The footprint of petroleum fuels

How much energy and GHG emissions are associated with fossil fuels?

There are various circumstances, in particular in the context of life cycle analyses (LCA) where it may be desirable to establish the footprint of fossil fuels in terms of cost, energy or greenhouse gas (GHG) emissions. This legitimate expectation raises a specific problem in the case of petroleum products. Indeed oil refining, through which they are produced, is a co-production process whereby a number of different products are obtained simultaneously through a complex combination of inter-related physical and chemical processes.

While the total resources required to run an oil refinery in terms of feedstocks, costs, energy and the resulting emissions can be established in a straightforward manner, there is no scientifically sound way of apportioning any of these between the different products of the refinery. Several attempts have been made to devise pseudo-scientific methods to allocate the resources used by each individual process unit to a particular final product on the basis of the destination of the main product of that unit. Simpler methods distribute the resources according to some arbitrary key such as mass, energy content, economic value, etc. All these methods are fundamentally flawed as they have no rational basis or justification. This is illustrated in the examples below.

Energy content is a popular allocation key; there is, however, no physical reason why a product with higher energy content should systematically attract more production energy. Another example is provided by naphtha reforming, a ubiquitous refinery process that dehydrogenates virgin naphthas into a high octane gasoline component. A superficial analysis would call for allocating most of the energy requirement of this process to gasoline production. However the bulk of that energy is chemical energy resulting from the simultaneous production of hydrogen which, in turn, is used for the desulphurisation of diesel components.

Such simplistic allocation methods ignore the complex interactions, constraints and synergies within a refinery and, where the scope is wider, also between the different refineries in a certain region. Importantly, they also make the implicit assumption that the refining system under scrutiny is static and cannot or will not evolve and change.

This inescapable fact is part of the everyday life of refinery economists who are regularly asked to pass judgement on the profitability of processing certain feedstocks or manufacturing certain products. These analysts have learnt that a refinery product does not have a single economic value but a range of values depending on circumstances, and that each tonne of product made by the refinery may well have a different value. The tool that allows a glimpse into this complex reality is usually called marginal or differential analysis. Its fundamental principle is to compare a base or 'business-as-usual' case with an alternative case where the production of a certain product is changed, all other parameters being kept the same. The changes in cost, energy, emissions, etc. between the base and alternative case can then justifiably be 'charged' to the amount of the specific product that was changed.

Differential analysis is a heavy tool, usually requiring complex models such as the linear programming models routinely used by refiners. It also has the drawback of yielding a different result every time something is changed in the base case or even between the base and the alternative. For instance it is not unusual to discover 'tiers' in the value of refinery products, i.e. step changes in the value of the marginal tonne depending on the quantity at stake. Changing the production of two products may not lead to effects that are the sum of those obtained when considering the same changes to each product separately.

Focusing on LCAs, there can be two broad reasons why the footprint of petroleum fuels needs to be quantified. Most life cycle chains involve the use of petroleum fuels at some stage, e.g. for transport of goods, heating, etc. In such cases the fuels are not the main products under scrutiny and play a secondary role in the total chain. Hence, a simplified approach involving allocation can be justifiable, particularly as the total energy/GHG footprint of petroleum fuels is dominated by their own energy content, the additional energy required to make them being typically only about 15% of the total. Because the amounts of fuel under consideration are small in relation to their total demand, it is also reasonable to assume that the refining system would not be significantly affected by such incremental or decremental demand, thus justifying the use of a generic and 'static' figure.

The second type of situation is when the petroleum fuel takes centre stage, i.e. when it is itself the target of some form of change or is being substituted. In such cases, one cannot consider that the refining system that is implied in the base case will still be valid after the change has occurred. Indeed the changes under consideration, which can involve volumes, quality or a combination of both, are likely to trigger possibly fundamental modifications in the way the refineries function and therefore to affect their global footprint. In such cases it is imperative to use the differential analysis method mentioned above in order to obtain a realistic answer.

