstock gases (European Commission, 2003). The chemical reaction can be expressed by Equation 3.1

Equation 3.1. Chemical reaction in hydrogen production plant.

$$C_xH_{(2x+2)} + 2xH_2O \rightarrow (3x+1)H_2 + xCO_2$$

According to Shires and Loughran (2004), there is a simple approach to estimate the CO_2 vent rate based on the average feed gas composition. This approach should be adequate for most refineries where the feed gas is similar to natural gas (i.e., predominantly CH_4 with small percentages of other low molecular weight hydrocarbons). The approach is based on an emission factor of 13.41[1] tonnes CO_2 per million scf [2]of H_2 produced. Some refineries use refinery gas, LPG or light naphtha as feed gas to the hydrogen production unit. This will result in higher specific CO_2 emissions (emissions per produced ton of hydrogen) than when using natural gas (due to a higher C to H ratio). Note that the CO_2 vent stream described by the reaction above does not include CO_2 emissions from process heaters associated with the H_2 plant (Shires & Loughran, 2004). Those emissions should be treated like other combustion sources.

There are some refineries that use another process for producing H_2, namely the partial oxidation process. In the case of such a process, site-specific data or an engineering approach should be used in order to estimate the CO_2 emissions. However, if no such data is available, Shires and Loughran (2004) suggest that a conservative approach assuming full conversion and using the simple approach emission factor be used.

According to the guidelines given by the European Commission (2004/156/EC), the CO_2 emissions resulting from hydrogen production should be based on the following equation:

CO_2-emissions = activity $data_{input}$ * emission factor , where
activity $data_{input}$ = amount of hydrocarbon feed [t feed]
emission factor = either reference value of 2.9 t CO_2/t feed processed[3] or value calculated from the carbon content of the feed gas [t CO_2/t feed].

Catalytic cracker
Catalytic cracking is the most widely used conversion process for upgrading heavier hydrocarbons into more valuable lower boiling hydrocarbons. Normally, the main feed stream to the process is the vacuum distillate stream from the vacuum distillation unit. This process uses heat and a catalyst to break the larger molecules into smaller ones (European Commission, 2003).
In the catalytic cracking process, coke is deposited on the catalyst as a by-product of the reaction. That coke is burned in order to restore the activity of the catalyst. The coke is continuously burned off in the regenerator. This process is a significant source of CO_2-emissions. According to Shires and Loughran (2004), there are two common approaches that can be used to estimate the CO_2 emissions from catalytic cracker catalyst regeneration:

[1] This emission factor has been determined based on a feed gas with the following composition: CH_4 = 93.07 % (vol.), C_2H_6 = 3.21% (vol.), C_3H_8 = 0.59 % (vol.), higher hydrocarbons = 0.32% (vol.) and Non-hydrocarbons = 2.81% (vol.) (Shires & Loughran, 2004).

[2] Scf = standard cubic feet.

[3] Conservatively based on ethane.

- process calculations based on coke burned
- process calculations based on air rates and CO/CO_2 concentrations

Equation 3.2 describes how the emissions from the regeneration of the catalyst are determined by using the first approach.

Equation 3.2 . CO_2 emissions from regeneration of catalytic cracker catalyst.

$$E_{CO_2} = CC \cdot CF \cdot \frac{44}{12}$$

Where: E_{CO_2} = emission of CO_2/year

CC = coke burn rate in tonnes/year
CF = fraction of carbon in the coke burned per weight
44/12 = conversion factor from CO_2- C to CO_2

The approach suggested by the European Commission (2004/156/EC) is also described by Equation 3.2, where the carbon fraction in the coke burned is determined in accordance with the provisions of section 10 in Annex 1 of the Commission Decision (2004/156/EC) [4]. The Commission suggests that the same method should also be used also for determination of CO_2 emissions from other catalyst regeneration.

Other catalyst regeneration
There are also other process units at a refinery with catalysts that have to be regenerated. Examples of such processes are catalytic reformers and hydro-processing units. Hydro-processing units are used for desulphurisation and conversion of any fractions into products with a lower molecular weight than the feed. Normally hydrogen, heat and catalysts are used in the hydro-processing units. In catalytic reformers, the heavy naphtha leaving the hydrotreating unit is upgraded for use as a gasoline blend stock. The octane number is significantly improved in the catalytic reforming process. Both hydro-processing and catalytic reforming units do have catalysts that have to be regenerated in order to maintain the function of the catalyst. There are two main types of catalyst regeneration:

- continuous regeneration
- intermittent regeneration: cyclic or semi-regenerative

The emissions from these types of catalyst regeneration can be determined by using Equation 3.2.

[4] The specific procedure to determine process specific emission factors should follow CEN, ISO or national standards. If no such standards are available, procedures can be carried out in accordance with draft standards or industry best practice guidelines. (For further information, see Commission Decision of 29 Jan. 2004).

Cokers
Coking is a severe thermal cracking process used mainly to reduce refinery production of low-value residual fuel oils and transform them into transportation fuels, such as gasoline and diesel. As part of the process, coking also produces petroleum coke, which is essentially solid carbon with varying amounts of impurities.
There are three main types of cokers:

- Delayed cokers
- Fluid cokers
- Flexi-cokers

Only fluid cokers and flexi-cokers have CO_2 emissions resulting from the coke burner. Delayed cokers do not have CO_2 emissions, other than from their process heaters that are calculated as any other combustion source (Shires & Loughran, 2004). Fluid cokers and flexi-cokers have a vent resulting from the coke burner. In this study, the CO_2 emissions from the coke burner were estimated by assuming that all of the carbon in the coke is oxidised to CO_2. Equation 3.2 for catalytic cracking units can also be used for fluid cokers or flexi-cokers.
According to the Commission (2004/156/EC), the CO_2 emissions from cokers should be calculated by **Equation 3.2** where the carbon fraction [t C/t coke] is based on industry best practice guidelines.

Other process vents
There are also other processes at a refinery that could be considered as potential sources of CO_2 emissions, such as:

- Asphalt blowing
- Thermal cracking
- Sulphur recovery units

In Shires and Loughran (2004), these sources are considered to be negligible in comparison to other sources. There are no specific guidelines on how to calculate these process vents given by the European Commission (2004/156/EC).

3.1.3 Point sources - other vents

These emissions constitute vents from sources such as storage tanks and pneumatic devices. According to Shires and Loughran (2004), the emissions from this source are mainly CH_4, whereas the CO_2 emissions are small. There are no specific guidelines on how to calculate these process vents given by the European Commission 2004/156/EC.

3.1.4 Non-point sources

According to Shires and Loughran (2004), non-point sources are negligible in comparison to the other sources. Non-routine activities are also, in most cases, negligible (mostly because they do not occur; if they do occur, they could be of significance). In the guidelines given by the European Commission (2004/156/EC), the non-routine activities are included in the combustion sources.

3.1.5 Indirects

Indirect sources include the balance of imported electricity, heat and steam. The main objective of this study was to compare the allocation and allocation methodology for refineries in different EU Member States. The requirement of CO_2 emission allowances is related to the actual emissions at the refinery. No allowances will be required for emissions that have occurred or will occur at other places than at the refinery. This means that the refinery is not required to hold emission allowances for CO_2 emissions related to electricity, steam or heat generated at an external unit but consumed at the refinery. On the other hand, the refinery is required to hold emission allowances for any CO_2 emissions generated during the production of heat, steam and electricity at the site, even if some of the surplus is exported from the refinery for use elsewhere.

3.2 General theory of CO_2 intensity

As described in the previous section, there are different sources of CO_2 emissions from a refinery. However, the major part of the emissions is connected to the combustion of fossil fuels, in other words the energy demand. The CO_2 intensity is therefore closely related to the energy intensity.

3.2.1 The Solomon energy intensity index

There is today a concept for comparing the energy intensity[5] of mineral oil refineries – the Solomon Energy Intensity Index (EII). Solomon Associates determine the energy intensity index for refineries by the following equation:

Equation 3.3 The Solomon Energy Intensity Index

$$EII = \frac{actual\ energy\ consumption}{reference\ energy\ consumption} \cdot 100$$

The actual energy consumption is determined by adding purchased energy (such as electricity and steam) to used fuels and subtracting sold energy (such as electricity, heat

[5] Intensity = 1/efficiency.

or steam). The value of primary energy is used, i.e. purchased electricity is converted to primary energy by assuming 9.59 MJ/kWh. The reference energy consumption is determined by the following equation:

Equation 3.4 Reference energy requirements according to Solomon

$$E_{reference} = \sum_{i=1}^{m} (Q_i \cdot e_i)$$

where Q_i = actual load /production in process *i*,
e_i = the Solomon process unit energy standard (either just a constant or an equation with process-related variables) for process *i*,
m = the total number of different processes at the refinery

The Solomon process unit energy standards are individual expressions for each of the processes in the refinery and state the average standard energy consumption for the process in comparison to process load or output (depending on the process). Solomon Associates have determined the values of the process unit energy standards by practical evaluation of 300 refineries worldwide. The currently used process unit energy standards are based on average industry efficiency for each process unit types in the mid-1980's (personal comm. Trout, 2004). At that time, the industry average EII was close to 100, whereas the index today average 90 or less. The reason for the decrease in the index over the years is that the refineries have improved their energy efficiency. Note, however, that the EII is not designed to determine CO_2 performance.

3.2.2 The IVL CO_2 intensity index for fuel refineries - theory

IVL has defined a CO_2 intensity index for fuel refineries, which will be determined in a way similar to the Solomon energy intensity index. The CO_2 intensity will be a relative measure of the CO_2 performance of a refinery in comparison to a sector expected value. The actual emissions of a production unit, a refinery, will be compared to a sector expected value. Generally, the CO_2 intensity can be described by Equation 3.5.

Equation 3.5. The CO_2 intensity

$$CO_{2,intensity} = \frac{CO_{2,A}}{CO_{2,R}} \cdot 100$$

Where $CO_{2,A}$ is the actual emissions from a specific refinery and $CO_{2,R}$ is the reference CO_2 emissions from a reference refinery of the same size and complexity. Note that the index is just a relative measure and whether or not the value will be above or below 100 depends on if the reference emissions are determined according to best technology, the average value (such as for the Solomon EII) or something in-between. If the reference emissions were determined according to the use of best technology, all refineries would have a value equal to or above 100. On the other hand, if the reference emissions were determined according to average emissions, half of the refineries would have a CO_2 intensity index below 100. In the IVL CO_2 intensity index, the reference emissions have been determined at a level above the best available technology but below the average value.

3.2.2.1 CO_2 emissions considered in the IVL CO_2 intensity index

As described in section 3.1, there are many sources of CO_2 emissions at a refinery. For the purpose of describing the CO_2 intensity, the CO_2 emissions from each process were divided into two sub-groups (the same sub-groups as used in the Commission Decision 2004/156/EC):

- energy (or fuel) related emissions
- process-related emissions (raw-material dependent)

In this study, the energy-related emissions were defined as the emissions due to combustion of fossil fuels (and the use of electricity). This includes all types of fuels, both replaceable and non-replaceable (such as coke in a catalytic cracker). The process-related emissions are emissions not related to combustion of fossil fuel with the purpose to produce energy. One such example is the emissions from a hydrogen production plant where there are chemical reactions not related to the oxidation of a fossil fuel, that occur in the process and give rise to CO_2 emissions.

3.2.2.2 Energy-related CO_2 emissions

The energy-related reference emissions are described by Equation 3.6 below.

Equation 3.6. The reference energy-related CO_2 emissions for a specific process i, in refinery B.

$$CO_{2,RE,i} = production_{B,i} \cdot \frac{energy\,consumption_{S,i}}{production_{S,i}} \cdot \frac{CO_{2,S,i}}{energy\,consumption_{S,i}}$$

The denotation *R* indicates that it is the reference emissions, the *E* indicates that it is energy-related emissions, *B* indicates a specific refinery, *S* indicates the sector reference[6] value set for the mineral oil refining sector and *i* denotes that it is a process-specific value. The production is the actual production at the refinery. The sector average energy requirements for a specific process is described by the second factor:

$$\frac{energy\,consumption_{S,i}}{production_{S,i}} = Solomon\;\; process\,unit\,energy\,standard\;\; for\;\; process\;\; i\;\left[\frac{KBtu}{bbl\;feed}\right]$$

[6] In this study we have used the emissions factor of refinery gas as a reference value for the use of fuels (except for non-replaceable fuels).

where the Solomon process unit energy standards have been determined by Solomon Associates through the evaluation of over 300 refineries worldwide. The third factor on the right hand side of Equation 3.6, $\frac{CO_{2;S,i}}{energy\,consumption_{S,i}}$, describes the emissions related to fuel use for the specific process. Equation 3.7 describes how the fuel-related CO_2 emission from a specific process is determined by using emission factors (g CO_2/MJ). These emission factors are determined by assuming a fuel mix for each process.

