INTERNATIONAL ENERGY AGENCY
AGENCE INTERNATIONALE DE L'ENERGIE

ASSESSING MEASURES OF ENERGY EFFICIENCY PERFORMANCE AND THEIR APPLICATION IN INDUSTRY

IEA INFORMATION PAPER

In Support of the G8 Plan of Action

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INTERNATIONAL ENERGY AGENCY

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Executive Summary

Energy efficiency improvement is a basic, yet significant, way of addressing both energy security and environment concerns. There are various measures of industrial energy efficiency performance, with different purposes and applications. This paper explores different measures of energy efficiency performance (hereafter referred to as "MEEP"): absolute energy consumption, energy intensity, diffusion of specific energy-saving technology and thermal efficiency. It discusses their advantages and disadvantages and their roles within policy frameworks.

MEEP may be necessary at several stages during policy design: in a developing regulatory framework; during the actual application; and in evaluation after policy implementation. Policy makers should consider the suitability of MEEP at each of these stages, based on criteria such as *reliability*, *feasibility* and *verifiability*.

The paper considers the importance of so-called boundary definitions when measuring energy performance, and how these affect the appropriateness of country comparisons to guide policy decisions. The use of energy data without detailed documentation of assumption and boundary definitions should be limited to the analysis of individual production units, and not for comparison beyond its boundary. International comparison requires more carefully considered data. When addressing the complex engineering and economic factors that influence energy use in a country, consistent and systematic methodology is essential.

The paper also addresses the limitations of both energy intensity and technology diffusion indicators as measures of energy efficiency performance. A case study on Japan's iron and steel industry illustrates the critical role of proper boundary definitions for a meaningful assessment of energy efficiency in industry. Depending on the boundaries set for the analysis, the energy consumption per ton of crude steel ranges from 16 to 21 GJ. Both a proper understanding of various methods to assess energy efficiency and the linkage with policy objectives and frameworks are important. Using the *diffusion rates* of specific energy-efficient processes is a technology-oriented approach which seeks to encourage the retrofitting or replacement of less efficient equipment. There are fewer boundary problems using diffusion rates than by calculating energy consumption.

The link between MEEP and policy design is essential, yet sometimes overlooked. First, policies need to recognize which entities are likely to implement energy efficiency improvements. These may be multi-national, multi-activity companies that have to face different country-level policies. Second, efficiency policy and analysis should be considered from the broader perspective of economy-wide energy efficiency improvement. Since industrial products are used all across society, energy efficiency should be measured, to the extent possible, in broader boundary terms, to decrease energy consumption from society as a whole.

Preparation of an accessible database of energy input/outputs would facilitate the calculation of MEEP in globally-applicable terms. Prior to the establishment of such an information source, governments and/or industrial actors should reach a consensus on the fundamentals of evaluation: defining boundaries, the processes within boundaries and those located upstream, and matching boundary definitions with objects, to enable a more meaningful, policy-relevant comparison.

The difficulty of a thorough data collection and the issue of the confidentiality of information cannot be overestimated. Industrial federations/associations play an important role in this particularly difficult context, yet the involvement of governments is critical for further development of databases which can be applicable for industry energy efficiency policy purposes and help, if desirable, policy convergence at some international level.

1 Various Measures of Energy Efficiency Performance (MEEP)

1.1 Context

The profile of energy efficiency has risen recently, due to increased concerns about local and global environmental impacts of energy use. Challenges to energy security have also brought energy efficiency to the fore, as they directly contribute to reducing energy use.

This paper responds to the July 2005 mandate of the G8 Gleneagles Summit, at which leaders of the G8 and five major developing nations addressed the challenges to climate change, sustainable development and energy security. As requested by the G8, the IEA has undertaken assessment of the performance of energy efficiency policy and identified areas ripe for further analysis in four key sectors: buildings, appliances, transport and industry.[1] The IEA's contribution is to analyse and identify best practices and to indicate potential efficiency improvements and appropriate policy approaches to realise potential efficiencies.

This paper focuses on industry and shows the IEA role in the provision of information on the issue of energy efficiency measurement, an essential component towards recommendations for enhancing energy efficiency in industry.

Given the number and the complexity of industrial processes and product end-uses, designing consistent and comparable efficiency indices is extremely difficult. The objectives of this paper are to describe indices of energy efficiency performance in industry, which will be used in policy-making/implementation processes, and to clarify the characteristics of each index, noting advantages and disadvantages, political implications and links to policy framework. The paper also addresses the importance of systematic methodology by presenting the case of the Japanese iron and steel industry to illustrate the importance of defining the boundaries of efficiency assessment.

1.2 Definitions and categories of MEEP (Measuring Energy Efficiency Performance)

There are ways to measure how energy is efficiently or inefficiently used in, for example, a particular factory, company or country. In this paper, such ways of generating certain indices to express those efficiencies are called "measures of energy efficiency performance" (MEEPs).

Several MEEPs have been applied to industrial energy use. In this paper, these indices include:

1) *Thermal energy efficiency[2] of equipment – energy value available for production/operation divided by input energy value,*
2) *Energy consumption intensity – energy value divided by certain physical value,*
3) *Absolute amount of energy consumption – energy value, and*
4) *Diffusion rates of energy efficient facilities/types of equipment.*

1) and 2) are traditionally presented as "energy efficiency".

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[1] See the communiqué of the G8 Gleneagles summit at: http://www.g8.gov.uk/Files/kFile/PostG8_Gleneagles_Communique.pdf

[2] Thermal efficiency is the term of thermodynamics and measures the ratio of *heat* and/or *work* to energy input. The maximum efficiency is limited to 1 (100%) by the second law of thermodynamics.

Patterson (1996) gave a thorough critical review of the range of thermodynamic energy efficiency "indicators". This included the above points numbered 1) and 2) as "physical-thermodynamic indicators". The categories of "economic–thermodynamic indicators" and "pure economic indicators" of energy efficiency, such as "energy: GDP" or "energy cost: GDP" were also mentioned in Patterson's review. This paper excludes these economic indices, as it primarily focuses on indices which are possibly used in policy processes for a specific industry sector. Economic indices have advantages when they are used in macro review in overall situations.[3]

1) Thermal energy efficiency of equipment

The thermal efficiency of a piece of equipment is expressed by: **energy output/energy input** for end-use technology and energy conversion technology. For example, the energy efficiency of a steam boiler is energy amount as steam output divided by input heat to boil the water inside. In the case of motors, it should be power output divided by input electricity.

