

Ramsey Pricing and Allocating of GHG Emissions from Oil Refining: Use or Abuse of Economic Theory?

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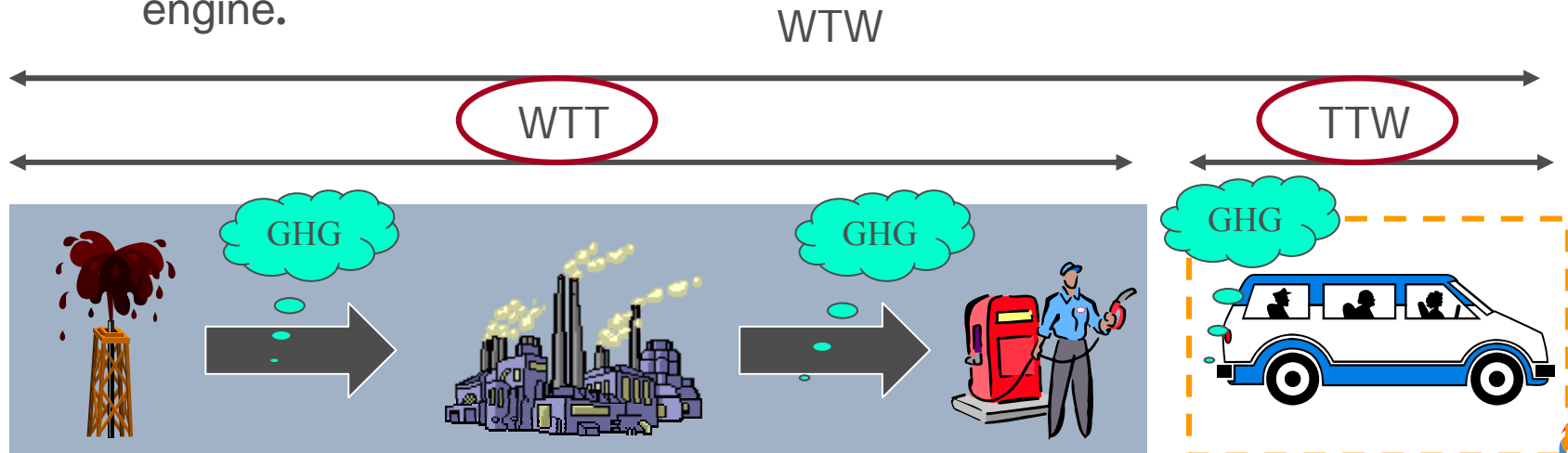
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Outline

- I. Objectives and main questions;
 - II. Adaptation of the Ramsey formula to allocating the CO₂ emissions of an oil refinery: mains objections;
 - III. An alternative approach;
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- IV. An oil refining case study.

Objectives and main questions

- **Well-to-Wheel (WTW)** studies assess the energy consumption and the associated GHG (e.g., CO₂) emissions associated with the production of different automotive fuels and consist in two parts:
 - The first part corresponds to the **Well-to-Tank (WTT)** analysis and assesses the stage from the extraction of feedstock until the delivery of automotive fuels to the vehicle tanks.
 - The second part corresponds to the **Tank-to-Wheel (TTW)** analysis and evaluates the environmental performance of automotive fuels in the engine.



Objectives and main questions



- Here, we only consider the WTT part.
- Within a WTT assessment, refining is the only step that differentiates diesel oil and gasoline production, with respect to CO₂ emissions and other GHG.
- Therefore, for a WTT analysis, we can reduce the boundary of the model to the only CO₂ emissions generated within the refinery.

Objectives and main questions

Prospective v.s. retrospective WTT studies

Prospective

What is the additional CO₂ emissions associated with an economic decision (e.g., marginal production of a given automotive fuel)?

Retrospective

How should the total CO₂ emissions of a refinery be allocated among the oil products?

Objectives and main questions



- ❑ Oil refining is a **joint production system** with an intrinsic joint technological linkage between process units and oil products.
- ❑ Joint production occurs when the production of one product **simultaneously** and **necessarily** involves the production of other products.
- ❑ How should the total profit, costs or emissions be allocated over some or all the oil products?
- ❑ This is a well-known economic problem to which **there is no unique and non controversial answer.**

Objectives and main questions



- The fundamental difficulty here is the amount of some CO₂ emissions which are released on behalf of **all the products simultaneously and completely**.
- In this case inseparability of the joint emissions results, and any way of attributing some of those emissions unambiguously to each of the products must depend on some **arbitrary criteria**.
- There is no way out of this.
- Once this difficulty is recognized, it becomes clear that one is dealing with a problem in the **area of arbitrary decisions**.