Equation 3.7. The reference CO_2 emissions for a specific process.

$$\frac{CO_{2,S,i}}{energy_{S,i}} = \sum_j n_j \cdot emission\,factor_j \left[\frac{t\,CO_2}{KBtu}\right]$$

Where $n = \frac{\text{energy supply from fuel}_{S,i,j}}{\text{energy supply total}_{S,i}}$

Hence, the use of fuels (*j*) in each process (*i*) is determined in order to estimate the expected energy-related CO_2 emissions from each process.

3.2.2.3 Process-related CO_2 emissions

The only identified process vent was the hydrogen plant. Often, the catalytic cracker and other processes where coke is formed and has to be burnt off are mentioned as process-specific emissions. Since the coke formed on catalysts and burnt in the process contributes to the energy supply of the process, these emissions were treated in this study as non-replaceable fuels under energy-related emissions.

Equation 3.8. The reference process-specific CO_2 emissions of process i**.**

$$CO_{2,RP,i} = production_{B,i} \cdot \frac{CO_{2,SP,i}}{production_{SP,i}}$$

where *R* indicates that it is the reference emissions and *P* that the emissions are process related. The other denotations have occurred in earlier equations. The second factor on the right hand side of Equation 3.8 is the sector average process related CO_2 emission factor for the process *i*:

$$\frac{CO_{2,SP,i}}{production_{SP,i}} \left[\frac{t\,CO_2}{t\,product}\right].$$

3.2.2.4 The total refinery CO_2 intensity

The reference emissions for each process of the refinery were described by summarising the energy-related emissions and the process-specific emissions of that specific process.

Equation 3.9. The total reference CO_2 emissions for a process i.

$$CO_{2,R,i} = CO_{2,RE,i} + CO_{2,RP,i}$$

The *R* stands for the reference emissions and *E* indicates that it is the energy-related emissions (due to combustion of fossil fuels) that are considered. *P* indicates process-specific emissions. The actual CO_2 emissions of a process are the sum of the actual energy-related emissions and the actual process-related emissions.

Equation 3.10. The total actual CO_2 emissions for a process *i*.

$$CO_{2,A,i} = CO_{2,AE,i} + CO_{2,AP,i}$$

The refinery CO_2 intensity was determined by the following equation

Equation 3.11. The CO_2 intensity of a refinery with *i* process units.

$$CO_{2,intensity} = \frac{\sum_{i}^{m} CO_{2,AE,i} + CO_{2,AP,i}}{\sum_{i}^{m} CO_{2,RE,i} + CO_{2,RP,i}}$$

The same denotation as in Equation 3.6 is used and the m stands for the total number of processes at the refinery.

3.2.2.5 Assumptions of the IVL CO_2 intensity index for fuel refineries

The IVL CO_2 intensity index for mineral oil refineries was based on the assumptions described in the following sections.

General assumption

It was assumed that energy demands for Utilities, Losses and Off-sites (one of the Solomon process unit energy standards) could be left out when calculating the reference CO_2 emissions. This includes energy consumed in utility distribution systems and operation of product blending, tank farms and environmental facilities. Some of the energy is demand of electricity for machines (e.g., motor driven pumps, compressors), some of it is heat loss during transportation (which again most probably could be minimised to negligible levels by designing the refinery in an efficient way and using heat exchangers), and some of it might be from other sources such as vents from storage or waste water plants. A reasonable assumption is that leaving these energy consumption sources out will result in an equal offset for all refineries. However, in the Solomon process unit energy standard for Utilities Losses and Offsites, the composite refinery configuration is one of the variables. This means that the complexity of the refinery influences the amount of energy needed for these sources. The offset would therefore not be equal for all refineries, but for refineries with similar composite refinery configuration. Since this is the only factor that considers electricity production, special consideration has been given to refineries that sell electricity to external units. This will reduce the differences between refineries of different complexity.

Combustion sources – stationary devices
Since flaring is a costly waste of energy, this process is limited as much as possible in all refineries. Therefore, no consideration to flaring was taken when calculating the reference emissions. The emissions, however, were still included in the actual total emissions.

Emissions from transport devices were considered negligible in comparison to other sources and were therefore not included when determining the reference CO_2 emissions. It should also be noted that CO_2 emissions from transport devices are not included in the EU emission trading system.

Point sources – process vents
The reference emissions from **hydrogen production** plants were determined by using the simple approach emission factor described in section 3.1.2. The simple approach emission factor was used both for steam reforming processes and partial oxidation processes. The reason for not using the suggested method in the Commission Decision 2004/156/EC as described in section 3.1.2 was the availability of data. Output data (i.e., amount of produced hydrogen) was more easily accessible than amount of hydrocarbon fed to the process.

The reference emissions resulting from the regeneration of the **catalytic cracker catalyst** and other catalysts were determined by using Equation 3.2, which is a method both suggested by the European Commission (2004/156/EC) and Shires and Loughran (2004). The reason for using this approach was also the availability of data; this approach is the least data intensive. The only process where catalyst regeneration was considered was the fluid catalytic cracker unit. All other catalyst regeneration was considered to be negligible in comparison. An example is given in the box below. It should be noted that the example given in Shires and Loughran (2004) for continuous regeneration uses a very high value of catalyst re-circulation (personal comm. Brinck 2004, Magill, 2004). CO_2 emissions from intermittent regeneration were considered to be negligible in this study (and in Shires and Loughran, 2004) in comparison to other sources and were therefore left out when determining the reference CO_2 emissions. The emissions are, however, included in the total actual emissions.

Example: A FCC (Fluid Catalytic Cracker) unit is of the capacity 25,000 bbl/cd [barrels per calendar day]

Data from Solomon study:
UUOT (unit utilisation outside turnarounds) = 0.88
Fresh feed density = 910.6 kg/m^3
Coke on catalyst (yield vol. % of fresh feed) = 4.8%
Conversion factor 1 bbl = 0.159 m^3

Coke burn rate per year:

$$25{,}000 \cdot 0.88 \cdot 0.048 \cdot 910.6 \cdot 0.153 \cdot 0.001 \cdot 365 \left[\frac{bbl\ \ kg\, m^3\ \ ton\ \ cd}{cd\ \ m^3\ bbl\, kg\ yr} \right] = 53{,}700 \frac{ton}{yr}$$

CO_2 emissions from FCC according to Equation 3.2:

$$\frac{53{,}700 \cdot 1}{12} \cdot 44 = 196{,}900\ ton\ \ CO_2\ /\ yr$$

The emissions could also be determined based on coke burn rate estimated by the operator.

The reference CO_2 emissions from fluid cokers and flexi-cokers should have been determined by Equation 3.2. However, due to lack of process –data, this could not be done. Only one refinery in the study had a fluid coker and one other had a flexi-coker. The amount of coke burnt could therefore not be estimated, which led to an underestimate of the reference CO_2 emissions connected to non-replaceable fuels for those two refineries.

Note that all coke burnt was considered as non-replaceable fuel. This means that the energy content in the coke burnt was considered to account for a part of the energy demand of the specific process.

Point sources – other vents
No CO_2 emissions from this source category were considered when determining the reference CO_2 emissions, mainly because the CO_2 emissions from these sources could be considered negligible compared to other sources. However, if a climate intensity index were to be calculated including greenhouse gases other than carbon dioxide, this assumption might have to be reconsidered since the main emissions from these sources are methane.

Non-point sources
These sources were not included in the IVL CO_2 intensity index since these sources can be considered negligible compared to other sources (see section 3.1.4).

Indirects
This study focused on emissions that actually occur at the refineries. No adjustments of reference CO_2 emissions were made to compensate for purchased steam or electricity or sold heat or steam. The consequence of that is that if a refinery purchases a lot of its electricity or steam from external producers, the reference CO_2 emissions will be overestimates. The operator will have lower emissions due to the fact that the emissions emanating from the production of the electricity or steam purchased occurred elsewhere. This refinery will therefore appear to have a low CO_2 intensity. Compensation was made for sold electricity. An extra amount of energy demand (and hence CO_2 emissions) was added for the amount of sold electricity. The reason for considering exported electricity is that this can be seen as a separate product. Of course the same argument could be used for heat export, but in this study, heat delivery to external users was seen as a way of efficiently using excess heat and not as a source for extra fuel requirements at the refinery. In order to generate extra electricity, fuel is needed and extra fuel consumption is considered in the index calculations.

4 Different tiers for calculating the IVL CO_2 intensity index

The original approach for determining the IVL CO_2 intensity index of the refineries within Norway and EU15 was to ask for the necessary data via a questionnaire sent to each of the refineries. However, very few of the 97 questionnaires were returned with full information. Many of the refineries were in the midst of the process of delivering data on historic emissions to their governments and had difficulty, either due to lack of time or sensitive information, providing all the data asked for in the questionnaire. Due to this reason, we had to find other sources in order to get the data required for calculating the CO_2 intensity index. Three different tiers of determining the CO_2 intensity index were developed, requiring different amounts of refinery-specific data.

Tier 1. The refineries delivered data by answering the questionnaire. Data given included: Solomon EII-index, fuel mix, amount of purchased electricity, CO_2 emissions from processes with process-specific CO_2 emissions, and actual CO_2 emissions. The data given was valid for 2002. The values on process capacities given in Stell (2002) were also updated by the operators, along with values given on actual utilisation of each process.

Tier 2. In the case where no answer to the questionnaire was received, the information of refinery configuration (process composition) and production capacity given in the Oil and Gas Journal's (O&GJ) 2001 worldwide refinery survey (O&GJ, 2001) was used together with statistical data on unit utilisation and other operational statistics from the Solomon study to determine the reference emissions. The actual CO_2 emissions from the EU15 refineries are available in the EPER database (http://eper.eea.eu.int/eper/). All data used in this tier was valid for 2001.

Tier 3. In some cases environmental reports from the refineries contained the needed data to determine the reference emissions and the actual emissions.

The following sections describe which data and calculation methodologies were used to calculate the CO_2 intensities for the refineries according to the different tiers.

4.3 Tier 1. Calculation of the CO_2 intensity index – data from questionnaires

The tier 1 methodology was used for refineries that answered the questionnaire[7]. Since all data asked for in the questionnaire was for 2002, the CO_2 intensity indices calculated according to this tier are valid for 2002. In the questionnaires, the amount of combusted fuels for running the processes, including the flared volume, was given. The amount of purchased electricity was also given.

In order to calculate the reference CO_2 emissions, the reference energy consumption according to Solomon was first determined. The Solomon energy efficiency index, which is calculated by Equation 3.3, was used to determine the reference energy consumption. First, the actual energy consumption was determined by the following equation:

Equation 4.1. Actual energy consumption at refinery**.**

$$actual\ energy\ consumption = fuel\ usage \cdot fuel\ \ thermal\ value + electricity\ balance + steam\ balance + heat\ \ balance$$

Using the information available from the questionnaires the Solomon reference energy consumption was then determined by combining Equation 3.3 and Equation 4.1 to **Equation 4.2**.

Equation 4.2 The Solomon reference energy consumption according to tier 1.

$$Reference\ energy\ consumption = \frac{(fuel\ usage \cdot fuel\ thermal\ value + electricity\ balance + steam\ \ balance + heat\ \ balance)}{Solomon\ EII\ /100}$$

The energy output from the burned fuels was calculated by simply multiplying fuel consumption by fuel thermal value. The electricity balance is the balance of sold and purchased electricity. The balance is a positive value if the refinery is a net importer of electricity and is negative if the refinery is a net seller of electricity. The steam and heat balances are analogous to the electricity balance. The total amount of energy achieved was divided by the Solomon EII /100 for the refinery, which gave us the reference

[7] Note: Only five refineries filled out the questionnaire, completely or partially.

energy needed according to Solomon. As mentioned in Section 3.2.2.5, a few adjustments were made to the Solomon approach and the reference energy required for utilities, losses and offsites was subtracted from the total amount of reference energy needed. This resulted in an adjusted reference energy amount that we refer to as the 'IVL reference energy consumption'. The reference CO_2 emissions were determined according to Equation 4.3.

Equation 4.3 Reference CO_2 emissions due to combustion of fossil fuels

$$\textit{Reference } CO_2 \textit{ emissions} =$$

$$\textit{reference energy consumption} \cdot \sum_i (\textit{fraction of fuel}_i \cdot \textit{emission factor}_i) + \textit{process related } CO_2 \textit{ emissions}$$

The reference CO_2 emissions were calculated by using the reference energy, a fixed assumed fuel mix (equal to all refineries) and emission factors.