This can be illustrated by two examples taken from our analysis of various actual and potential changes affecting European refineries.

Marginal road fuel production

European refineries consume on average roughly 6.5 to 7% of their intake as energy and emit about 5 g of CO_2 per MJ of product. A typical allocation by energy content would more or less attribute that same number to all refinery products inasmuch as the calorific value of the materials involved do not differ by more than about 10%.

Figure 1 shows the result of the marginal analysis of the energy footprint of European road fuels starting from a future (2010) demand scenario. The first observation is that most points are well above the global energy and CO_2 emission figures showing that producing the marginal tonnes of road fuels is more energy intensive than the average. The second observation is that the marginal figures are not the same when either decreasing or increasing production and they also change when the decrement becomes larger. A special feature of the European situation is the high level of imbalance between diesel and gasoline demand which

Below: The refining footprint of marginal EU road fuels is higher than the average for all refined products and changes according to the scenario considered.

Figure 1 The refining energy and GHG footprint of marginal EU road fuels

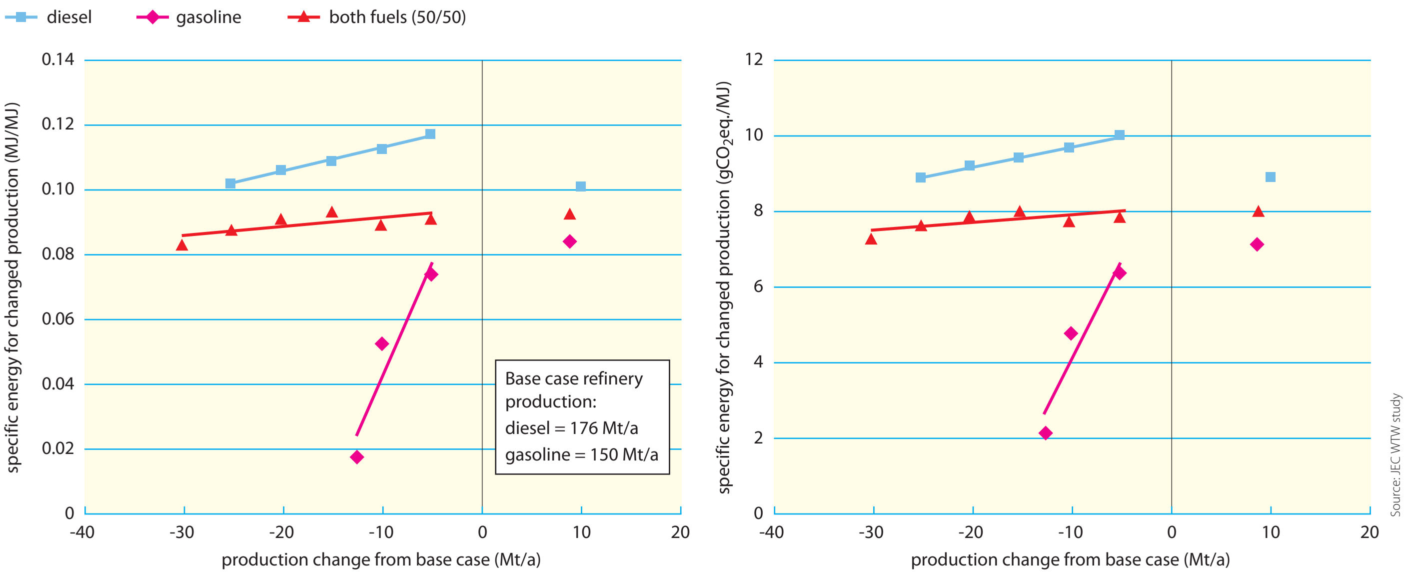

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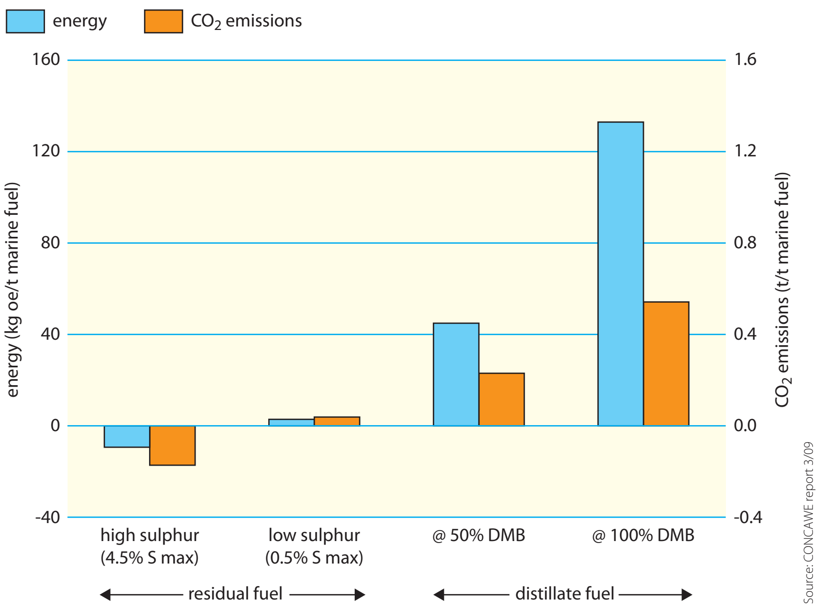
Figure 2 Energy and CO_2 emissions associated with marine fuel production



Above: Refinery energy consumption and CO_2 emissions associated with marine fuel production are highly dependent on the quality of the fuel.

causes the energy footprint of the marginal gasoline to tumble when demand is reduced (i.e. one saves less and less energy by making less and less gasoline).

Marine fuel production

The second example relates to marine fuels and more specifically to the shift from high sulphur residual to low sulphur residual fuels and possibly to distillate fuels. Based on allocation by energy content, all fuel grades would receive similar footprints. Figure 2 reveals a very different reality. The starting point was a series of scenarios consistent with demand for the 2020 time horizon and each representing a different end point in terms of marine fuel quality. For each scenario the marine fuel demand was changed by + and – 10% and the impact on the total energy consumption and GHG emissions of EU refineries was recorded. The figures shown are the averages.