Objectives and main questions



Recapitulation:

- ❑ Allocating the refinery's CO₂ emissions to the oil products is required for the inventory phase of a WTT study.
- ❑ There is no obvious answer to this question and any allocation rule is inevitably arbitrary.

The only thing to do is to adopt an allocation rule which is based on some **plausible convention** and **commonly accepted hypotheses** among the intended users of these allocations data.

Objectives and main questions

- ❑ Recently, the well-known **Ramsey pricing solution**, from the welfare theory, has been suggested as one method of emissions allocation.
- ❑ The authors propose allocation of total CO₂ emissions from refining to specific refined products, on an inversely proportional basis to a specific **product's price elasticity**.
- ❑ Using this approach, it is assumed that the resulting allocation of emissions among refined products reflects a distribution that **maximizes societal welfare**.

Adaptation of the Ramsey solution

Objection 1

Originally, Ramsey solution answers to two questions:

- Within an optimal competitive situation, a given revenue is to be raised by proportionate taxes on some or all uses of income. How should these taxes rates be adjusted in order to maximize the social welfare?
- A regulated (natural) multi-product monopoly operating under a profit constraint in which the firm attempts to receive a fair return on capital as well as recover the short-run marginal costs of production.

Adaptation of the Ramsey solution

Objection 1

- WTT studies are not concerned with neither optimal taxation nor pricing policy.
- Oil refineries are not (natural) monopolies and operate to maximize profit (and unfortunately not the societal welfare!).

From the very beginning, application of the Ramsey pricing model to refining context is inappropriate, since the major assumptions underlying the model are not met.

Retrospective LP-based emissions

Objection 2

- The application of Ramsey solution involves numerical estimates of the consumer demand for all type of final, and intermediate products.
- Standard final products: propane, butane, naphtha, gasoline (95, 98), diesel, heating oil, heavy fuel oil (LS, HS), bitumen ...
- The reliance on empirically derived measures of elasticity (when they exist) even without worrying about obsolete numbers is totally impractical.
- The choice of a particular elasticity is arbitrary when different elasticities exist for the same oil product in the literature.

The required data, i.e., direct products' price elasticity, is hardly available (and some times not available)

Retrospective LP-based emissions

Objection 3

- In order to simplify the Ramsey formula, the substitution effects among oil products are supposed to be zero. This hypothesis is too strong for oil products.
- Example: **gasoline demand and diesel price in Europe**. The higher pricing and taxing of gasoline has been a key determinant in dieselization trends of the light vehicle fleets and in the development of diesel vehicle technology in European countries.
- Therefore, the introduction of these substitution effects should not be regarded as "unnecessary complexity" but rather as informative signals from the consumers' behavior pattern.
- The numerical estimate of cross elasticity among many oil products does not exist.

The amount of data required to **correctly** apply the Ramsey formula to the oil refining context makes its use completely impractical.

Adaptation of the Ramsey solution

Objection 4

- According to the Ramsey's conclusion, the most elastic oil products receive the lowest CO₂, and the least elastic ones get the highest CO₂.
- Ramsey rule would allocate lower CO₂ emissions to oil products with more competitive alternatives and would assign more CO₂ to oil products with **fewer or any competitive alternatives**.
- Bitumen has the less alternatives and should be the least elastic one.
- As a direct consequence of Ramsey solution, **bitumen would be assigned a grater part of the refinery's CO₂ emissions**.

This conclusion is wrong from an oil refining point of view!

Adaptation of the Ramsey solution

Objection 5

- The identification of environmental improvements is one important application of WTW studies.
- A minimum requirement of a CO₂ allocation method is to point out innovations which result in an overall decrease of the refinery's CO₂ emissions.
- In the games theories literature, Young (1985) demonstrated that Ramsey pricing method fails this right "incentive" test even in the simplest cases.
- This means that, Ramsey rule might attach a penalty to efficiency by assigning more CO₂ to oil products and process units whose environmental performance are improving.