Note that the guidelines from the European Commission (2004/156/EC) state that when determining the CO_2 emissions from combustion of fossil fuels, one should use values of fuel consumption, emission factors and oxidation factors. The default values of oxidation factors are 0.99 for solid fuels and 0.995 for gaseous fuels. In this study, we did not consider the oxidation factors when determining the reference CO_2 emissions.

4.3.1 Energy-related CO_2 emissions – combustion of fossil fuels

Both the combustion of non-replaceable fuels (process-related fuels) and the combustion of other fuels was, in this study, considered as energy related emissions. However, in this study the combustion of non-replaceable fuels was considered as process related emissions. The assumption made concerning the fuel mix was that the rest of the energy (except for the energy from non-replaceable fuels) at the refinery was produced by burning refinery gas. Refinery gas has an emission factor of 66.73 t CO_2/GJ and a fuel thermal value of 48.15 TJ/ k tonnes[8]. According to the Reference Document on Best Available Techniques for Mineral Oil Refineries (European Commission, 2003), the ratio of gas to liquid refinery fuel depends on many factors. The ratio can vary from 80/20 for a stand-alone, moderate complex refinery to 40/60 for a highly complex refinery, which also serves as a chemical complex. It is also said that the ratio can be increased when energy conservation measures are applied and the gas availability becomes sufficient for the energy supply for the refinery. Hence, it can be said that the assumption that the only fuel used except for non-replaceable fuels is refinery gas could be true for a highly energy efficient refinery.

[8] Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories; Reference Manual. This is also the source for emission factors and thermal values used by the European Commission (2004/156/EC).

4.3.2 Process vents – process-related CO_2 emissions

These emissions include process vents and non-replaceable fuels.

4.3.2.1 Non-replaceable fuels

Processes in which there are non-replaceable fuels were considered separately. These processes include:

- regeneration of catalytic cracker catalyst and other catalysts
- cokers

Regeneration of the catalyst in catalytic cracker and other processes
The regeneration of the catalyst in the catalytic cracker results in a significant amount of CO_2 emissions. The operators were asked for the amount of coke burnt annually. The reference CO_2 emissions from the coke burnt were determined by the conservative assumption that carbon fraction in the coke burnt was 1.0, and that all of the carbon was oxidised to CO_2. (Most likely the actual carbon fraction is somewhere between 0.9-1.0). Equation 3.2 describes how the CO_2 emissions were calculated. Petroleum coke has a thermal value of 28.05 GJ/ton (Feldhausen et al, 2004)[9]. The CO_2 emissions from the regeneration of other catalysts were considered negligible in comparison to other sources included and were therefore not considered when calculating the reference emissions.

Coking
Only fluid cokers and flexi-cokers may have CO_2 emissions resulting from the coke burner. The same equation and calculation methodology can be used as for the catalytic cracking units. It could be assumed for cokers that all of the carbon in the coke is oxidised to CO_2 and that the carbon fraction is 1.0. Only two refineries in this study had cokers other than delayed cokers - one had a fluid coker and another had a flexi-coker. Neither of these two refineries answered the questionnaire, and hence the tier 2 methodology was used for estimating the reference CO_2 emissions.

4.3.2.2 Process vents

The only process vent considered in this study that is not related to burning of fossil fuels for energy purposes and that can not be considered a non-replaceable fuel is hydrogen production.

[9] This is the Swedish specific value and there exist a number of different values for different countries. The Swedish value has been used for all refineries.

Hydrogen production plant.
The production of hydrogen results in a significant vent of CO_2. A simple approach of an emission factor of 13.41 tonnes CO_2 per million standard cubic feet of H_2 produced was used. This emission factor is given in the API Compendium 2004 and is based on a stoichiometric conversion for a feed gas with an average natural gas composition. The amount of produced hydrogen was asked for in the questionnaire. According to the Commission, the CO_2 vent from the hydrogen production plant should be determined by using data on the composition and amount of feed to the process. The reason for not using that approach was the lack of data. Data on production was more easily accessible.

4.3.3 Actual CO_2 emissions

The actual amount of CO_2 emissions was given directly by the operator in the questionnaire.

4.4 Tier 2. Calculation of the CO_2 intensity – O&GJ /Solomon

In those cases we did not get a positive response from the refineries (they could not participate in the survey by filling out the questionnaires), we used other sources and calculation methodologies and data sources in order to determine the CO_2 intensity. All data sources used for this tier are valid for 2001, except for the Solomon study, which is only performed every second year and hence the 2002 study was used.

Used documents/studies are, amongst others:

- **The Solomon study** (Solomon Associates 2002), which consists of a few documents:

  The process unit energy standard document describing all processes in the refinery and the corresponding process unit energy standard [KBtu/bbl feed] (thousands of British Thermal units per barrel feed).

  The process statistics document, with statistics for most of the processes (most common) including:

  - number of installations included in the study,
  - UUOT (unit utilisation outside turnarounds) in different regions or for different sized installations,
  - other parameters important for the energy consumption and CO_2 emissions.

- **The Worldwide Refining survey** - every year **The Oil and Gas Journal (O&GJ)** completes a document called the Worldwide Refining Survey listing all oil refineries in the world. For each refinery, charge/production capacities for the main processes are given. The information from the Worldwide Refining Survey has been used in order to determine the reference energy demand of the refineries. Each of the processes given in the O&GJ (2001) was identified as one of the processes given in the Solomon e-factor document.

4.4.1 Energy related emissions – combustion of fossil fuels

The reference energy consumption for tier 2 was determined by using the Solomon process unit energy standards and production data as described by Equation 3.4. In this study, the load/production (Q) of each process was determined by the charge[10] capacity values given in the O&GJ 2001(see below) and the Unit Utilisation Outside Turnaround (UUOT) factors given in the Solomon study. Equation 4.4 determined the reference energy consumption for each refinery

Equation 4.4 Reference energy consumption for refinery as determined in this study

$$Reference\ energy\ consumption = \sum_{i=1}^{m} Solomon\ process\ unit\ energy\ standard_i \cdot charge\ capacity_i \cdot UUOT_i$$

where, Solomon process unit energy standard [Btu/bbl]
Reference energy consumption [Btu/yr]
i indicates the process
m is the total number of process at the refinery
Charge capacity is the size of the process unit [bbl/calendar day][11]
UUOT = unit utilisation outside turnarounds, implying Equation 4.5

Equation 4.5. Determination of actual utilisation/load

$$charge\ capacity \cdot UUOT = actual\ load\ \left[bbl/yr\right]$$

When determining the reference CO_2 emissions according to Equation 4.3 the fuel mix used was process-specific fuels (i.e. coke) and refinery fuel gas just as in the tier 1 methodology.

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[10] Note that for some processes the unit of the process unit energy standard is Btu/product in tonnes. The production capacity should therefore be used instead of charge capacity when determining the energy demand. In order to simplify the reasoning, we used charge capacity although it was production capacity for some of the processes.

[11] In O&GJ, the capacity is defined as the maximum number of barrels of input that can be processed during a 24-hour period, after making allowances for the following: a) types and grades of inputs to be processed, b) types and grades of products to be manufactured, c) Environmental constraints associated with refinery operations, and d) Scheduled downtime such as mechanical problems, repairs and slowdowns.

When determining the reference CO_2 emissions from process related fuels and vents, the same methodology was used as in tier 1. The only difference was the estimation of unit utilisation, which was made by using statistics from the Solomon process statistics document. The UUOT value used was the one for the closest geographical region.

Equation 3.2 was used for calculating the reference CO_2 emission from a catalytic cracker. In the calculations here, the coke burn rate was determined by the following equation (see also the example given in section 3.2.2.5):

Equation 4.6. Determination of the coke burn rate in catalytic crackers

$$Coke\ burn\ rate = Catalytic\ Cracker\ Capacity \cdot UUOT \cdot Feed\ Gas\ Density \cdot Coke\ Production$$

where, Catalytic cracker capacity [bbl/yr.] = the value is given in the Worldwide Refining Survey (O&GJ, 2001)

UUOT = the unit utilisation outside turnarounds, given in the Solomon study[12].

Feed gas density [kg/m^3] = given in the Solomon study[12].

Coke production [% wt of fresh feed] = given in Solomon study[12].

The carbon fraction of the coke burned and the fraction oxidised was estimated in the same way as for tier 1. Equation 3.2 was used for calculating the CO_2 emissions.

Other processes in a refinery might also have a catalyst that will have to be regenerated. As mentioned in section 4.3, the regeneration of coke in processes other than the catalytic cracker have been considered negligible in comparison.

Due to lack of process data for cokers, the emissions could not be determined. Only two of the 89 refineries in this study had cokers other than delayed cokers. The reference CO_2 emissions for those refineries are therefore underestimates.

4.4.2 Process vents – process-specific CO_2 emissions

When calculating the reference emissions from the hydrogen production the same calculation methodology was used as in tier 1, except for the estimation of the unit utilisation, which in tier 2 was estimated by the statistics on process operation in the Solomon study.

4.4.3 Actual emissions

The actual CO_2 emissions from the refineries were in most cases taken from the EPER database (http://eper.eea.eu.int/eper/). In some cases, where EPER data was not

[12] The average value for Western Europe or Central & South Europe was used, depending on the location of the refinery.

available, data was taken from the national allocation plan of the Member State in question.

4.5 Tier 3. Calculation of the CO_2 intensity – other data from producers

Since the uncertainty of the CO_2 intensity based on tier 2 is relatively large (see Section 6 below) and only a few of the refineries answered the questionnaire, a third methodology for determining the CO_2 intensity was established. The tier 3 methodology is a mixture of tier 1 and 2. Some of the refinery-specific data used was gathered from information on refinery performance and emissions provided by the producers in public documents such as environmental reports. Since this data did not exactly correspond to the data given by the questionnaires, some extra calculations were necessary in order to get the wanted variables. The data used in this tier are valid for 2001.

5 Data collection

In order to collect specific data from the refineries, a questionnaire was sent out to 97 refineries in the EU15 Member States[13] and Norway. Subsequently, bitumen refineries were excluded, mostly because the production at those refineries differs from the fuel refineries (many of them are not included in the Solomon study). The total number of refineries included in this study was thus 89. The questionnaires were specific for each refinery. 56 of the refineries responded to the circular. 90% of those answered that they could not participate by filling out the questionnaire. Only five refineries answered the questionnaire - three Swedish, one Finnish (only part of the questionnaire was filled out) and one German. The reason for not being able to participate differed among the companies. In some countries, the process of preparing for the national allocation plan was at a very early stage where the national government not yet had asked the installations for emission data. It was then considered a sensitive issue to answer the IVL questionnaire. In some cases, the workload at the refineries was very high and the questionnaire was not given high priority. However, the majority of refineries/-companies answered that CONCAWE (the European Oil companies' association for environment, health and safety in refining and distribution) ought to be involved. Unfortunately, CONCAWE was not able to join the project under the planned time frames.

[13] Luxembourg has no mineral oil refineries.

5.1 Tier 1

The refineries that answered the questionnaire gave the following information used for the calculations of the CO_2 intensity (note that the data asked for in the questionnaires was valid for 2002):

- Use of fuels and fuel thermal values
- Capacity and actual production for the processes given in the O&GJ
- Solomon EII
- Total amount of CO_2 emissions
- Amount of electricity purchased
- Any extraordinary coincidences occurring at the refinery during the year in question (2002) that could have altered the amount of emissions significantly

Data of the composite refinery configuration factor and crude oil density was taken from the Solomon study. The regional average values were used. The amount of steam and heat purchased or exported was not asked for, but has been extracted from other sources.

5.2 Tier 2

Since only five completed questionnaires were returned, other data sources had to be used. The Oil and Gas Journal annually completes a worldwide survey of refinery capacity (Stell, 2001). In that study, the charge/production for each of the major processes at each refinery is given. Stell (2001) was used as the source for which processes the different refineries have and what capacity they have. The Solomon study of energy efficiency at refineries includes almost 200 refineries (85 in Europe) as well as a lot of process-specific statistics. One parameter used in this study is the unit utilisation outside turnarounds (UUOT), which is given for each process in the Solomon study. The value was used together with the charge/production capacity in order to estimate the actual production/load for each of the processes.

In the tier 2 calculations, the Solomon process unit energy standards were used in order to estimate the reference energy for each process at the refinery. Each of the processes in the O&GJ was connected to a specific process unit energy standard as defined by Solomon Associates. The total amount of reference energy at the refinery was used as a basis for calculating the CO_2 emissions. For many of the processes, the data needed for calculating the total energy needed from the process unit energy standard was the load or the amount produced. However, in some cases this had to be complemented with other statistics of the process, such as the density of input product or coke yield. All such data was taken from the Solomon study.