2) Energy consumption intensity (unit of energy consumption, specific energy consumption)

For this index, the energy consumption is divided by the physical output value (or some economic value) thereof. In a similar way to point 1), it can be expressed as **energy input/output**.

In comparison to the application of thermal efficiency measurement, indices of energy consumption can be used to assess and compare energy performance for a broader set of objects: processes, factories, companies, and even countries. A recent IEA publication, *Tracking Industrial Energy Efficiency and CO2 emissions* (IEA, 2007b), called a statistical tool, as one of MEEPs, "indicator", which measures energy use based on physical production of industrial products. This indicator is not influenced by price fluctuations (IEA, 2007) and can be directly related to process operations and technology choice.

Because the denominator of energy intensity is a physical value, comparison of energy use in different units and aggregate efficiency for the whole of manufacturing is effectively impossible without the conversion of the physical units' value into a common value. Even at disaggregated levels like a single industry, the energy data corresponding to products and processes are not always forthcoming. Another problem related to the energy consumption intensity index, the definition of proper and comparable boundaries (boundary definition), is discussed below (See Box 1 and Chapter 3).

3) Absolute amount of energy consumption – heat value

The absolute amount of energy consumption is sometimes used as MEEP, although the measure loses its relevance from an energy efficiency perspective if it is not accompanied by an indication of production volumes. A problem similar to *energy consumption intensity* arises when we compare various boundary definitions, as addressed in more detail in the box in this section and in Chapter 3.

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[3] A recent IEA publication, *Energy Use in the New Millennium* (IEA, 2007c) adopted energy use and CO_2 emissions per unit of value-added, for country comparisons of specific industries (e.g. iron and steel, cement, aluminium, etc.). The denominator for this measure is the economic value. This approach enables the comparison of energy use across different sub-sectors inside a given industry, although these sub-sectors often generate different products. However, economic-based indicators suffer from vulnerability to a range of pricing effects that are not related to changes in the level of underlying physical production.

4) Diffusion rates of energy efficient facilities/types of equipment

The diffusion rate indicates the rate of deployment of a specific technology which has been identified as being energy efficient. Individual technologies share some common features, including energy performance, with slight variations from one location of use to the other. The rate of diffusion of well-identified energy efficient technologies can therefore indicate progress towards enhanced energy efficiency, assuming that installation implies actual use of the equipment. (The application of, and issues related to these measures are discussed in section 2.4.2.)

Because MEEPs seek to measure performance, they are of a strategic value and readily used for comparisons, while there can be great variation in the way a single MEEP is used from one factory or country to the next. Such comparisons should not be carried out without further documentation on how each MEEP is computed. Furthermore, some indices are elaborated for a given analytical purpose, yet used for another. The following documentation of indices is therefore crucial:

- the assumptions and data used;
- uncertainty of the background data due to difficulties in data collection;
- their suitability for the original analytical purpose; and
- their suitability for a broader and longer-term application, beyond the original purpose.

It is essential that MEEP be appropriately documented before they are used, especially in the process of policy making, or for the evaluation of specific policy measures. The above four MEEP are by no means interchangeable and should therefore be selected with care.

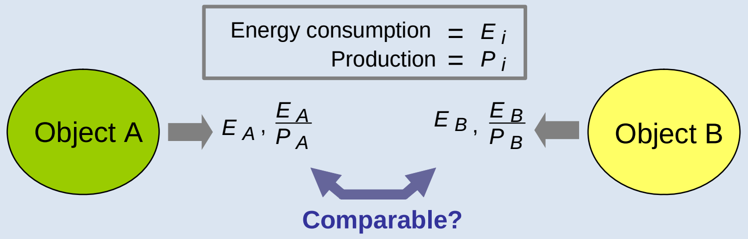
Box 1: An object's defined boundary influences the object's energy efficiency

Assume a case of calculation of energy consumption of certain objects. The energy consumption is counted within some ranges (e.g. country, company, mill) based on assumptions. These conditions of ranges and assumptions for each assessment will be referred to here as the *boundary*. Logically, the measurements of two objects' energy consumption for the comparison purpose are least complicated when the objects are structurally identical during the observation period, *i.e.*, the objects' boundaries are identical (see Figure 1). When objects' boundaries are incongruent, care must be taken in drawing conclusions from an energy efficiency comparison.

When assessing how much energy is consumed to produce similar products, the products' uniformity can be difficult to justify. While the calculation of thermal efficiency *does* involve a single product, energy, in the form of heat or power, few other industrial products are as straightforward to compare. Assessment of the energy consumed by industrial materials production can involve a range of products: steel, cement, chemical products, pulp and paper. Here, energy efficiency calculation is first and foremost a problem of boundary definition, i.e., which objects and which characteristics of these objects can be compared in a meaningful way. When we talk of *energy consumption divided by production volume* (E_i/P_i), the question is what the production covers. In the case of steel, are we considering pig iron or crude steel or finished steel products including all kinds of steel? In the case of cement, are we using clinker (the main component of cement) or various blended cements as indicators of output?

A second problem of boundary definition is what the object consists of in its boundary, as this defines what energy flows are included in the analysis, i.e. in Ei. For the sake of illustration, let us assume two objects A and B, which are defined with a certain boundary (e.g. a country, an enterprise or a single mill). In our example, we assume that our MEEP indicates a lower efficiency for object A.