This conclusion is a serious handicap for using Ramsey-based allocations for life cycle assessment studies.

Adaptation of the Ramsey solution

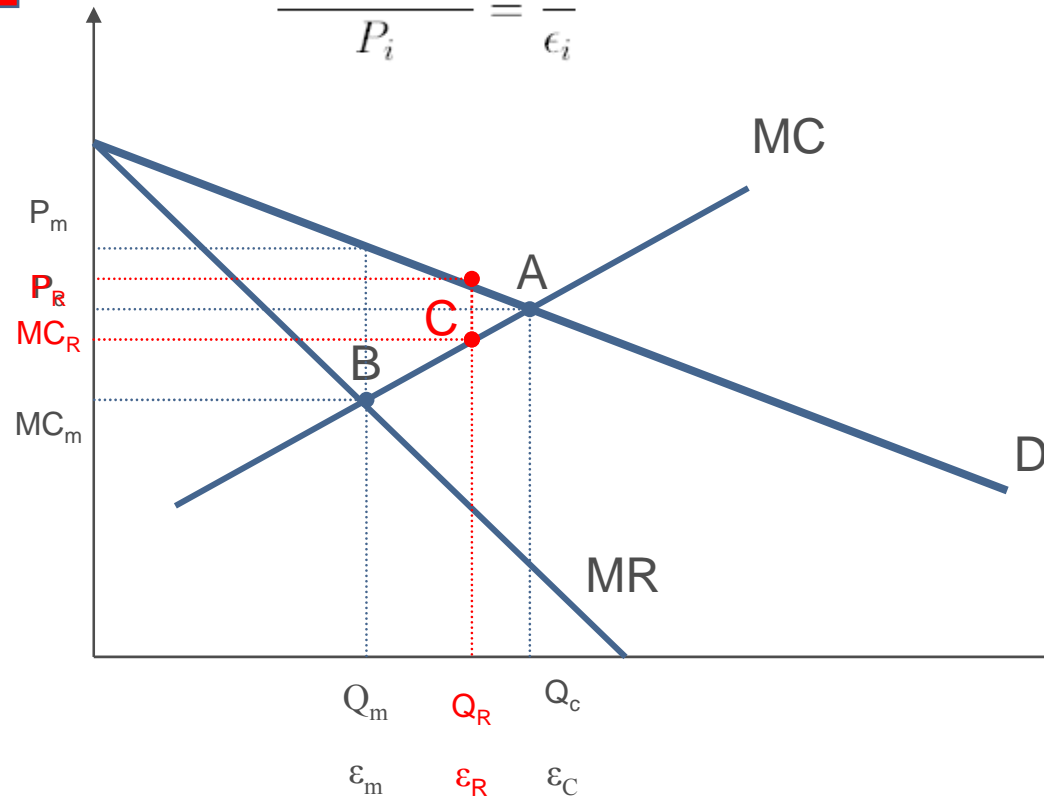
Objection 6

$$\frac{P_i - MC_i}{P_i} = \frac{k}{\epsilon_i}$$

A : $k = 0$

B : $k = 1$

C : $0 \leq k \leq 1$



Adaptation of the Ramsey solution

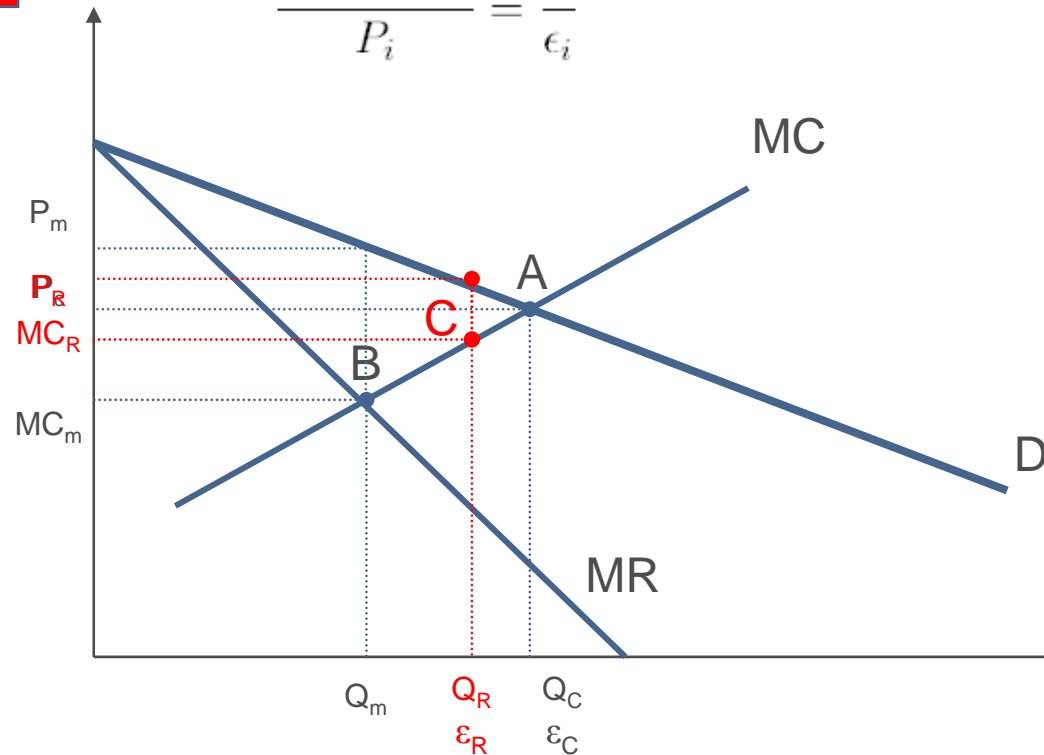
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$$\frac{P_i - MC_i}{P_i} = \frac{k}{\epsilon_i}$$

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- The “inverse elasticity rule”, i.e., Ramsey formula, is extracted from a welfare maximization solution, and should be applied to ϵ_R .
- The CO₂ emissions of any real-type refinery is ϵ_C .
- Applying the Ramsey formula to ϵ_C , instead of ϵ_R , is meaningless and does not maximize the societal welfare.

Alternative approach

- Consider a refining LP model, with a given average output price and input costs vectors. The refiner operates in a **short-run** competitive environment.

Total CO₂ emissions generated in the refinery

$$\left\{ \begin{array}{l} \min c^T x \longrightarrow \text{Total accounting variable cost} \\ s.t. \\ Ax \geq b \longrightarrow \text{(product demand constraints)} \\ Dx = 0 \longrightarrow \text{(material balance constraints)} \\ Ex - \mathcal{E} = 0 \longrightarrow \text{(CO}_2 \text{ balance equation)} \\ Fx \leq f \longrightarrow \text{(capacity constraints)} \\ x, \mathcal{E} \geq 0 \end{array} \right.$$

- At the optimal solution, the total amount of CO₂ is ε^* . *But it is not clear how to fairly allocate these emissions among the oil products.*

