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Assessing global resource utilization efficiency in the industrial sector

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HIGHLIGHTS

- The global industrial sector and its industries are assessed by using energy and exergy methods.
- Global industrial sector efficiencies are evaluated as 51% based on energy and 30% based on exergy.
- Exergy analysis shows global industrial energy to be less efficient than does energy analysis.
- A misleadingly low margin for efficiency improvement is indicated by energy analysis.
- A significant and rational margin for efficiency improvement exists from an exergy perspective.

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ABSTRACT

Designing efficient energy systems, which also meet economic, environmental and other objectives and constraints, is a significant challenge. In a world with finite natural resources and large energy demands, it is important to understand not just actual efficiencies, but also limits to efficiency, as the latter identify margins for efficiency improvement. Energy analysis alone is inadequate, e.g., it yields energy efficiencies that do not provide limits to efficiency. To obtain meaningful and useful efficiencies for energy systems, and to clarify losses, exergy analysis is a beneficial and useful tool. Here, the global industrial sector and industries within it are assessed by using energy and exergy methods. The objective is to improve the understanding of the efficiency of global resource use in the industrial sector and, with this information, to facilitate the development, prioritization and ultimate implementation of rational improvement options. Global energy and exergy flow diagrams for the industrial sector are developed and overall efficiencies for the global industrial sector evaluated as 51% based on energy and 30% based on exergy. Consequently, exergy analysis indicates a less efficient picture of energy use in the global industrial sector than does energy analysis. A larger margin for improvement exists from an exergy perspective, compared to the overly optimistic margin indicated by energy.

1. Introduction

Designing efficient energy systems is a significant challenge, in light of economic, environmental and other objectives and constraints, such as the world's finite natural resources and large energy demands. It is therefore important to understand actual efficiencies and limits to efficiency, which quantify margins for efficiency improvement. Energy analysis yields energy efficiencies that do not provide limits to efficiency and is thus inadequate. Exergy analysis, however, is a beneficial and useful tool that permits meaningful and useful efficiencies for energy systems to be determined, and losses to be clarified.

Exergy analysis is often used, sometimes with great benefit, in the analysis and design of engineering technologies and systems, but it can also be applied to agglomerations of systems like regional, national and global systems as well as sectors of the economy. Insights can thereby be attained that are particularly important for identifying limits to efficiency and margins for efficiency improvement. By describing the use of energy resources in society in terms of exergy, important knowledge and understanding are gained, and areas are better identified where large improvements can be attained by applying measures to increase efficiency (Reistad, 1975; Wall, 1990). Such insights can help identify and prioritize areas in which technical and other improvements should be undertaken in regions and countries, and in economic sectors.

During the past few decades, exergy has been increasingly applied to regions, nations and the world, as well as economic sectors, by using the methodology described above or variations or extensions of it. Exergy-based analyses have been carried for the world (Nakicenovic et al., 1996), as well as numerous countries, e.g., Canada. Turkey and Saudi Arabia (Dincer and Rosen, 2007), as well as the United States (Reistad, 1975; Ayres et al., 2003), China (Chen and Qi, 2007), the United Kingdom (Gasparatos et al., 2009; Warr et al., 2008) and the Netherlands (Ptasinski et al., 2006). Some regional, national and global studies have focused on particular sectors, including the industrial sector (Utlu and Hepbasli, 2007, 2008; Hepbasli and Ozalp, 2003; Oladiran and Meyer, 2007).

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In this article, the global industrial sector and industries within it are assessed by using energy and exergy methods, with the objective of improving the understanding of the efficiency of global resource use in the industrial sector and facilitating the development, prioritization and ultimate implementation of rational improvement options. This article extends preliminary information on this topic presented in the chapter on industry end-use efficiency (Banerjee et al., 2012) in the recently published *Global Energy Assessment*, a comprehensive integrated energy assessment coordinated by the International Institute for Applied Systems Analysis that analyzes energy challenges, opportunities and strategies, for developing, industrialized and emerging economies.

2. Energy and exergy analyses of the global industrial sector

The global industrial sector of the world is composed of many industries, each of which has different attributes and technologies. The global industrial sector and its efficiency have been investigated by Banerjee et al. (2012), who show that aggregate energy intensity in the industrial sector in most countries has shown steady declines over the last two decades due to improvements in energy efficiency and a change in the structure of the industrial output. The energy used by each of the industries in the global industrial sector for the year 2005 is considered here, as reported by the IEA (2007a,b). The most significant industries, based on the quantity of energy used in 2005, are iron and steel, chemical and petrochemical, non-metallic minerals, paper, pulp and printing, and food and tobacco. With this and other data, energy and exergy utilization in the global industrial sector is evaluated and analyzed.