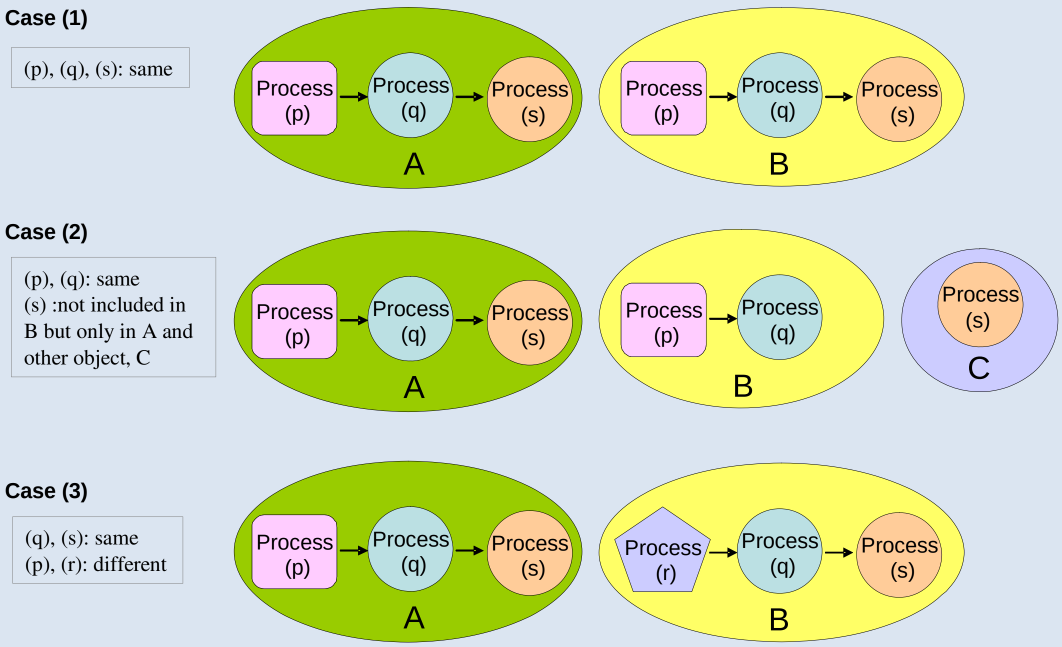
Figure 1: Comparison of energy efficiency between two objects



The question arises when one (policy maker, or company) tries to compare and close the gap between the energy efficiency of A and B, or whether both A and B's values should be improved to aim for a benchmark target. If the components of B differ greatly from A, one may doubt the validity of comparing these objects' efficiencies. Generally speaking, the difference of components grows with the breadth of the system boundary. In the case of equipment, which is used at each process in Figure 2, the element for comparison is easy to select, and can be readily compared.

Three cases for different components of A and B are assumed in Figure 2. Case (1) is where processes are identical in A and B. In this ideal case, EA and EB are comparable. Case (2) assumes that the last process (s) is outsourced to object C. In this case, the comparison between A and B is not appropriate. Some kind of data treatment would be necessary to make the comparison valid, e.g. adding up B and C, or, separating process (s) in A.

Figure 2: Different components within the same boundary



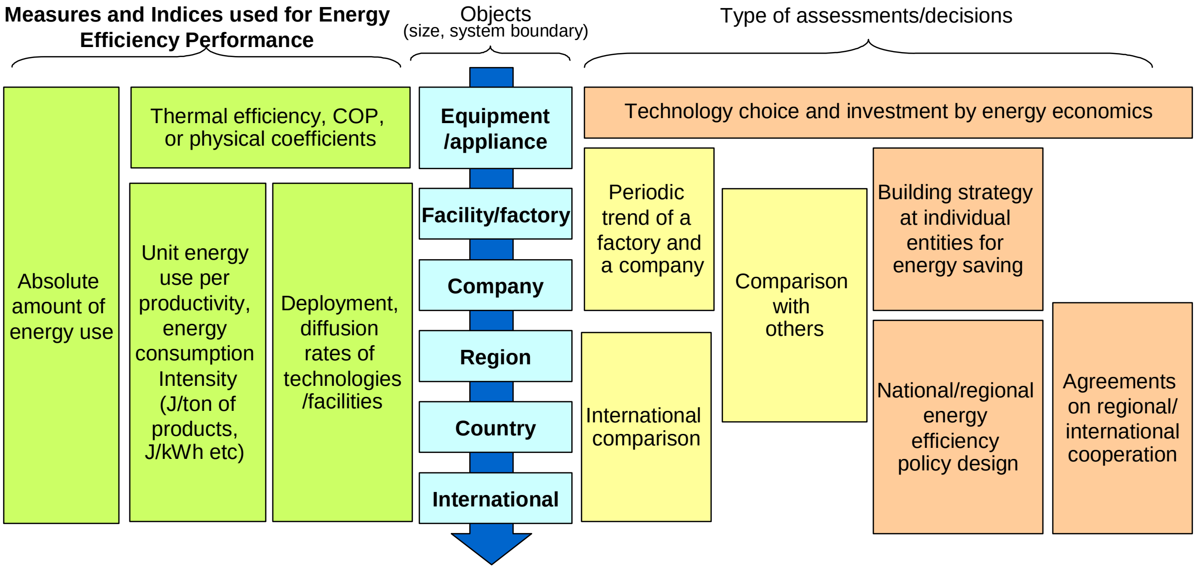
In case (3), the first process is process (r) in B, different from (p) in A. A comparative assessment in such circumstances is like weighing and comparing two baskets: one with apples and bananas, and another with apples and grapes, with results subject to interpretation. In principle, direct comparison would not be valid as components differ; however if process (r) were perfectly substitutable to process (p) and available to A without practical problems, such as problems of a legal, economic, geographical or social nature, a comparison of E_A with E_B would be possible. It could indicate whether A should seek an improvement through the adoption of process (r). Such cases may be rare, however, as various considerations influence decisions regarding individual components.

1.3 Applications/Uses of MEEP

The above measures of energy efficiency performance can be applied to suit a range of purposes. These examples illustrate the choice of measures and their strategic application (see also Figure 3).

- An industrial facility operator seeking to use energy economically may focus on *thermal efficiency* as MEEP, *i.e.*, the total output of useable energy divided by energy input.
- If a company wants to see the trend of energy use in different factories and compare their productivity per unit of energy used (so-called "*energy consumption intensity*" or "*unit energy consumption*"), it may adopt the energy input divided by output for each facility.
- Total amount of energy use is sometimes used as a target in an industry's voluntary agreement. The estimation of how industry predicts its energy consumption and production in future is flexible in the agreement.[4]

Figure 3: Measures and indices of energy efficiency performance



Indeed, the MEEP used should depend on the strategic purpose of its calculation. Inappropriate use of MEEP may mislead the political direction or decision. For example, assume the case that a policy maker gathers data of the energy consumption intensity that was originally produced to investigate each company's trends. The data are useful as background information of energy consumption profiles for each company. The individual or aggregated data, however, cannot be compared with others for further application such as national or regional energy policy design or agreement, as each number was calculated in a unique boundary definition.