Prospective LP-based emissions

- An interesting feature of this LP model is its capability to transform the input-related emissions into an oil product-related emissions based on a **marginal principle**:

$$\mathcal{E} = \overbrace{\sum_{i \in M} \alpha_i b_i}^{\text{product-related}} + \overbrace{\sum_{j \in S} \gamma_j f_j}^{\text{process-related}}$$

- This equation relates the total CO₂ emissions of the refinery to the oil products (b) and the scarce unit processes (f) through their respective marginal CO₂ contributions.
- Here, the marginal product emissions (α) corresponds to the additional CO₂ attributable to the marginal production of the i -th oil product b_i , *ceteris paribus*.

Prospective LP-based emissions

$$\mathcal{E} = \overbrace{\sum_{i \in M} \alpha_i b_i}^{\text{product-related}} + \overbrace{\sum_{j \in S} \gamma_j \bar{f}_j}^{\text{process-related}}$$

- Relevance of these marginal product emissions (α):
 - The only way to attribute the additional CO₂ emissions to a given joint product is when the variation of this latter is very small.
 - The computation of the marginal CO₂ coefficients takes advantages of a parallel structure between economic market and physical variables.
 - The marginal CO₂ coefficients correspond to the supply-demand equilibrium of the refinery; and, they can reflect the real underlying difficulties of meeting the oil product demand in terms of CO₂ emissions.

These marginal CO₂ emissions are relevant for prospective WTT.