The data on total CO_2 emissions during 2001 was taken from the EPER database. In order to reduce the uncertainty of that data, some of it was verified by comparing to data given in the national allocation plans of the countries.

5.3 Tier 3

In some cases, refinery-specific data was collected from environmental or other reports, or from individual refinery's web sites.

6 Uncertainties

In this section, the uncertainties associated with the different calculation methodologies and tiers are estimated. There are a number of sources to uncertainty in the final determined CO_2 intensity index of the individual refineries. The uncertainty of tiers 2 and 3 are far greater than the uncertainty of tier 1.

A general uncertainty is the electricity export that many refineries have but for which we were unable to obtain data. If a refinery exports electricity, that should be considered as an extra source of fuel. It was also considered that the heat that many refineries deliver does not need extra fuel, but is rather a way of using excess heat. If some refineries indeed use extra fuel in order to deliver heat, which would cause an underestimate of the reference CO_2 emissions.

It should be noted that the IVL CO_2 intensity indices calculated according to tier 1 are valid for the year 2002 whereas the indices calculated according to tier 2 and 3 are valid for the year 2001.

6.1 Tier 1

The uncertainties associated with this calculation methodology are mainly connected to the uncertainties in the values given by the operators. The values of composite refinery configurations and electricity export also affect the uncertainty. Obtaining data directly from the operators and not using average values could have reduced the uncertainty caused by those factors. The effect of using the Solomon average value of crude density is probably negligible.

6.2 Tier 2

There are a lot of assumptions made within this calculation methodology and the uncertainty is much greater than for tier 1. In the tier 2 methodology, where most of the data was taken from the Worldwide Refining Survey 2001 and the Solomon study, the uncertainty is quite large.

The reference CO_2 emissions were mainly based on the energy consumption of each of the processes at the refinery. Which processes are present at each refinery and of what size they are was found in Stell (2001). We learnt by the few answers that we received from the refinery operators that there are discrepancies between the data given in Stell (2001 & 2002) and the actual refinery data.

We used the data on processes and capacity from Stell (2001) together with data on process energy standards and other process-specific data from the Solomon study to determine the reference energy consumption. A source of uncertainty in these calculations was the difference in resolution between the two sources. The Worldwide Refining Survey by Stell (2001) is not as detailed as the Solomon study (there are more different processes) and it was not always obvious which process in Stell (2001) corresponded to which process in the Solomon study. This is considered as one of the main sources of uncertainty in the tier 2 calculations.

It should also be mentioned that the process data and the unit utilisation (utilisation of capacity) were based on average values for the refineries in a certain region and not on refinery-specific data, which further adds to the uncertainty.

Another important data source is the EPER database, from which actual emissions for the refineries were determined. However, not all refineries could be found in EPER and not all of them were associated with emissions over the threshold value set in EPER (100 000 t CO_2/yr) even though the size of the refinery indicated that the emissions by all means should be greater than the threshold. In order to eliminate large errors in the actual emission data, the EPER data was compared to the historic emissions or the allocation data given in the national allocation plans. Not all countries have included such information in their national allocation plans, but in the cases where it was possible, this comparison was done. In those cases where it was obvious that the EPER value was incorrect, the CO_2 emissions were taken instead from the annual report of the refinery.

In the tier 2 calculations, no consideration was given to export of electricity, since such data was lacking. For individual refineries, this will strongly affect the CO_2 intensity index (which then falsely might be higher than for refineries with no “excess” electricity production).

The CO_2 intensity index of some of the refineries determined using the tier 2 methodology ended up with values exceeding 250-300. Some of these values are probably too high due to the uncertainties described earlier in this section and were therefore excluded when determining the country or regional average.

6.3 Tier 3

The tier 3 calculation methodology was only used in a few cases, mostly because of the time-demanding data collection. The purpose of using this methodology was to reduce the uncertainty compared to the tier 2 methodology. Most of the data used was found on the web, in environmental reports, or in other descriptions of the refinery operation.

7 Results

The objective of this study was partly to assess data on emissions, allocation and production for the mineral oil refining industry in Europe. Data on CO_2 emissions was assessed for most refineries included in the study. Some Member States have given individual allocation data (as of 2 September 2004) for the refineries and these figures can be found in Appendix 1 to this report. The IVL CO_2 intensity index of the refineries was determined, but the values for individual refineries are very uncertain so the section below presents average values for the different regions within the studied area. Data on production, such as the utilisation of the different process units at the refineries, was requested in the questionnaires. However, since only a few refineries (five of 97) responded, these data were not compiled and will not be presented here. The fact that only a few of the refineries answered the questionnaire resulted in the use of the tier 2 calculation methodology of the CO_2 intensity index for the majority of refineries. If nothing is mentioned, the refineries did not fill out the questionnaire and tier 2 calculation methodology was used. The values of the Solomon EII given for the regions are all valid for 2001. The IVL CO_2 intensity indices calculated according to tier 1 are valid for 2002 and the IVL CO_2 intensity indices calculated according to tier 2 and 3 are valid for 2001 (if not otherwise noted).

7.1 The CO_2 intensity for refineries by country

In this section the IVL CO_2 intensity indices for the EU15 and Norwegian refineries are presented. The presentation is made by country and the tier used for the calculations is noted.

7.1.1 Austria

There is one refinery in Austria – the Schwechat refinery owned by OMV AG. There is an extensive report written by Ecker and Winter (2000) in which the historic emissions and fuel usage of the Schwechat refinery is described. This report was used to determine the CO_2 intensity index according to a combination of tier 2 and 3. The Schwechat refinery delivers heat to both Vienna airport and households in Vienna. The information in Ecker and Winter (2000) also reveals that there are two large power plants producing electricity both for the need of the refinery and for sale to external users. In the

calculations, the amount of delivered electricity was considered.
Since there is only one refinery in Austria and individual refinery values are not given, the average value for Austrian and German refineries were combined and the combined average was determined to be 121. In Figure 7.1 the European Inland bar represents the Austrian and German refineries and the Solomon EII for that region is 80.

7.1.2 Belgium

There are five refineries in Belgium, as listed in Table 7.1. Of these five refineries, only four were included in this study. The Nynas Petroleum refinery in Antwerp was not included as it is a bitumen-producing refinery with a production quite different from fuel refineries.

Table 7.1. The Belgian refineries.

Refinery	Owner
Antwerp	Nynas Petroleum AB
Antwerp	Belgian Refining Corporation
Antwerp	ExxonMobil
Fina Raffinaderij Antwerp	TFE
Universal	Petroplus

According to the Solomon study, the EII index for the seven refineries included in the BeNeLux countries range between 66-80, with an average of 75. A weighted average (weighted by CDU, Crude Distillation Unit,-capacity) results in the IVL CO_2 intensity index for Belgian fuel refineries being 88. The average CO_2 intensity index for the BeNeLux region was determined to be 97 (the Dutch Pernis refinery was excluded[14] from the average. If included, the average would have been 119).

7.1.3 Denmark

There are two refineries in Denmark - Fredericia (Shell) and Kalundborg (Statoil), as listed in Table 7.2. None of the operators filled out the questionnaire, but data required for tier 3 calculations were available on the operators' websites and that methodology was used when determining the CO_2 intensity index. The electricity export of the Fredericia refinery was considered in the calculations.

[14] The reason for excluding this refinery was the very high value of the CO_2 intensity index received. The reason for the high value might be that there are processes at this refinery that have not been considered properly or that some of the input data for the calculations were inaccurate.

Table 7.2. The Danish refineries

Refinery	Owner
Fredericia	Shell
Kalundborg	Statoil

The Danish refineries were included in the Scandinavian average value of the IVL CO_2 intensity index, which was calculated to be 96. The weighted Solomon EII index for the Scandinavian refineries is 72.

7.1.4 Finland

In Finland there are two refineries – the Porvoo and Naantali refineries, both owned by Fortum Gas Oy, as listed in Table 7.3. The Porvoo refinery partly answered the questionnaire and some additional information was found on the operator's website so that a combination of tier 1/tier 3 methodology could be used when determining the IVL CO_2 intensity index. Data required for tier 3 calculations of the Naantali refinery was found on the company's website. In the 2002 calculations for Porvoo, the fact that the refinery sold electricity to external users was considered. The reported 2002 CO_2 emissions for the Porvoo refinery were much higher (156 %) than in 2001. Data for 2002 was used (i.e., data on actual emissions and on refinery capacity).

Table 7.3The Finnish refineries.

Refinery	Owner
Naantali	Fortum
Porvoo	Fortum

A weighted average of the IVL CO_2 intensity index for the Scandinavian refineries was determined to be 96. The average Solomon EII for Scandinavia refineries is 72.

7.1.5 France

There are 13 refineries in France, as listed in Table 7.4. The ExxonMobil refinery in Dunkirk was not included in the survey as that refinery does not have a CDU process and mainly produces lubricant oils, which means that the production is not similar to the average of other fuel refineries. The fact that some of the larger refineries lack emission data of CO_2 in EPER and that some of the calculated CO_2 intensity indices were very high indicates that the validity of the EPER data must be questioned. In some cases the emission data given in the French national allocation plan (NAP)was used. The emission data used is the allocation base, i.e. the average emissions during 1998-2001. According to the list given in the French NAP, there are 14 refineries. However, one of them, the SARA Refinery in Le Lamentin, is not included in the O&GJ survey and, due to lack of data, was not included in this study. According to the French national allocation plan, it is a small refinery.

Table 7.4 The French refineries

Refinery	Owner
Lavera	BP PLC (no value of CO_2 emissions in EPER, NAP value used)
Port Jerome	ExxonMobil
FosSurMer	ExxonMobil (no value of CO_2 emissions in EPER, NAP value used)
Dunkirk	ExxonMobil (not included in this survey)
Petite Couronne	Shell
Reichstett	Shell
Berre L'Etainge	Shell (no value of CO_2 emissions in EPER, NAP value used)
Donges	Total
Dunkerque/Loon Plage	Total
Chateauneuf les Martigues	Total (no value of CO_2 emissions in EPER, NAP value used)
Feyzin	Total
Grandpuits	Total
Gonfreville l'Orcher/Harfleur	Total

The average Solomon EII for French refineries was 86 in 2001 (min = 77, max = 96), which is above the Western European average (81). The weighted average of the IVL CO_2 intensity index for the French refineries was calculated to be 133.

7.1.6 Germany

There are 17 refineries in Germany, as listed in Table 8.5. Of these, 16 included in this study; only the Addinol refinery in Krumpa was not included as there is no CDU and the refinery mainly produces lubricants. Only one of the refineries filled out the questionnaire, while most of the others had different reasons for not participating. The weighted average of the IVL CO_2 intensity index for those German refineries where a value could be calculated and the Austrian refinery was 121. If outliers were excluded, the value would have been 112. The average Solomon EII for the refineries in the European inland is 80.

Data on CO_2 emissions could not be found for all refineries in the EPER. It is not probable (due to the size of the refineries) that these refineries have CO_2 emissions lower than the threshold value unless they were closed down during a longer time period of 2001. A reason for not having a value of CO_2 emissions in EPER might be due to the division of utilities as separate units. In the list of installations attached to the German national allocation plan, many of the refineries are divided into more than one installation. In the German NAP there is so far (2 Sept. 2004) no list with allocation to installations or historic emissions. Another reason for unreasonably high or low values in the German refineries could be electricity production and gasification projects. There is at least one known gasification project among the German refineries.

Table 7.5. The German refineries.

Refinery	Owner
Vohburg/Ingolstadt/Neustadt	Bayernoil
Hamburg	BP (no value of CO_2 emissions in EPER)
Heide/Graasbrook	Dea (no value of CO_2 emissions in EPER)
Wesseling	Dea
Godorf	Shell
Harburg	Shell
Ingolstadt	ExxonMobil (no value of CO_2 emissions in EPER)
Salzbergen	Pharmazeutische
Holborn	Holborn Europa Raffinaderi
Karlsruhe	Oberrhein
Leuna	Mitteldeutsche Erdol
Burghausen	OMV Mineralölraffinerie Werk Burghausen
Schwedt	PCK Raffinerie GmbH
Gelsenkrichen	Ruhr Oel GmbH
Lingen	Deutsche BP Aktiengesellschaft
Willhelmshafener	Willhelmshavener

7.1.7 Greece

There are four refineries in Greece, as listed in Table 7.6. The weighted average of the IVL CO_2 intensity index of the Greek refineries was calculated to be 146. If the Elefsis refinery was excluded from the average, the value was reduced to 118. The Elefsis refinery is a refinery of simple structure with only a few processes. For refineries like Elefsis with only a few processes (no VDU, Vacuum Distillation Unit), it seems to be more important that the energy usage of utilities losses and off-sites are excluded in the index. The reason might be that they have fewer possibilities to "recycle" heat and efficiently save energy. The average Solomon EII for South & Central European refineries is 105. In the group of South & Central European refineries used by Solomon, there are 13 refineries included. Exactly which countries these refineries are situated in is not explicitly given in the Solomon study. Since all other refineries[15] were included in other Solomon-defined groups, the Greek refineries alone constitute this group in our study.