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[4] For climate change policy purposes, total GHG emissions have been used as a comprehensive indicator of a country's overall contribution to atmospheric GHG concentrations This is the case for GHG emissions under discussion on climate change negotiation, not for energy efficiency. There is no national target for energy efficiency under any international scheme yet.

More comprehensive indices exist that include the broader energy implications of industrial products, including their ability to be recycled or their transformation into energy at the end of their lifetime (*e.g.* petro-chemicals that use fuels as feedstock). This MEEP considers products' full lifecycle use rather than limiting the analysis to production alone, with boundaries limited to a company or a single country.

This paper does not cover such broad-based, life-cycle oriented measures of energy efficiency performance. Instead, the primary objective of this paper is to clarify how measurement of energy efficiency performance can inform the creation and implementation of sound policy. The indices seeking to cover a product's lifecycle in the longer term need to be evaluated beyond the energy use on the factory floor, tracking its use across boundaries regulated by various policy instruments, going beyond the domain of energy efficiency policy.[5] The choice of MEEP must be guided by its strategic use in a policy-making context.

2 Policy and MEEP

2.1 Policy application of MEEP

Several policies in place today rely on MEEP, primarily to evaluate regulatory performance. According to Jollands and Patterson (2004), "the need for indicators (particularly national-level indicators) to be relevant to policy is a common theme throughout the indicators' literature." In industry, examples include the energy efficiency of electric motors (output over power input) used in the USA Energy Policy Act and EU energy labels (US, 2005; IEA, 2006a). The Dutch benchmark Covenant and the Japanese Energy Conservation Law both use energy intensity targets expressed as energy per ton of products (Netherlands, 1999) (ECCJ 2007). The Canadian GHG Challenge Registry encourages the Canadian industry to reduce its CO2 emissions based on an absolute target (CSA, 2007). The UK Emission Trading System (DEFRA, 2001a), the UK Climate Change Agreement (DEFRA 2001b) and Japan's Keidanren (Japan Business Federation) Voluntary Action Plan (Keidanren, 1997) all adopt both intensity and absolute amounts of energy and CO2 as MEEP. China's 11th Five-Year-Plan (NDRC, 2007) targets annual 4% reduction of domestic energy consumption per GDP. The Plan specifies the closure of several energy-inefficient industrial facilities, indirectly stimulating the diffusion of higher-efficiency facilities. Table 1 summarises these examples.

Table 1: Current policies and measures involving MEEP

	Total energy consumption	Energy consumption intensity	Diffusion rate of technology	Thermal energy efficiency
China Five Year Plan		x	x	
Dutch Benchmark Covenants		x		
Japan Energy Conservation Law		x		
Japan Keidanren Voluntary Action Plan	x	x		
EU Energy Labels				x
UK Emissions Trading System	x	x		
UK Climate Change Agreement	x	x		
USA Energy Policy Act				x

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[5] In the case of steel, the life-cycle is 50-100 years, when used in buildings and infrastructure.

2.2 Fundamental issues for application of MEEP in policy

2.2.1 Country, company or global level

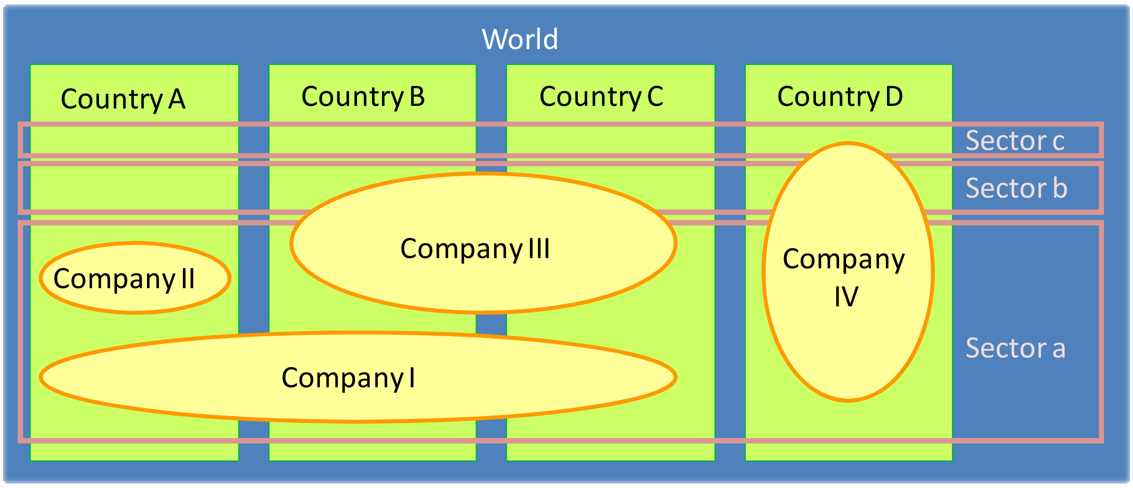
As multinational industrial companies become ever more widespread, why do countries' energy authorities and analysts persist in maintaining country-wide measures of energy efficiency performance? The answer is simple. In most cases, policy is decided at the national level and enforced at the national and sub-national levels, where its effects can be observed and assessed. Moreover, national circumstances also matter, among which energy price levels are a principal consideration in technology and energy choices. Rather than making international comparison a purpose in and of itself, it should be targeted to make useful indices for country policy, based on a method whereby regional and national differences can be clearly considered – only then can sources of inefficiency be best identified, as opposed to national circumstances, changes to which could be well beyond the reach of energy efficiency policy.

On a company level, when energy is an important component of cost, MEEP ought to be used as an indicator for strategic planning. The boundaries of a single company sometimes cover multiple regions (such as Companies I and III in Figure 4), with different regulatory frameworks, as well as economic and other national circumstances. Some companies cover several sectors (such as companies III and IV in Figure 4).