Retrospective LP-based emissions

- Achieving retrospective LP-based coefficients requires the reassignment of the total process-related emissions over oil products.

$$\mathcal{E} = \sum_{i \in M} \alpha_i b_i + \sum_{j \in S} \gamma_j \bar{f}_j$$

$$\gamma_j = E_B^T \left(\sum_{i \in M} \Omega_i + \Omega_\ell \right) \zeta_j$$

- The process-related emissions can be reallocated over petroleum products based on the **Marginal Rate of Technical Transformation (MRTT)** between the active unit processes involved in the production plan and the petroleum products at the optimum.

Retrospective LP-based emissions

- It can be shown that, in a competitive situation and within a linear technology, the total CO₂ emissions of the refinery can be fully allocated over oil products based on their **direct** and **indirect** contributions to the refinery's emissions:

$$\mathcal{E} = \sum_{i \in M} (\alpha_i + \underbrace{\sum_{j \in S} E_B^T \delta_{ij} + \bar{\theta} \vartheta_j}_{\alpha_i^A}) b_i$$

- The **direct** contribution corresponds to the marginal CO₂ content (α) of each automotive fuel (i.e., prospective LP-based emission coefficients).
- The **indirect** contribution is based on the production elasticity of the active unit processes at the optimal solution.

Retrospective LP-based emissions

Recapitulation

- **Prospective studies:** marginal effects are of importance.

$$\mathcal{E} = \sum_{i \in M} \alpha_i \vartheta_i + \sum_{j \in S} \gamma_j \bar{f}_j$$

- **Retrospective studies:** average effects and allocation principles are of importance.

$$\mathcal{E} = \sum_{i \in M} \underbrace{\left(\alpha_i + \sum_{j \in S} E_B^T \delta_{ij} + \bar{\theta} \bar{\vartheta}_i \right)}_{\alpha_i^A} b_i$$

Contrary to the application of Ramsey formula, these LP-based emission coefficients capture the interdependencies embodied in the model and depend totally upon the technical relationships that define the operating state of the refinery.

Reference

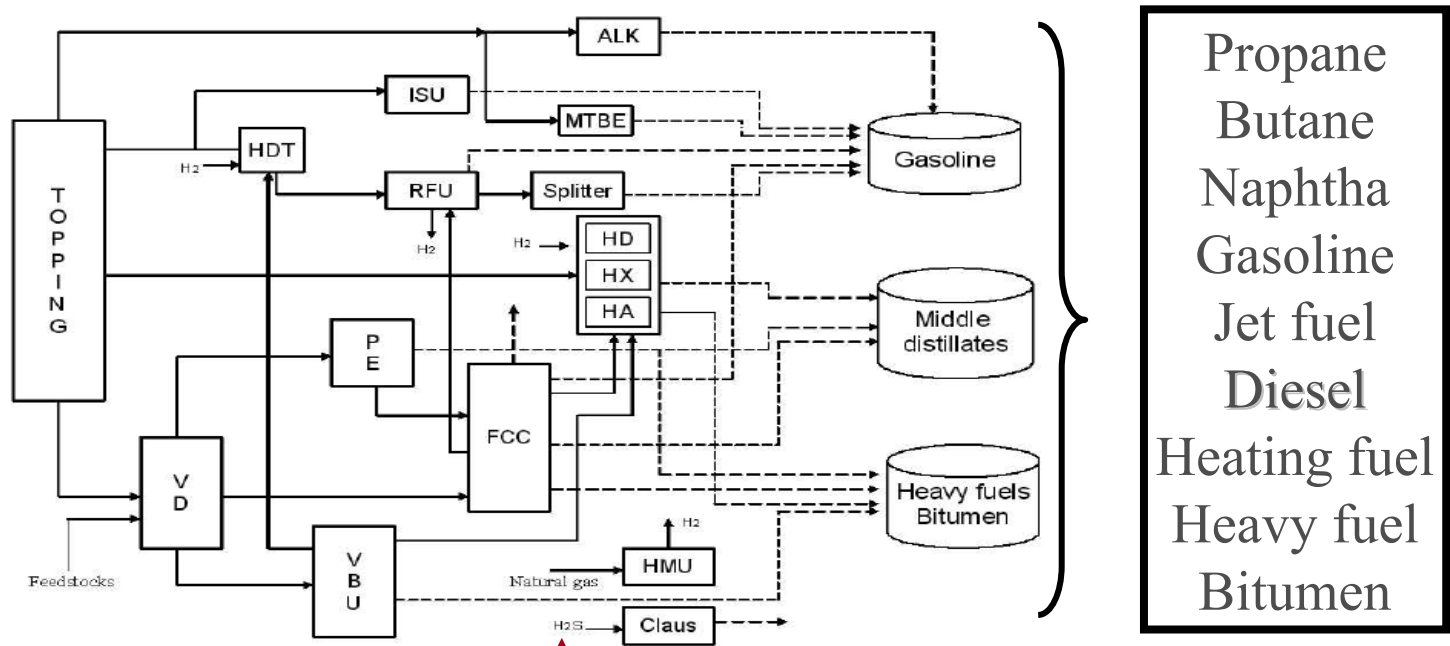
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Practical application