For an exergy analysis, a country can be modeled as economic sectors (residential/commercial/institutional, industrial, transportation, utility), and the energy and exergy flows through the overall system and its sectors. For each of the process occurring in the system, energy and exergy efficiencies can be determined. The main process types are as follows: heating (electric, fossil fuel, other), cooling (electric, thermal, other), work production (electric, fossil-fuel), electricity generation, and kinetic energy production. In evaluating exergy commodities, one needs to specify a reference environment. In the present analysis, a reference environment which emulates the actual physical environment is utilized.

Each of the industry categories in the industrial sector are analyzed separately, and then combined in a comprehensive assessment of the sector. In the present analysis, a simplified approach is taken to evaluating exergy parameters. Here, we utilize global energy data for the industrial sector in 2005 as provided by IEA (2007a,b), which provides energy inputs, in terms of energy type, to each industry category in the global industrial sector. We then incorporate the energy and exergy efficiencies for the utilization of the different energy commodities in the industry sector, as determined in a previous global energy and exergy analysis (Nakicenovic et al., 1996). The assumption incorporated here is that efficiencies on a global scale have not changed significantly on a global scale over the last ten to 15 years for the different industries in the global industrial sector. This assumption may not introduce significant inaccuracies, because although the efficiencies of technologies utilized in highly developed countries may have risen over the last decade, the same phenomenon may not be true in many developing countries where the focus has been on increased energy use to drive economic development. In addition, the observation of Nakicenovic et al. (1996) that heat input to the industrial sector is predominantly for low- and medium-temperature heating, as well as process heating, is used, so the exergy of the heat input to the sector is thus taken to be 28% of the energy.

The energy and exergy inputs and product outputs for the overall global industrial sector are presented in Table 1. For simplicity, exergy and energy values are assumed equal for commodities which normally exhibit an exergy–energy ratio of approximately one (e.g., most fossil fuels). Also, it is assumed for biofuels that the energy–exergy ratio is unity, and that the energy–exergy ratio for biofuels is representative of that for all the renewables. In the present analysis, a reference environment which emulates the actual physical environment is utilized. The input energy and product energy quantities are the same for heat because the heat is treated as a product and thus requires no processing, so the input flows through to the product. A similar observation is made for the input exergy and product exergy quantities for heat.

Note that the input energy to the 2005 global industrial sector shown in the present energy and exergy analyses differs from that reported in the IEA Energy Technology Perspectives document, which lists a value of 115 EJ. The difference is due to coke ovens, blast furnaces and feedstock energy for petrochemicals being included and treated as parts of other sectors and excluded from the industrial sector in the present analysis, even though they are included in the industrial sector in the IEA report. The impact of this difference on the results is minor, as the efficiencies and fractional conversions of energy and exergy in the present analysis do not change significantly if coke ovens, blast furnaces and feedstock energy for petrochemicals are included in the present analysis.

The overall efficiencies for the global energy sector, evaluated as the ratio of product to input using values from Table 1, are found to be 51% based on energy and 30% based on exergy. Consequently, exergy analysis indicates a less efficient picture of energy use in the global industrial sector than does energy analysis. A larger margin for improvement exists from an exergy perspective, compared to the overly optimistic margin indicated by energy. An energy analysis of energy utilization in the global industrial sector does not provide a true picture of how well energy resources entering it are utilized. An assessment based on energy can be misleading because it often indicates the main inefficiencies to be in the wrong sectors, and a state of technological efficiency higher than actually exists. Exergy parameters provide a powerful tool for indicating to industry and government where emphasis should be placed in programs to improve the use of the exergy associated with the main energy resources. Furthermore, such knowledge provides important insights about potential priorities for future research and development initiatives, in that the greatest potential for improvements is likely in processes where the margin for improvement is greatest.

3. Analysis of industries in the global industrial sector

It is useful to assess separately the different industrial groups that make up the global industrial sector. Such an analysis is reported here, by using the relevant industry groupings. A breakdown by energy commodity type of the energy and exergy flows in the industry groups is presented in Table 2. Energy and exergy efficiencies of the

Table 1
Global industrial sector energy and exergy flows (in EJ) in 2005, by energy commodity type[a].

Energy commodity	Input energy	Product energy	Input exergy	Product exergy
Coal and coal products	21.5	9.3	21.5	3.3
Crude, NGL & feedstocks, petroleum products	13.6	3.4	13.6	3.0
Natural gas	18.1	10.2	18.1	3.7
Electricity	22.3	15.7	22.3	12.7
Heat	4.6	4.6	1.3	1.3
Renewables (including combustible renewables and waste, geothermal, and solar/wind/other)	7.5	1.5	7.5	1.0
Nuclear	0.0	0.0	0.0	0.0
Hydro	0.0	0.0	0.0	0.0
Total	87.6	44.6	84.3	25.1

[a] Columns may not sum exactly due to round-off errors. Units are exajoules (EJ), which is equal to 10^{18} J or 23.8846 mtoe (million tons of oil equivalent).