The entity normally set its economically optimal strategy by region, together with consideration of the global strategy which influences the whole company. Recent international efforts to improve energy efficiency on a global scale include the Asia-Pacific Partnership on Clean Development and Climate (APP) and the G8 Gleneagles Action Plan, (although neither seems to intend to send up a binding regulatory framework). Potential frameworks using indices of energy efficiency include those by industrial sector by sector.

When considering the use of any MEEP at national or broader levels, we should remember that the principal decision-maker may be a company, whose activities may span beyond a single country's boundaries, and beyond a single sector. Policies need to recognize who would actually save energy consumption – industry or business in most cases – and what would be the incentive and disincentive for them.

Figure 4: Schematic views of world in different group



2.2.2 An all-inclusive MEEP: looking beyond the production stage

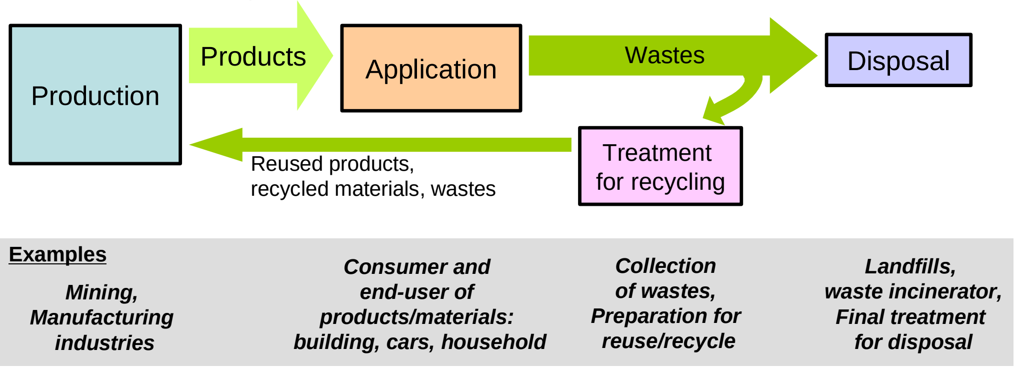
Modern society uses many materials manufactured by industry; it cannot function as it does without them. As mentioned in section 1.3, there is an issue of society-wide energy use. Industrial sectors relate to other sectors, such as residential and transportation sectors. Buildings use cement/concrete and steel for their structures, cars and many appliances use metals (steel and aluminium and so on) and plastics. Secondary materials after the end-use are recovered as re-used products or recycled materials, which reduce the amount of primary material production. Moreover, waste from industry, commercial or residential sectors can be sometimes used as an energy source or feedstock for other production processes.

Life-cycle assessment (LCA) of products can gauge energy use and efficiency within the broad context of societal use of the products. As a recent IEA publication (IEA, 2007b) focuses on life-cycle assessment, this paper briefly introduces LCA as applied within a policy framework.

Figure 5 depicts a schematic view of the various stages from production to disposal of manufactured products. Current energy efficiency policy for industry typically targets the production process only.

In most cases, products and manufactured materials are part of a society-wide flow, as shown in the figure below. When energy saving is the ultimate objective in society as a whole, measurement of energy efficiency should encompass as broad a section of society as is relevant. A product's energy efficiency should be considered throughout its lifecycle, rather than merely at the production stage. As companies specialised in production have limited control over the later use of their products, it seems wise for policy and regulation to indicate how best to achieve the broad objective of energy efficiency.

Figure 5: Scheme of stages from production to disposal of manufactured products



One example covering the production and application stage is the application of light vehicle materials in passenger cars. Fuel economy (energy consumption per distance travelled) increases as vehicle weight decreases. However, the production of lighter but tough steel (high tensed steel) requires slightly more energy than production of conventional steel.[6][7] For energy consumption, Table 2 includes this estimation (JISF, 2006a).

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[6] The hot rolling process to thin the steel is particularly energy-intensive.

[7] The Japanese iron and steel industry estimated that the contribution of high tensed steel for CO_2 emissions reduction of 7.9 Mt-CO_2 in FY 2006, which includes the effects of the decrease in weight and increase of energy used for production. This figure is approximately 4% of total CO_2 consumption from the sector (JISF, 2008).

Table 2: Energy consumption/saving at production and application stages of iron and steel, Japan (2004)

	PJ	Stage*
Passenger Cars		
Fuel savings in transportation sector from using light weight cars	77.7	Application
Energy savings at steel production stage by reducing amount of steel use in cars	18.8	Production
Energy increase according to production of high-tensed steel	0.5	Production
Energy saving total for passenger cars	**96.0**	
Shipping		
Fuel saving in transportation sector by using light weighed vessel	34.6	Application
Energy savings at steel production stage by reducing amount of steel use in vessels	12.2	Production
Energy increase according to production of high-functioned steel	1.5	Production
Energy saving total for shipping	**45.3**	
Transformer (for voltage transformation)		
Electricity savings from decreased energy loss using magnetic steel	75.0	Application
Energy saving at steel production stage by downsizing transformer	0.7	Production
Energy saving total for transformer	**75.7**	

Source of estimation: JISF (2006a)
* Production stage depicted in Figure 5, above.

Another example from the iron and steel industry is the use of blast furnace slag[8] in the cement industry as a feedstock. This is an instance of interaction among industries at the production stage. For the iron and steel sector, slag is a by-product; iron and steel manufacturers expend no added energy to produce it, aside from in its transportation to cement production plants.[9] This is the case of interaction between production stages but of different industries.

Relative to traditional products, "eco-products", can be broadly defined in two ways: products which consume less energy (or emit less CO_2) during their production, or, as mentioned in the case of steel industry above, products which consume more energy during their production, but lead to lower energy use during their application, or elsewhere in their lifecycle. Essential to either definition is the broad boundary within which energy efficiency is defined: in these examples, the energy conserved by society as a whole during all stages of a product's lifespan.