[15] The Solomon group 'European Inland' also includes 13 refineries. In our study, we have included the German and Austrian refineries, which might not be the same refineries as in the Solomon study. Some of these refineries might belong to the group 'Central & Southern Europe'.

Table 7.6 The Greek refineries.

Refinery	Owner
Aspropyrgos	Hellenic Petroleum
Thessaloniki	Hellenic Petroleum
Corinth	Motor Oil Hellas
Elefsis	Hellenic Petroleum

7.1.8 Ireland

In Ireland there is only one refinery - the Whitegate refinery owned by Conoco Philliphs. The average IVL CO_2 intensity index for British and Irish refineries was 127. The average Solomon EII for British and Irish refineries is 87.

7.1.9 Italy

There are 17 refineries in Italy, as listed in Table 7.7. The EPER data of CO_2 emissions from Italian refineries does not seem to be complete. In some cases where the calculated IVL CO_2 intensity index is very high (or low), there might be special processes or production at the individual refinery that need to be considered. The average Solomon EII for Italian refineries is 81. The weighted average of the IVL CO_2 intensity index for the Italian refineries, for which the index was calculated, was 159. If outliers were excluded (Gela Ragusa, Falconara and Sarroch) the average IVL CO_2 intensity index was 135. At Falconara, Priolo Gargallo and Sarroch there are gasification projects present. No list of installations with historic emissions is available in the Italian national allocation plan (2 Sept. 2004).

Table 7.7 The Italian refineries.

Refinery	Owner
Milazzo	Agip/Eni
Priolo Siracusa	Agip/Eni
Gela Ragusa	Agip/Eni
Sannazzaro	Agip/Eni
Livorno	Agip/Eni
Taranto	Agip/Eni
Port Maghera	Agip/Eni
Falconara	API SpA
La Spezia	Arcola Petrolifera (no value of CO_2 emissions in EPER)
Priolo Gargallo	ISAB SpA
Augusta	ExxonMobil
Busalla	Iplom SpA
Sarroch	Saras
Cremona	Tamoil
Trecate	Sarpom
Mantova	Italiana Energia
Raffineria di Roma	TFE

7.1.10 The Netherlands

There are six refineries in the Netherlands, as listed in Table 7.8. Only five of the refineries were included in this survey. The Smid & Hollander refinery was omitted as it is a bitumen refinery and not a fuel refinery. A weighted average of the Dutch and Belgian (BeNeLux) IVL CO_2 intensity index was determined to be 97 (when outliers were excluded). The IVL CO_2 intensity index for the Dutch refineries was only 105 (excluding outliers, see footnote 14). According to the Solomon study, the EII index for the seven refineries included in the BeNeLux countries range between 66-80 with an average of 75.

Table 7.8. The Dutch refineries.

Refinery	Owner
Rotterdam	ExxonMobil
Rotterdam	Q8
Europoort	Nerefco
Pernis	Shell
Amsterdam	Smid & Hollander (not included, bitumen refinery)
Vlissingen	Total

7.1.11 Norway

Norway was included in this survey although it does not belong to the EU15 Member States. The reasons for the inclusion were because Norway has shown interest in participating in the EU ETS from the beginning in 2005 and because they are competitors to most of the EU15 refineries. There are two fuel refineries in Norway, as listed in Table 7.9. The weighted average IVL CO_2 intensity index of the Scandinavian refineries was calculated to be 96 and the Solomon EII for the region is 72.

Table 7.9The Norwegian refineries.

Refinery	Owner
Slagen	ExxonMobil
Mongstad	Statoil

7.1.12 Portugal

There are two refineries in Portugal - the Porto and Sines refineries both owned by Galp Energia, as listed in Table 8.10. The average value of the IVL CO_2 intensity index for the refineries on the Iberian Peninsula was calculated to be 140.

Table 7.10 The Portuguese refineries

Refinery	Owner
Porto	Galp Energia
Sines	Galp Energia

The average Solomon EII index of the 11 refineries included in the Solomon study on the Iberian Peninsula is 88.

7.1.13 Spain

There are nine refineries in Spain, as listed in Table 7.11. The Spanish refineries have a few processes for which no statistics on UUOT were available in the Solomon study. The average Solomon EII for the refineries on the Iberian Peninsula is 88. A weighted average of the IVL CO_2 intensity index of the Spanish and Portuguese refineries was calculated to be 140. Two of the Spanish refineries were excluded when calculating the average because the intensity values for those refineries were very high, most likely due to lack of or erroneous data. Had those two refineries been included, the CO_2 intensity for the Iberian refineries would have been 160. There are gasification projects at two (at least) of the Spanish refineries (SFA Pacific, 2000).

Table 7.11. The Spanish refineries.

Refinery	Owner
Castellon de la Plana	BP
La Rabida, Huelva	CEPSA
Cadiz, Gibraltar	CEPSA
Tenerife	CEPSA
Cartagena	Repsol YPF
La Coruna	Repsol YPF
Puertollano	Repsol YPF
Somorrostro	Repsol YPF
Tarragona	Repsol YPF

7.1.14 Sweden

In Sweden, there are three refineries that were included in this study. There are also two additional refineries that mainly produce bitumen. The included Swedish refineries are listed in Table 7.12. All three refineries filled out the questionnaire and the IVL CO_2 intensity indices were determined according to tier 1and, hence, are valid for 2002.

Table 7.12. The Swedish fuel refineries.

Refinery	Owner
Göteborg	Preem
Göteborg	Shell
Lysekil	Scanraff

The weighted average of the IVL CO_2 intensity index of the Scandinavian (Sweden, Norway, Finland and Denmark) refineries was 96. The weighted mean of the Solomon EII index for the Scandinavian refineries is 72.

7.1.15 The United Kingdom

There are nine fuel refineries in the United Kingdom, as listed in Table 7.13. There are also two bitumen refineries in the UK the Eastham and the Dundee refineries. They were both excluded in this study since they have a significantly different production. The IVL CO_2 intensity index of the UK refineries was calculated using mainly tier 2 but some extra information on processes was available from the Institute of Petroleum. The average CO_2 intensity for the Irish and British refineries was calculated to 128. However, the individual values for some of the refineries seem to be high and might be due to own production of electricity.

Table 7.13. The UK fuel refineries.

Refinery	**Owner**
Fawley	ExxonMobil
Stanlow	Shell
Grangemouth	BP
Lindsey	TotalFinaElf
Pembrok	Chevron Texaco
Coryton	BP
Humber	Conoco Phillips
MilfordHaven	TotalFinaElf
Teesside	Petroplus

7.2 Summary of the IVL CO_2 intensity index

Figure 7.1 below shows the result of the IVL CO_2 intensity index calculations. Countries with only one or a few refineries were grouped (as described in the previous sections) and an average value for each region was calculated.

A correlation between CO_2 and energy intensity can be seen. Countries with low energy-intensive refineries also have low CO_2-intensive refineries (some deviation). The uncertainty is probably lower for the Scandinavian CO_2 intensity index as tier 1 and 3 methodologies were applied when determining the indices. All Swedish refineries filled out the questionnaire; the Danish refineries were treated by using tier 3 calculations. Tier 3 methodology was also partly used for the Finnish refineries.

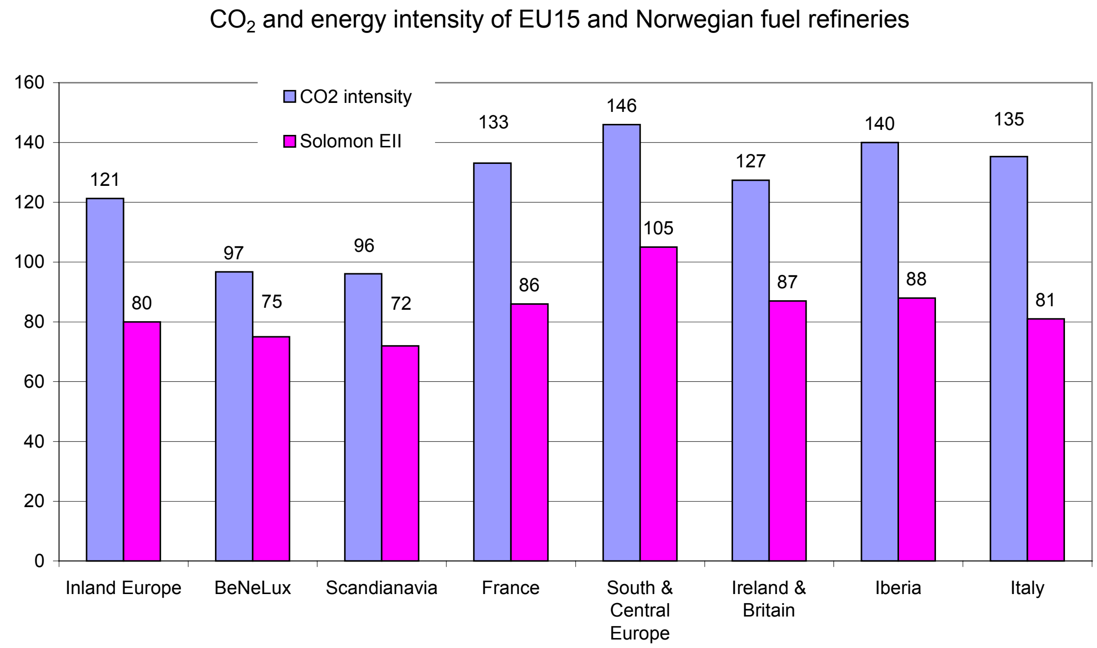

Figure 7.1. The CO_2 intensity index as determined by IVL and the energy intensity index as determined by Solomon Associates. The denotation of the groups of countries is the one used by Solomon. The groups made when determining the average IVL CO_2 intensity indices are: Inland Europe = Germany and Austria; BeNeLux = Belgium and the Netherlands (there are no refineries in Luxembourg); Scandinavia = Denmark, Finland, Norway and Sweden; South & Central Europe = Greece; Iberia = Spain and Portugal.

7.3 Allocation to the Mineral Oil Refining Industry

The national allocation plans of twelve of the EU25 countries have been analysed in Zetterberg et al (2004). In that analysis, special attention was given to the energy and mineral oil refinery sectors. Much of the information given in this section was given by Zetterberg et al (2004).

The EU15 allocation plans analysed in Zetterberg et al (2004) were for Austria, Belgian (only draft version of Flandern), Denmark, Germany, Finland, Ireland, Luxembourg, the Netherlands, Portugal (draft version), Sweden and the United Kingdom. Figure 7.2 on allocation vs. historic emissions and projected emissions is a modification of Figure 4.2 in Zetterberg et al (2004), where additional information given by the countries to the Commission has been added. However, Germany has not given current emissions of the refining sector and Greece has still not published a national allocation plan (2 Sept. 2004). Belgium, France, Italy and Spain submitted their allocation plans very late (they were not included in the analysis made by Zetterberg et al 2004) and therefore only data, and no allocation methodology, were extracted from those allocation plans.