It may seem odd to find a negative number for high sulphur marine fuel but, on further analysis, this is perfectly logical. If a market is available for such a product, there is no need to spend a large amount of energy to upgrade it to lighter grades and, consequently, increasing the demand actually reduces the total energy consumption of the refineries. Quite apart from other considerations such as pollutant emissions, there is no doubt that burning high sulphur residual fuel oil in ships is a very efficient way of using energy, particularly so as marine engines have excellent efficiencies even when using such heavy fuels.

As sulphur content is reduced more energy is consumed for processing and the footprint becomes slightly positive. Switching to distillates further increases the footprint dramatically, as much more sophisticated processing is required, including deep residue conversion.

The CO_2 footprint follows the same pattern. The particularly large increase in the case of distillates is related to the large increase in hydrogen requirement.

In the above examples, the analyses covered the total EU refining sector, ensuring that demands for all other products are satisfied in all cases. A similar exercise for individual refineries would lead to different results depending on the particular circumstances of each installation, particularly in terms of their complexity. In practice though, individual refineries would be unlikely to maintain the same production for all other products. Any change in the demand of a particular product would be rebalanced at the level of a large enough supply envelope, and it is only at that level that this type of analysis makes sense.

These two examples demonstrate the importance of using appropriate analytical tools and the relevant scale when looking at the impact of changes in the production or quality of refined products. Simplistic methods will invariably lead to unrealistic and misleading figures that will not capture the complex interactions between different plants and products within a refinery, and between refineries inside a common supply envelope.