The importance of such eco-products has been recognised (IPCC, 2007; BMVBS, 2007), but few practices exist in which LCA thinking is applied in a policy scheme except for the second generation of Long-Term Agreement on energy efficiency (LTA2) in the Netherlands. In this agreement, the scope of "energy efficiency production development (EEPD)" has been expanded to incorporate all energy savings achieved outside companies participating in the scheme, *i.e.*, all stages of a product's life cycle (SenterNovem, 2007).

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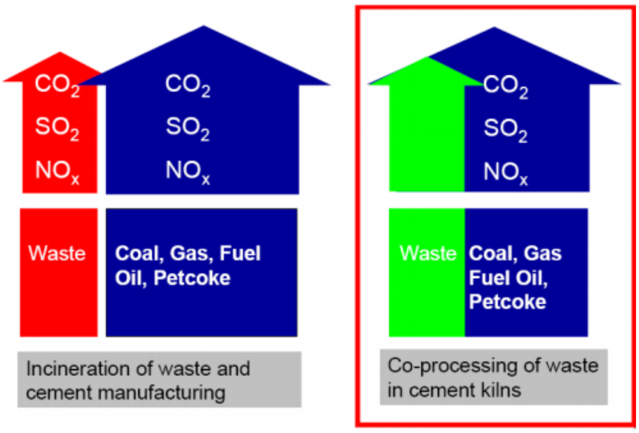
[8] Blast furnace slag is a by-product during the pig iron making process and is composed of nonferrous minerals, which are originally contained in iron ore, lime and cokes. Due to the similarity in contents to cement, the slag is used at cement production.

[9] The Japanese iron and steel industry estimated the CO_2 reduction by this substitution of domestically used slag for new fuel of 4.56 Mt-CO_2 in 2006.

Figure 6 illustrates an example of efficiency including a product's disposal stage.

Figure 6: Merit of waste application in cement industry



Source: Verhagen, 2006

Waste, which will be burned in incineration plants, can be used as fuel at cement production. Such recycling reduces the cement plants' fossil fuel consumption and reduces net CO_2 emissions from fossil fuel, though cement plants themselves have not reduced CO_2 emissions. In order to precisely estimate CO_2 emissions from society, which relates to cement application, the assessment boundary should be extended to the disposal stage.

The above examples illustrate the importance of a broadly-defined boundary for assessment of the efficiency or environmental impact of a particular product. Proper application of MEEP also involves careful selection of the policy and regulatory framework to be measured in assessing an object's energy use. It is probably unrealistic to hope that all interactions and substitutions among sectors and between various stages in a product's lifecycle can thus be assessed and resolved to set a perfect, all-inclusive indicator. The broader the boundary of assessment, the more dynamic the system, and the more difficult it is for one to consistently track changes. In the context of regulation, policy makers should focus initially on remarkable energy increases/decreases in related sectors or stages and explore effective policies to therein promote energy efficiency.

Theoretically, with a proper energy/CO_2 price signal, one would not need full LCA to calculate the "right" contribution of, for example, high-tensed steel, because car users themselves would opt for more efficient cars – if all other conditions were equal. Car makers would respond by buying the appropriate steel, given its overall impact on CO_2 emissions and the cost involved in bringing emissions down. In turn, the steel makers would take the right measures to lower the energy/CO_2 content of their products. In the real world, however, negotiated pricing mechanisms between car manufacturers and iron and steel industries skew the energy/emissions price signal assumed in a perfect market. Car consumers are not entirely economically rational in their choice of vehicle, a further potential distortion in broad-based assessment of product efficiency.

2.3 Criteria for assessment of MEEPs for policies and measures

Policy makers and evaluators of energy efficiency sometimes choose MEEP which would best suit a particular policy purpose. The criteria of *reliability*, *feasibility* and *verifiability* can help identify which indicators to use.

Figure 7: Three criteria for the selection of MEEP

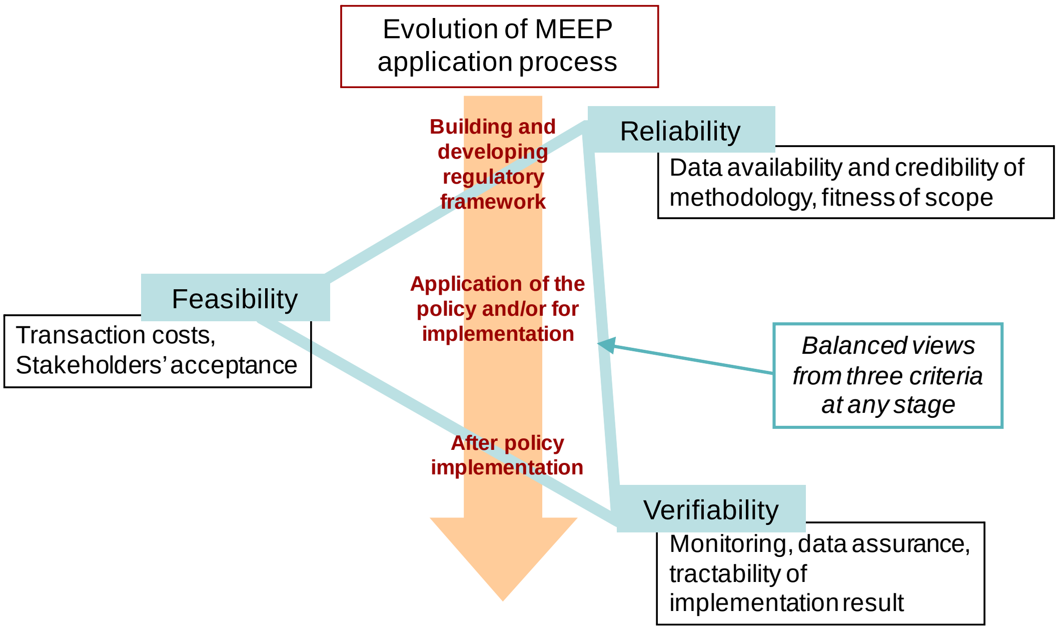


Figure 7 illustrates the application of these three criteria to the MEEP. MEEP may be necessary at several stages during policy design. For example, those stages include the use of indices as resources and information to recognise the present situation *in building and developing regulatory framework*; using indices to set targets for the actual *application of the policy and/or for implementation*; and to evaluate after policy implementation, including verification. MEEP for each stage may either be the same or may vary through all stages. The three dimensions of criteria, which are briefly described below, apply to all stages of the measurement process.