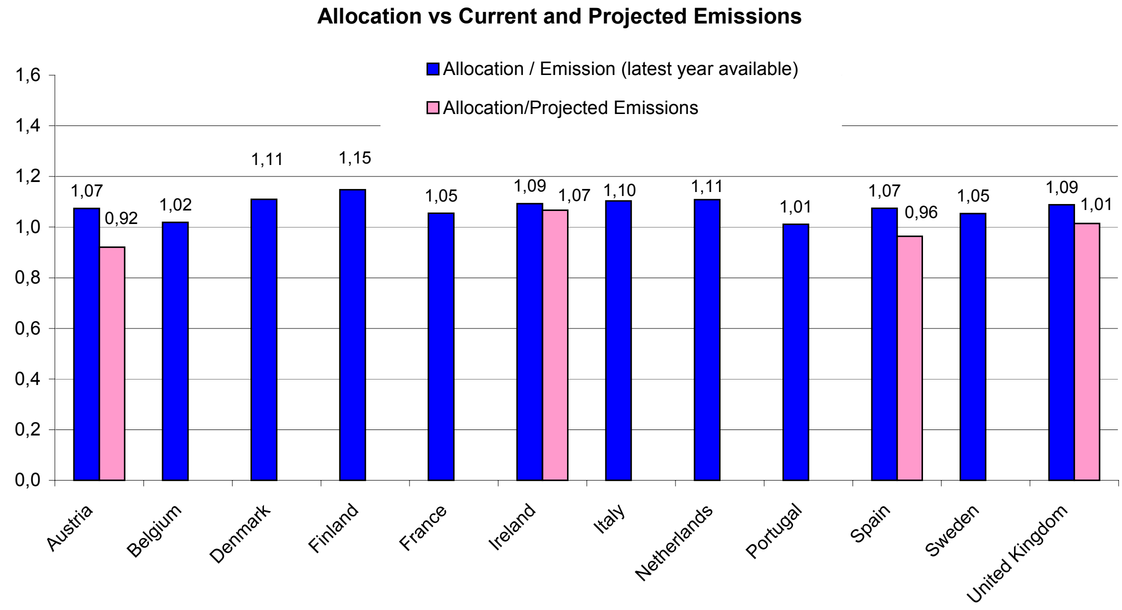

Figure 7.2. The allocation vs. current and projected emissions to the mineral oil refining sectors in different Member States. Unfortunately, not all Member States gave data on current and/or projected emissions for the mineral oil refining sector.

Generally, in most countries the refinery sector has been allocated more allowances than corresponding current emissions. However, the allocation includes both allowances to existing installations, new entrants and to expansions. Some large new entrants/expansions are known, such as the Gasification Project at Scanraff refinery in Sweden and the upgrade at the Porvoo refinery in Finland. It was only in the Swedish case that the amount of allowances allocated to the new installation/expansion could be identified and excluded from the amount of allowances allocated in Figure 7.2. In the Finnish case, the allowances allocated for the expansion/upgrade could not be distinguished in the allocated amount and are therefore included in Figure 7.2. There might also be other known new installations or expansions in other countries that not have been excluded, making the allocation appear to be more beneficial for the refinery sector in those countries than it is in reality. It should also be noted that what is considered as projected emissions differs between countries. Only four countries gave values for projected emissions for the mineral oil refining sector (2 Sept. 2004). It has not been decided formally whether or not Norway will link up with the EU ETS (2 Sept. 2004).

In Figure 7.3, both the quotas for allocation/historic emissions and the IVL CO_2 intensity indices for the refining sector in the countries included in this study are plotted. Note that not all of the original EU15 Member States are included in Figure 7.3 since not all countries have published historic emissions and/or allocation to the refining sector specifically (2 Sept. 2004). Germany, Greece and Norway (which is not a Member State) are not included due to these reasons. The Member States have been plotted in order of increasing IVL CO_2 intensity index. A higher value of the IVL CO_2 intensity index means higher emissions of CO_2 per produced unit compared to a lower value of the IVL CO_2 intensity index.

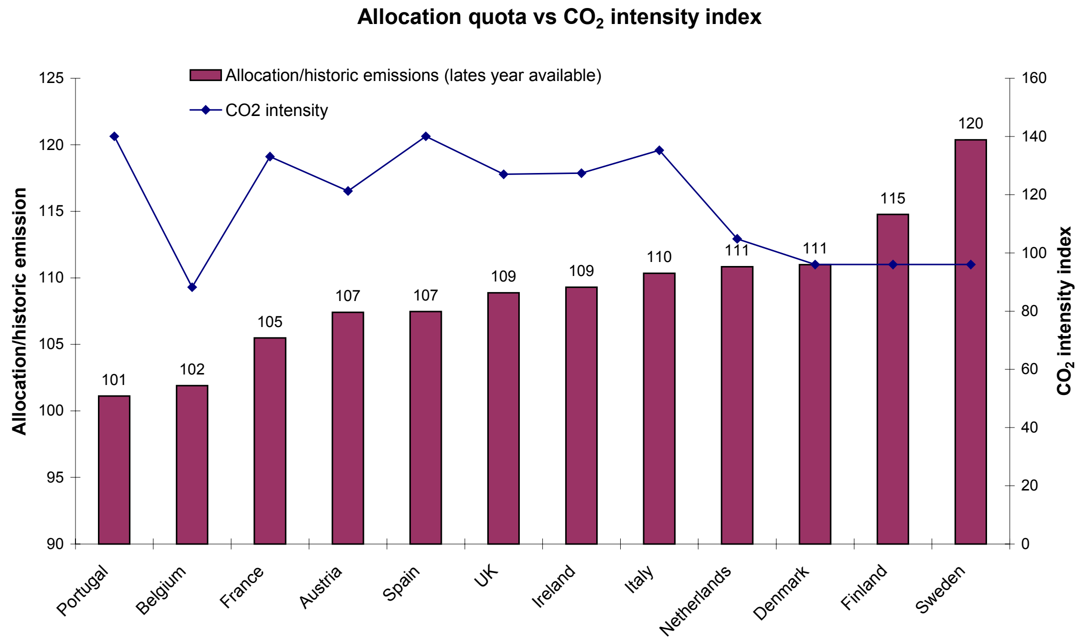

Figure 7.3. The average IVL CO_2 intensity index of the refining sectors in different Member States and the ratio between allocation and historic emissions. Note that the regional values of the IVL CO_2 intensity indices have been used for countries with less than four refineries. That means that the values of the IVL CO_2 intensity indices for Denmark, Sweden and Finland are represented by the Scandinavian average. Correspondingly, the Austrian value is represented by the European Inland value, the Spanish and the Portuguese values are represented by the Iberian value and the Irish and the British values are represented by the Ireland & Britain average value. Note that in this figure, the ratio of allocation and historic emissions for Sweden also includes a new large Gasification project at the Scanraff refinery.

If the CO_2 intensity/efficiency had been rewarded on a European level when allocating to the mineral oil refining sector, relatively less allowances would have been allocated to CO_2-intense installations. Or in terms of Member States, those with a CO_2-intense refining sector would have allocated relatively less allowances to that sector than countries with less CO_2-intensive mineral oil refining sectors would have. That means that the bars and the curve in Figure 7.3 should be negatively correlated, i.e., as the bars get higher, the curve should decline. As can be seen, this is the case for the refining sectors in some countries, but not all.

Figure 7.4 is a slight modification of Figure 7.3, where the allocation to the large expansion at the Scanraff refinery in Sweden was excluded (since there are no historic emissions from this installation that will be commissioned in 2006). Even though it seems as if the country with the lowest allocation compared to current emissions is also amongst the countries with the most CO_2-intensive refinery sector, i.e. Portugal, there are also countries with a relatively CO_2-efficient refining sector that do not get much higher allocation (relatively), such as Belgium (and Sweden according to Figure 7.4). There are also other countries with relatively high CO_2 intensity, such as United Kingdom, Ireland, Italy and Spain that have allocated relatively high amounts of allowances to their refining industry. It can also be seen that the Scandinavian countries (except Sweden according to Figure 7.4) and the Netherlands, who have relatively CO_2-efficient mineral oil refining sectors, have allocated relatively high amounts to their sectors. Further, France, with a relatively low CO_2 efficiency has allocated relatively few allowances to its mineral oil refining sector.

Criterion 5 of Annex III to the Directive concerns the competition between companies and sectors. In order to avoid differences in allocation methodology between companies within the same sector, the Commission could have compared the allocation to the same sector between Member States. However, the national allocation plans have been individually scrutinised by the Commission and sectors have been treated differently in different Member States.

The allocation in most cases includes allowances to new installations. In other words, if the sector is expanding, the allocation to the sector should also be higher than the historic emissions. For example, in the case of the Swedish and the Finnish refinery sector, we know that the allocation includes a considerable amount for new installations or expansions. If the allowances allocated to new installations are excluded, the picture of the allocation vs. historic emissions would look different. This can be seen by comparing Figure 7.4, where the allocation to the large expansion at the Scanraff refinery in Sweden was excluded, and Figure 7.3. The exclusion of the allocated amount to the large expansion in Sweden makes the figure look quite different and, most probably, the Finnish bar would also be diminished radically by excluding the allocation to the upgraded part of the Porvoo refinery. There might also be corresponding adjustments to be made for other countries that are not known to us. There have been difficulties in distinguishing between allocation to present installations and new installations or expansions. The Commission asked many countries to make clarifications and amendments to their allocation plans. It is therefore possible that the Commission had access to more information when scrutinising the allocation plans than we have been able to obtain.

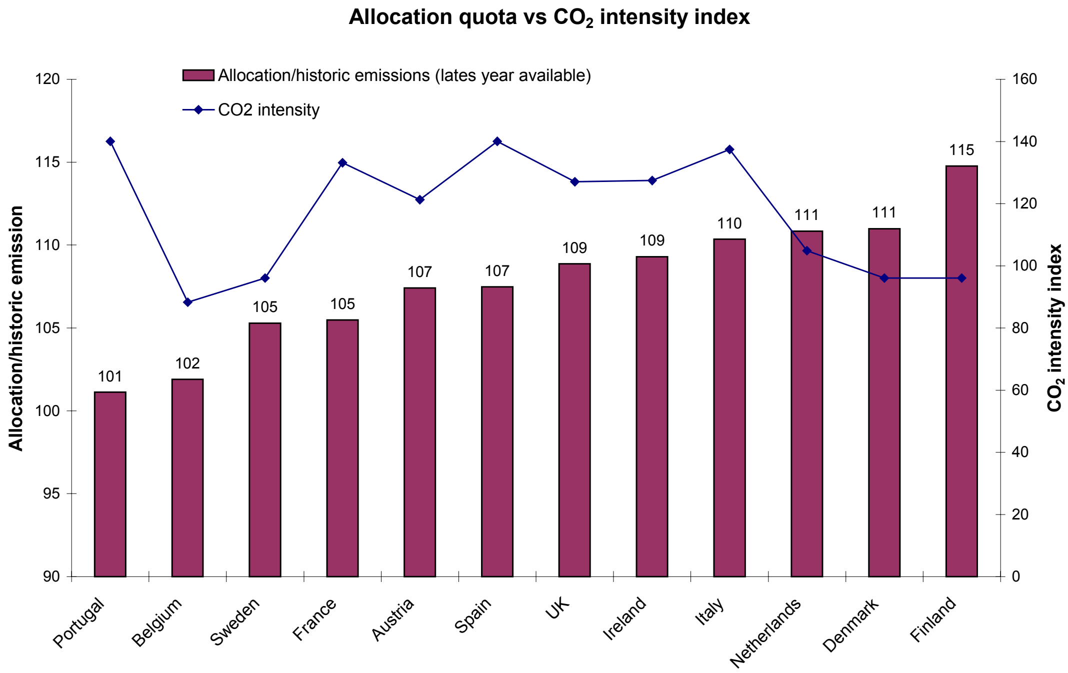

Figure 7.4. Modification of Figure 7.3. The new entrants have been excluded in the Swedish amount of allocated allowances.

8 Discussion

8.1 The differences in CO_2 intensity between refineries

There are a few important factors that determine the difference in IVL CO_2 intensity index between refineries. One of them is the difference in fuel mix. In Figure 8.1, the weighted emission factors show differences in CO_2 intensity of the fuel mix used at refineries in different countries. Note that purchased electricity, steam or heat is not included. Even if the refining sector in a country is relatively energy efficient, the use of more CO_2-intense fuels will make them less CO_2 efficient.

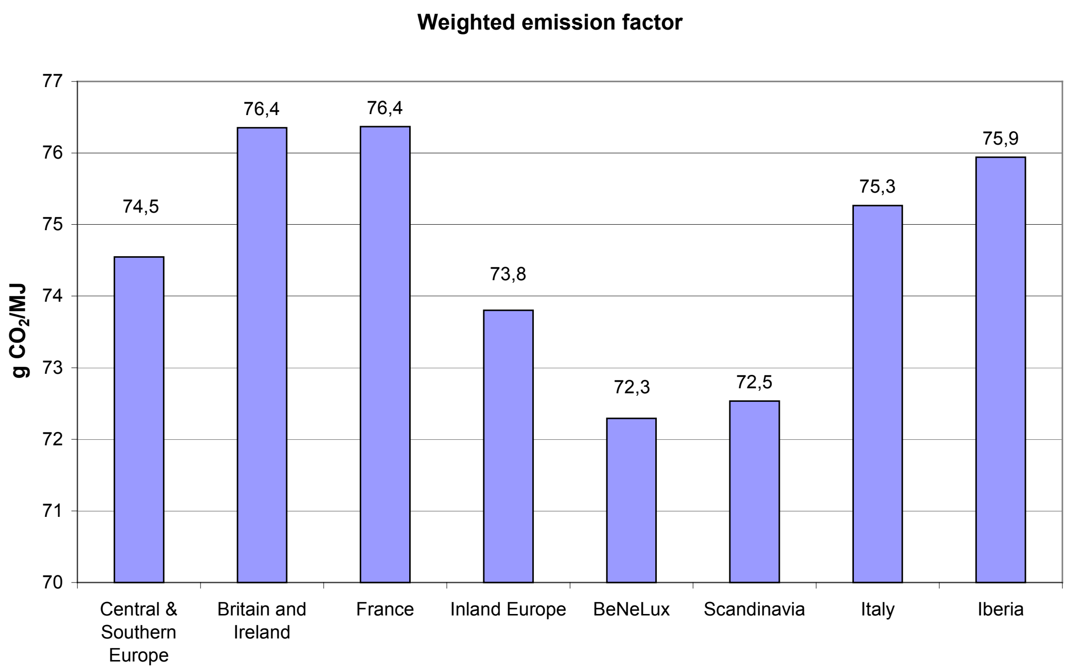

Figure 8.1. The weighted emission factor is a based on the actual fuel mix at the refineries in different regions. Data source: Solomon Associates (2002).