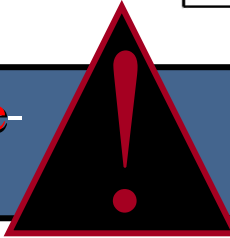
Typical **European** refinery LP model developed by IFP (800 constraints and 1800 variables).



- Propane
- Butane
- Naphtha
- Gasoline
- Jet fuel
- Diesel
- Heating fuel
- Heavy fuel
- Bitumen

Refinery structure: **Gasoline-**oriented technology

Oil market structure: **Diesel-**oriented demand



Practical application

- **Objective:** to evaluate the impact of tightening the oil products sulfur specifications on the marginal and average CO₂ content of automotive fuels at the gate of the refinery.

<i>unites: ppm</i>	Scenario 2005	Scenario 2008	Scenario 2010
Gasoline	50	30	10
Diesel	50	30	10
Heating oil	2000	1000	1000

- For each simulation: oil product demands, crude oil supplies and all input and output prices are supposed to be the same as the base year 2005.

Practical application

Evolution of **marginal** CO₂ content

<i>tCO₂/t</i>	Scenario 2005	Scenario 2008	Scenario 2010
Gasoline	0.205	- 2.483	- 1.010
Diesel	0.357	0.690	0.800

Evolution of **average** CO₂ content

<i>tCO₂/t</i>	Scenario 2005	Scenario 2008	Scenario 2010
Gasoline	0.302	- 1.189	- 0.931
Diesel	0.567	0.752	1.503

Main observations:

- In the base year (2005), both the marginal and average CO₂ contents of diesel are higher than those of gasoline.
- The gap between the marginal and average CO₂ content of these two automotive fuels will be enlarged until 2010.
- The marginal and average CO₂ content of gasoline continues to decrease and become even negative from 2008.

Practical application

Technical explanations (1)

- ❑ By 2005, European refineries have already expanded the diesel fraction beyond its optimum balance with gasoline yield to meet the domestic diesel-oriented market demand.
- ❑ Technically, this imbalanced production ratio has most probably resulted in higher production cost and energy consumption for diesel as compared to gasoline.
- ❑ Adding the ultra-low sulfur specifications into the current imbalanced situation would further increase the energy consumption and the resultant CO₂ emissions associated with diesel.

Practical application

Technical explanations (2)

- ❑ The negative CO₂ content of gasoline from 2008 is due to the ultra-low sulfur specifications that would significantly increase the **hydrogen requirement** of the refinery.
- ❑ For cost reasons, it happens that **catalytic reforming unit** (whose function is to produce gasoline) operates at full capacity not in order to meet the gasoline demand (which is decreasing in Europe) but to meet the increasing hydrogen requirement of the refinery.
- ❑ This additional hydrogen is mainly used in HDS units in order to satisfy the sulfur specifications of **diesel**.
- ❑ Since the LP solution accounts for all these **interdependencies**, the extra energy consumption of the reforming unit and its resultant additional CO₂ emissions would be assigned to the diesel pool rather than the gasoline output.

Conclusions

- ❑ Oil refining is one of the most complex joint production system for which traditional WTT methods might fail to provide correct prospective and retrospective data.
- ❑ The main objective of this paper is to show how the information associated with an optimal LP solution can be properly used in order to fully allocate the CO₂ emissions of a refinery to its joints products, without having to need ant further assumptions or information.