2.3.1 Reliability

- Data credibility

  Measurement of energy efficiency performance first recognizes the uncertainties inherent to available data.

  First, the evaluator must ask *whether the available data are correct.* For example, the IEA book, *Energy Technology Perspectives (IEA, 2006, p. 399)* shows energy use per ton of pig iron in its production at the section of industry. The figure includes lower energy consumption than the theoretical minimum use for iron production, though this is rare.

  Second, a problem in data consistency is observed upon starting the evaluation process. Existing statistics may have been developed for divergent purposes by different organisations. A problem lies in consistency within existing statistics. For example, data on energy consumption and production of the paper and pulp industry differ in current FAO data and IEA data (IEEJ, 2006). [10]

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[10] In this case, it is because such countries, which seem not to have consumed energy, sometimes reported to the IEA their consumption as non-specified industry, not as pulp/paper industry, due to difficulties of data collection by industry.

Third, data conversion/transformation might be an issue. Without conversion, raw data cannot generally be used to calculate efficiency indices. Transformation must render these data scientifically credible and standardized for the purpose intended (Jollands, 2006). They sometime cause the data consistency problems mentioned above. For example, IEA statistics and published member country statistics sometimes show different numbers of energy consumption, even based on the same raw data. Different conversion coefficients, *e.g.* physical to energy units applied by IEA and the country, caused this discrepancy. This could happen whenever raw data is turned into complex statistics. Both sets of statistics are valid, but data users should recognize and understand the driving differences that may arise in definition, application or purpose to avoid any confusion.

- Data availability

We note that current public data are sometimes not available at the level of interest to monitor certain policy instruments. It must therefore be created or gathered as part of the implementation of the new policy. For instance, the scarcity of public information inhibits the assessment of the diffusion of technology in most industrial sectors. To avoid such scarcity of information and indirectly encourage policy compliance, such policies should be accompanied by proper reporting and a monitoring mechanism.

MEEP should be applied within the appropriate scale. Andreasen *et al* stated that "the 'best' scale depends on the scientific and management questions that are being asked" (Andreasen *et al*, 2001). In cases where only aggregated sectoral figures are available for industry, the data are difficult to use for industry-specific policy making in detail. If bottom-up calculation is based on same scale of data, the range of the original estimate determines the final data coverage.

- Data comparability

In developing national policies, policy makers, tend to use energy data as a means to assess change within their country. Credible data with continuity are useful in this kind of trend analysis. In the absence of a proper documentation of how energy efficiency performance indices were drawn – including boundary conditions – their use should be restricted to these national analyses; international comparisons (or comparisons beyond the original data collection boundary) should be treated with extreme care.

Technology-based information for *thermal efficiency* is generally robust and in most cases, sufficiently detailed data will be available for comparison. However, certain technologies reach different efficiency levels depending on local conditions, including the quality of input and style of operation (plant availability and maintenance methods), both of which could differ from entity to entity, or country to country. A plant which operates intermittently for a few hours in the course of a week will record a lower level of efficiency than a plant running continuously over the same period, even if the equipment is identical in both plants.

2.3.2 Feasibility

- Transaction costs

Collection of new data is nearly always costly in terms of both money and time. Existing data should be carefully checked to see whether they can be used for the intended purpose, in terms stated in '*Reliability*' (above). If some modifications are necessary, cost is a factor in '*Feasibility*'. Given that certain data or statistics are well-established, such modification would be as difficult as new data collection, since most aggregate data do not display the level of detail required by the user. How much cost can be acceptable for new collection or modification depends on the policy maker's view of cost effectiveness. Jollands and Patterson (2004) stated that "cost effectiveness is a function of several aspects, including data availability, data volume required, calculation complexity and data processing required." The feasibility should be considered from the contexts of different criteria at same time.

- Industries' acceptance and data confidentiality

Once an agreement exists on the need to collect energy data for a defined purpose, such as *absolute amount of energy consumption* and/or *energy consumption intensity*, evaluators and/or the evaluated industry must define a common method of establishing boundaries for assessment. This normally requires considerable time. Another data barrier is confidentiality, which is always an issue for any index, since they frequently contain competitively sensitive information if generated at the individual plant level.

What may seem like an effective policy may prove less than effective if based on improper or incomplete data provided by industry. In some cases, the threat of policy will trigger industry to share information.

Industrial federations and associations, either national or international, play an important role in this regard. Such organisations can treat energy or technology data confidentially and can supply users of those data with only what they need. For example, the International Aluminium Institute (IAI) and the International Iron and Steel Institute (IISI) have succeeded in collecting data (energy and/or technology) from their member companies in the past. The Cement Sustainable Initiative of the World Business Council of Sustainable Development (WBCSD/CSI) has also agreed and already started to collect energy/CO_2 data according to a well-established protocol. In such cases, however, strong leadership, convening power or reasonable incentive for industry voluntary participation is essential.

2.3.3 Verifiability

- Data monitoring and feedback

It is important to consider whether improved performance in energy efficiency – *e.g.* energy-saving between current consumption levels and the target – is traceable, and whether a cost or dynamic assessment is possible after implementation of the policy using MEEP. The basic questions and their answers depend on the policy scheme: when and how often the policy needs to be assessed; how much authority the evaluator needs and how much confidentiality the assessment requires. Then, as

Gallopín (Gallopín, 1997) summarized, "means for building and monitoring the indicators should be available. This includes financial, human, and technical capacities."

The policy's targeted unit, installations, companies or sectors, will determine the complexity of establishing a data tracking system, necessary in the measurement of *absolute amount of energy consumption* and/or *energy consumption intensity*. The setting of wider boundaries for assessment would better reflect the reality of a product's lifecycle, as previously discussed, but at the expense of an increasingly complex data tracking system. Monitoring the data involved in measurement of *diffusion rates* and *thermal energy efficiency* focuses on targeted technologies and facilities. While including more and more kinds of technologies and facilities reflects the actual industrial situation more closely, the assessment process becomes more costly.

Transaction costs and the overall success of the policy and its framework also influence these considerations.