The total amount of used energy and the amount of purchased energy (steam and electricity) also affect the CO_2 intensity index, as described earlier. Figure 8.2 shows the energy consumption per utilised equivalent distillation capacity (EDC), a measure of total refinery utilisation, at the refineries in different regions in Europe.

The amount of purchased electricity affects the CO_2 intensity since purchased electricity is not associated with any CO_2 emissions. Figure 8.3 shows the amount of purchased electricity and produced electricity at refineries in different regions in Europe.

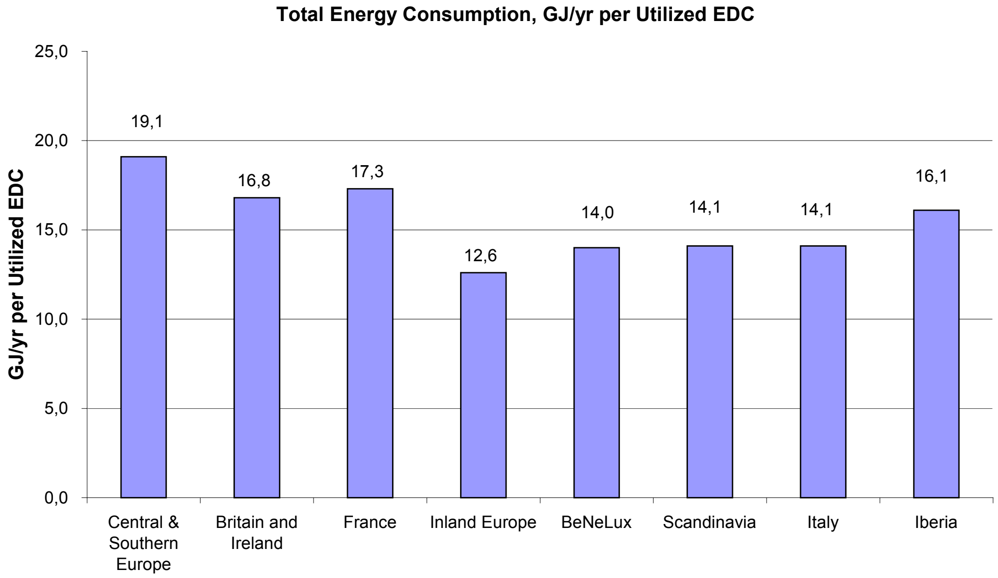

Figure 8.2 Total energy consumption [GJ] per utilised EDC (equivalent distillation capacity) at refineries in different regions in Europe. Note that the complexity of the refinery and the product slate will affect this factor. Source: Solomon Associates (2002).

Due to data availability, the calculated IVL CO_2 intensity indices in this report are affected by the electricity production at the refineries. In most cases, it was not possible to consider the extra CO_2 emissions needed for the exported electricity due to lack of data. If more detailed data had been available and the IVL CO_2 intensity index could have been determined according to the tier 1 methodology, this problem would have been eliminated. However, the amount of exported electricity does not have a great impact on the regional level since the refinery sector is not a net seller of electricity in any of the regions. Still, there might be individual refineries producing a lot of electricity and for which the impact on the CO_2 intensity will be of importance.

Together, the fuel mix, the amount of produced electricity and the amount of energy used per utilised EDC at the refineries in the different countries explain a large portion of the pattern of different IVL CO_2 intensity indices of refineries in different countries/regions. This is shown in Figure 8.4. However, it does not explain the whole difference. Also, the product slate of the refineries will be of importance. The composite refinery configuration (i.e., the complexity of the refinery) is partly a description of the potential product slate and is a measure that varies significantly between regions. One should also remember that there are large uncertainties in the calculated values of the CO_2 intensity for the individual refineries. Since there are Member States with only a few refineries (less than four), even the national average values are sometimes quite uncertain. In some countries with only a few refineries, a large error in the index will still make a large impact on the average. On the higher aggregated level, the trends are probably more certain, which is why we have used the aggregated averages in the comparison to the allocation.

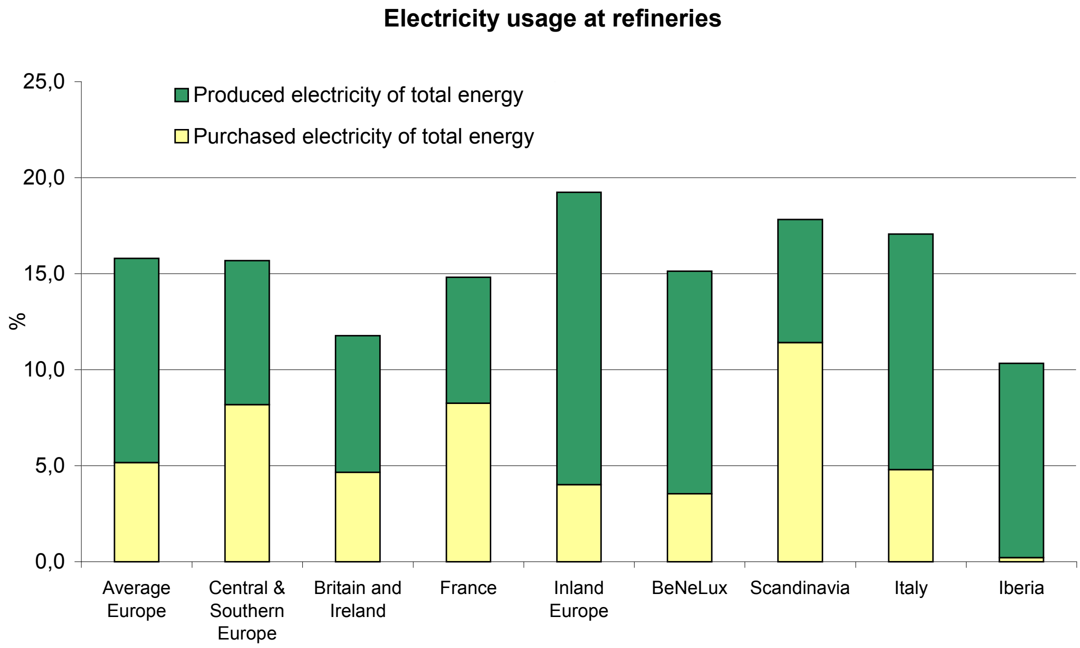

Figure 8.3. Electricity usage and production at European refineries. Amount of electricity that is used, purchased and produced by the mineral oil refining industry in different European regions. Source: Solomon Associates (2002).

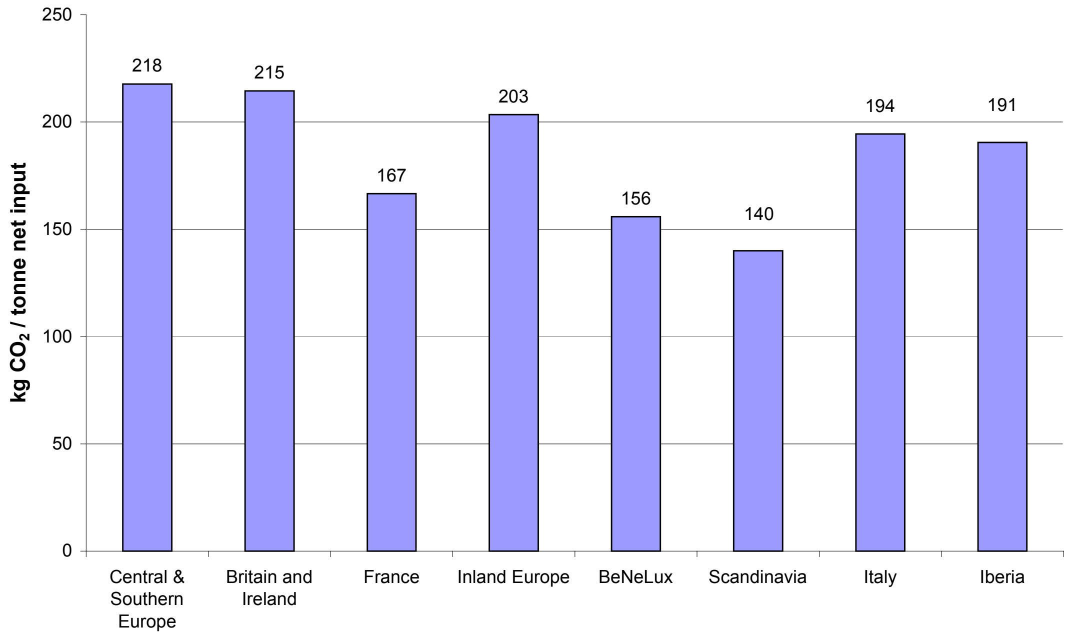

Figure 8.4. Amount of CO_2 potentially emitted per tonne net input. Calculated as (1-ratio of energy usage that is purchased electricity) · weighted emission factor · energy usage per tonne net input. Source: Solomon Associates (2002).

8.2 For what purposes can the IVL CO_2 intensity index be used?

The IVL CO_2 intensity index has many of the advantages that are also associated with the Solomon Energy Intensity Index (EII). For instance, it considers the differences in complexity between refineries. But there are also other advantages that are not included in the Solomon EII.

- The index is directly related to CO_2 emissions (not only energy consumption).
- The index considers process-related emissions (both fuels and process vents) that cannot be easily substituted.
- The index reveals differences in the use of CO_2-intensive fuels. Even though a refinery is energy efficient, more CO_2-intensive fuels can be at use, which can be indicated by the index.
- The index can easily be expanded to include greenhouse gases other than carbon dioxide, making it a greenhouse gas intensity index. This might be useful when/if the EU Emission trading scheme is expanded to include more gases.

However, the uncertainty of the index such as calculated in this study is great and in order to use the index more widely, the uncertainty will have to be reduced. This can be done by using refinery-specific data given by, for instance, the refineries themselves.

The principles of the IVL CO_2 intensity index could be used as guidance for an international benchmark for allocating to mineral oil refineries. Of course, it would require refinery-specific data, but the majority of the refineries in the EU15 are part of the Solomon study and therefore have access to the data used in this study to calculate the IVL CO_2 intensity index. Solomon Associates has also made a study on a greenhouse gas performance index for mineral oil refineries that has a lot in common with the IVL CO_2 intensity index presented in this study (Solomon Associates, 2003). An international benchmark for the mineral oil refining sector used in the allocation within the EU ETS would reward CO_2-efficient refineries.

8.3 Expectations and Outcome of the EU ETS national allocation plans

One of the main reasons for conducting this study was to see if some refineries were treated more favourably than others in the allocation process. In particular, we wanted to see if refineries with low energy intensity or low CO_2 intensity were treated more favourably than less efficient refineries.

According to the criteria for the national allocation plans, a list of installations should be included in the ETS, together with the quantities of allowances intended to be allocated to each. The plans should also contain the total number of allowances to be distributed within the trading sector and the methodology used when determining the number of allowances to each installation. From this study and the analysis of the national allocation plans by Zetterberg et al (2004), it was clear that:

- Few of the national allocation plans were submitted in time to the Commission
- Only a few of the national allocation plans actually included a list of installations and the number of allowances intended to be allocated to them. Note that some of the national allocation plans might have been complemented on request of the Commission. (2 Sept. 2004).
- The description of allocation methodologies used was not easy to penetrate. In many cases, a growth factor was used when determining the amount of allowances to be allocated, but what that growth factor represented exactly was sometimes difficult to see.

These circumstances are some of the reasons that have made the system less transparent than we hoped for (and that originally was announced in the Directive) and explain, in part, why the CO_2 intensity index turned out to be quite uncertain at the installation level. However, it should be noted that we have not seen the answers to the clarifications required by the Commission before approving the allocation plans.

Based on the analysis of the national allocation plans, it can generally be concluded that the mineral oil refining industry has been allocated allowances corresponding to higher emissions than the current emissions. Both new installations and Directive 2003/17/EC concerning the production of low-sulphur liquid fuels should be considered, as these will in fact increase CO_2 emissions at refineries (but reduce the emissions for consumers). Many countries have taken Directive 2003/17/EC into consideration when allocating to the mineral oil refineries, but not all. In Germany, for example, a refinery will only be considered in the allocation process if it can prove that the Directive results in increased emissions by at least 10%. It should also be noted that some countries allocate more allowances than the projected emissions.

8.4 Future challenges

The time schedule for implementing the EU ETS has been very tight. However, the Commission has now approved the majority of the national allocation plans and all countries should have issued the emission allowances to the installations by the end of February 2005. This means that one very important first step towards a functioning emission trading system has been taken. Verifying the emissions will probably be the next big challenge for the EU ETS. Each Member State will individually determine how the measurements at the different installations should be performed. There is a guidance document from the Commission but it allows for interpretation by the Member States. In the guidance document (2004/156/EC) on monitoring and reporting, it is said that installations with emissions > 500 000 tonnes CO_2/a should monitor with an uncertainty < 1.5%. Many of the refineries fall into this category, but it will be a great challenge to put measuring techniques in place in order to fulfil the requirement of such low measurement uncertainty. Improving the measurement uncertainty of the emissions at many of the emitting installations and thereby declining the overall uncertainty of the total emissions is also one of the great advantages of the EU ETS.

Since the allocation to the trading sector in general has been generous (Zetterberg et al 2004), the impacts might, at least on the refining sector, not be very great during the first period 2005 - 2007. However, the system is now in place and it has great potential to regulate the emissions from installations included in the future. The importance of objectivity and transparency will therefore be even greater in the future. If international benchmarks were used across the EU for sectors or installations when allocating, the participants might have found that they were treated more equally. Such a system would also motivate installations to reduce their CO_2 intensity if they knew that the next allocation was going to be based on benchmarks instead of historic emissions.

9 Conclusions

It can be concluded that there are substantial differences in the IVL CO_2 intensity index of the mineral oil refineries in different regions within Europe and that these differences have not been considered in the allocation process. However, for some countries there is still some correlation between allocation and CO_2 efficiency.

The uncertainty of the values of the IVL CO_2 intensity indices for the individual refineries is large, especially in those cases where the tier 2 and 3 methodologies have been used (97% of the cases). Still, the general trends that could be discovered when comparing the CO_2 intensities of different countries/regions are probably valid.

From the analysis of the national allocation plans it can generally be concluded that the mineral oil refining industry has been allocated allowances corresponding to higher emissions than its current emissions. It should be noted that the allocation also includes future expansions and new installations, which means that for individual installations, the allocation might not be higher than current emissions.

It can be concluded that a few countries (of those whose national allocation plan have been evaluated) have considered energy or CO_2 efficiency in the allocation process. Austria, Germany and the Netherlands have mentioned energy efficiency or reduction potential due to CO_2 intensity of fuels used. A few countries also mention early action although most countries have only considered that by using historic emissions as a basis for allocation. Most countries have considered co-generation of heat and electricity as a clean technology, rewarding better allocation than other production methods. However, no country has explicitly used an efficiency or intensity index for energy or CO_2 at refineries. This is not beneficial for energy and CO_2-efficient refineries since they have fewer possibilities to reduce emissions than less efficient refineries do.

Most countries have based the allocation on historic emissions and an estimated growth factor. Basing allocation on historic emission could be beneficial for refineries that have made emission-reducing measures in recent years. However, most countries have used emissions in recent years as allocation basis, which diminishes these benefits.

Only Denmark has explicitly given a value of a benchmark that will be used for allocation to new mineral oil refineries. The use of benchmarks will always be beneficial for CO_2-efficient installations.

10 Further research/improvements

In order to improve the CO_2 intensity index, the uncertainty should be reduced. This is probably best done by a closer co-operation with the refining industry. Additional data that could be useful are the heat and steam balance (export/import) and the factors taken from the Solomon study (composite refinery configuration factor). A well-developed CO_2 intensity index could be used as guidance for an international benchmark when allocating to refineries. This would also help the sector to make the cheapest CO_2 emission-reducing measures while not affecting the regional competition.

The CO_2 efficiency and environmental advantages of producing energy at refineries could be investigated further. In so-called gasification projects where Integrated Gasification Combined Cycle technology is used, refineries use low-grade fuels for producing steam, hydrogen and electric energy with the highest conversion efficiency possible (European Commission, 2003). These should probably be given more "credits" in the CO_2 intensity index. One could also consider heat delivery in a different way, especially if extra fuel is used with the primary objective to increase heat delivery.

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11.3 Web-sites

http://europa.eu.int/comm/environment/climat/emission_plans.htm

Appendix 1

Country	Refinery	Emissions according to EPER [ton CO_2 in 2001]	Emissions according to NAP [ton CO_2/yr]	Allocation [ton CO_2/yr]	Comments
Austria	Raffinerie Schwechat	2 560 000	2 587 000		
Belgium	Belgian Refining Corporation	462 000			
Belgium	Esso Raffinaderij Antwerpen	1 610 000			
Belgium	Fina Raffinaderij Antwerpen	3 230 000			
Belgium	Nynäs	< threshold			Not included in survey
Belgium	Petroplus Refining Antwerp	191 000			
Denmark	Dansk Shell A/S, Fredericia	263 000			Emissions according to Environmental Report: 263 000
Denmark	Statoil A/S, Kalundborg	486 000			
Finland	Fortum Oil and Gas Oy, Porvoo	1 480 000		2 707 877	Emissions according to owner (2002): 2 312 000 ton CO_2
Finland	Fortum Oil and Gas Oy, Naantali	385 000		352 956	Emissions according to owner (2002): 355 197 ton CO_2
France	Raffinerie de Lavera (BP Lavera SNC)	< threshold	1 568 498		
France	Shell Couronnaise Raffinage	1 390 000	1 454 715		
France	Shell, CRR Compagnie Rhenane de Raffinage	587 000	604 208		
France	Esso Raffinage FosSurMer	< threshold	857 114		
France	ExxonMobil Port Jerome	2 870 000	2 528 449		
France	Raffinage de Provance site de la Mede, Total, Chateauneuf les Martigues	< threshold	1 554 921		
France	ExxonMobil Sté de la Raffinerie de Dunkerque	650 000	265 008		
France	Total Raffinerie Gonfreville l'Orcher Harfleur	2 380 000	3 239 098		
France	Total Feyzin	1 240 000	1 279 317		
France	Total Fina Elf Dunkuerque, Loon Plage	1 230 000	1 245 772		
France	Total Fina Elf Raffinerie de Donges	1 320 000	1 369 939		
France	Total Fina Elf Raffinerie de Grandpuits	688 000	780 704		
France	Shell Berre L'Etainge	1 603 000	1 304 951		

Country	Refinery	Emissions according to EPER [ton CO_2 in 2001]	Emissions according to NAP [ton CO_2/yr]	Allocation [ton CO_2/yr]	Comments
Germany	Krumpa, Addinol				Not included in survey
Germany	BP Hamburg	Could not be found in EPER			No value of CO_2 intensity could be calculated
Germany	DEA MineralOel Wesseling	2 150 000			
Germany	Deutsche Shell GmbH Godorf	1 630 000			
Germany	Ruhr Oel GmbH, Gelsenkirchen	3 393 000			
Germany	Bayernoil, Vohburg/Ingolstadt/Neustadt	1 732 000			
Germany	Deutsche Shell GmbH Raffinerie Zentrum Harburg	850 000			
Germany	Erdölraffinaderie Emsland GmbH & Co KG, Lingen	1 160 000			
Germany	Esso Deutschland – Raffinerie Ingolstadt	< threshold			No value of CO_2 intensity could be calculated
Germany	MIRO Mineralölraffinerie Oberrhein	2 628 000			
Germany	Holborn Europa Raffinaderie; Hamburg	491 000			
Germany	MIDER Mitteldeutsche Erdoel Raffinerie, Leuna, Spregau	1 010 000			
Germany	OMV Werke Burghausen	803 000			
Germany	Raffinerie Schwedt PCK	3 640 000			
Germany	H&R, Schmierstoff Raffinaderie Salzbergen	184 000			Emissions according to owner in 2002: 175 107 ton CO_2
Germany	Shell & Dea Oil GmbH Raffineri Heide/ Graasbrook	< threshold			No value of CO_2 intensity could be calculated
Germany	Willhelmshaven, European Vinyls Corporation (Deutschland)	715 000			
Greece	Hellenic Petroleum, Asporpyrgos	1 500 000			
Greece	Hellenic Petroleum, Thessaloniki	221 000			
Greece	Motor Oil Hellas, Corinth	1 440 000			
Greece	Petrola Hellas, Elefsis	458 000			
Ireland	Irish Refining Company, Whitegate	355 000	338 015		

Country	Refinery	Emissions according to EPER [ton CO_2 in 2001]	Emissions according to NAP [ton CO_2/yr]	Allocation [ton CO_2/yr]	Comments
Italy	ENI S.p.A Taranto	837 000			
Italy	ENI S.p.A Livorno	561 000			
Italy	IES Italiana Energia e Servizi, Mantova	364 000			
Italy	Iplom Busallla	244 000			
Italy	Raffineria di Augusta	2 240 000			
Italy	Raffineria Falconara Marittima	1 510 000			
Italy	Raffineria di Gela	3 610 000			
Italy	Raffineria di Milazzo, Messina	2 320 000			
Italy	Raffineria di Roma	385 000			
Italy	Sannazzaro, Agip	1 950 000			
Italy	Saras, Sarroch	5 990 000			
Italy	Sarpom, Trecate	1 310 000			
Italy	ENI S.p.A Port Maghera (Raffineria di Venezia)	703 000			
Italy	Priolo Siracusa, Praoil	1 680 000			
Italy	Priolo Gargallo, Isab SPA	2 640 000			
Italy	La Spezia	< threshold			No value of CO_2 intensity could be calculated
Italy	Tamoil, Cremona	493 000			
Netherlands	Esso Nederland / Raffinaderij Rotterdam	2 160 000		2 658 806	
Netherlands	Q8 Europort	491 000		618 744	
Netherlands	NEREFCO Europoort	2 240 000		2 239 380	
Netherlands	Shell Nederland Pernis Rotterdam	6 300 000		6 580 258	
Netherlands	Esha Smid and Hollander Amsterdam	Not in EPER			The refinery is opted out due to emissions < 25 kton.
Netherlands	Total Raffinaderij Nedeland BV, Vlissingen	1 350 000		1 689 940	
Norway	Esso Norge AS, Slagen	352 000			
Norway	Statiol, Mongstad	1 530 000			
Portugal	Sines	1 440 000			
Portugal	Porto	958 000			

Country	Refinery	Emissions according to EPER [ton CO_2 in 2001]	Emissions according to NAP [ton CO_2/yr]	Allocation [ton CO_2/yr]	Comments
Spain	BP Oil castellon	745 000			
Spain	Petroleos del Norte	2 060 000			
Spain	Raffineria di Gibraltar (Cadiz)	1 790 000			
Spain	Raffineria la Rabida	942 000			
Spain	Raffineria Tenerife	459 000			
Spain	Repsol Puertollano	2 850 000			
Spain	Repsol Cartagena	814 000			
Spain	Repsol la Coruna	1 580 000			
Spain	Repsol Tarragona	2 710 000			
Sweden	Preem Raff Göteborg	534 000		502 226	
Sweden	Shell Göteborg	573 000		576 245	
Sweden	Scanraff Lysekil	1 100 000		1 123 425	
UK	BP Oil Coryton Refinery	2 070 000		2 255 071	
UK	BP Oil Grangemouth Refinery Ltd	2 310 000		1 616 960	
UK	Conoco Ltd Humber Refinery	2 010 000		2 639 008	
UK	Eastham Refinery	< threshold			Not included in survey
UK	Elf Oil UK Milfordhaven	1 060 000		1 175 557	
UK	Esso Refinery Fawley	2 740 000		3 796 970	
UK	Lindsey Oil Refinery	1 940 000		2 418 272	
UK	Nynas UK Dundee	< threshold			Not included in survey
UK	Petroplus Refining Teessside	272 000		300 226	
UK	Shell UK Ltd Stanlow Manufacturing (Wirral)	2 800 000		2 926 576	
UK	Texaco Pembroke	2 980 000		2 033 647	

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