Using these criteria, evaluators can employ the MEEP appropriate to a particular context. Several related issues are more concretely illustrated below.

2.4 Issues related to indices derived from MEEP

2.4.1 Benchmarking

Benchmarking is originally a strategic management technique whereby a company or organisation evaluates its performance and compares it with best practices to explore the possibility for an improvement in productivity. In the context of energy efficiency, benchmarking involves the measurement of energy efficiency performance according to a standardized format, and setting a particular target based on best performance data called the "benchmark".

The benchmark "Covenants" adopted in the Netherlands have been used to evaluate and improve the energy intensity of a range of industrial processes, including in oil refining, cement, chemical, iron and steel, and non-ferrous metal plants. The participating companies, in collaboration with the government, use the energy intensity of every process as the basis for their future goal, which is to be within the top 10% in performance worldwide. A recent benchmarking study in the iron and steel industry in Canada (NRCAN/CSPA, 2007) uses the best practical model plant, as defined by the International Iron and Steel Institute (IISI, 1998).

As policy makers consider the revision of the EU ETS[11] for 2013 onward, benchmarking has been proposed as an option to allocate emission allowances to various installations within any given industrial activity (Vanderborght, 2006, IEA, 2006b). The option would rest on a CO_2 performance standard that establishes a benchmark for similar activities. For example, the benchmark could be the performance of the top 25% of the enterprises in a sector for a specific parameter. If CO_2 emissions are higher than the benchmark level, emissions must be reduced – or allowances must be purchased to cover emissions in excess of the benchmark – and if lower, the operator receives excess allowances that can be sold or banked for future use. Such an approach would provide a direct incentive to improve the CO_2 intensity of production for under-performing installations, as their production cost would be immediately affected by the

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[11] The European Union Emission Trading Scheme

use of benchmarking to allocate CO_2 allowances. However, the benchmark should be designed to ensure that it encourages a broad improvement in the CO_2 intensity of production, and does not encourage the relocation of certain CO_2-intensive processes outside the plant, at the expense of the environmental goal. In the spirit of linking the EU ETS with other emissions trading systems, the establishment of similar benchmarks and stringencies should preclude divergent treatment of industry at the expense of the environment. The use of benchmarking in the next phase of the ETS is by no means certain, but the quantitative expertise that it brings is certainly useful as governments seek to deliver the right economic signal to industrial sources covered by emissions trading.

2.4.2 Diffusion rates as MEEP: applications and limitations

Across the industrial sector, energy efficiency could be improved by retrofitting or replacing existing equipment. Here we consider the diffusion rate of well-identified energy efficient processes as a MEEP in the context of the policy aims set as part of a government or international promotion of the application of energy efficient technologies, either regionally or globally. The Chinese 11th Five-Year Plan is an example of this. Another example of broad geographical coverage without regulatory intervention is way that the Steel Task Force of the Asia-Pacific Partnership on Clean Development and Climate has surveyed use of various technologies in the iron and steel industry.[12] The primary objective of the survey was to "promote emissions reduction of gases such as CO_2 through the development, introduction, and implementation of existing and emerging cost-effective, cleaner technologies and practices, as well as the transfer of expertise." (APP, 2007)

The diffusion rate as a MEEP avoids several possible difficulties associated with boundary definitions (described in Box 1, pages 8-9). That is simply because this focuses on individual technology, regardless of the total amount of energy consumption in a certain boundary.

Potential estimation

In further application of this index, the potential for improvements in energy efficiency can be estimated by the use of diffusion rates in the equation below.

$$P_{EET} = \Sigma\ P_{EEt} = \Sigma\ (DR_{Tt} - DR_{Ct}) \times EEI_t$$

P_{EET}: total energy efficiency improvement potentials;
P_{EEt}: energy efficiency improvement potentials of each energy efficient technology (equipment/facility, etc);
DR_{Tt}: target diffusion rate of technology;
DR_{Ct}: current diffusion rate of technology;
EEI_t: energy efficiency improvement by technology which is the difference between the processes with and without the technology.

The DR_{Tt} varies due to market, economic, and social factors, such as actual priorities for introduction and energy cost. The EEI_t could be clearly defined because it is focused on a specific technology and a specific process; assumptions about the technology to be replaced should also be carefully considered.

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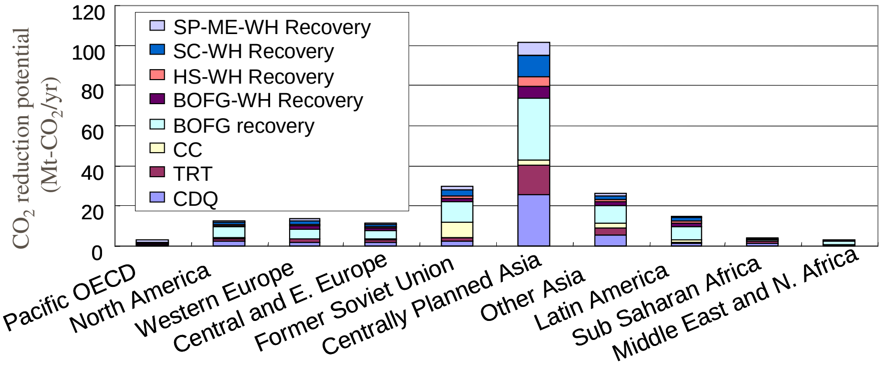
[12] An initial survey was completed at the end of September 2006.

This method has been applied for the estimation of CO_2 emission reduction potentials of the iron and steel industry as of 2030, relying on a survey of DR_{Ct} drawn from the literature, interviews of experts, and questionnaires. It assumed a 100% rate of diffusion of the best available technology - DR_{Tt} (Tanaka *et al.*, 2006). Figure 8 shows results from this research: 0.2 billion tons of CO_2 emissions can be reduced by use of energy efficient technologies in iron and steel on a global scale, with 8 selected technologies.

Figure 8: CO_2 reduction potential of eight technologies (2030, IPCC B2 scenario[13])



Source: Tanaka *et al.*, 2006

Note: Selected technologies include: CDQ (Coke Dry Quenching); TRT (Top-pressure Recovery Turbine); CC (Continuous Casting); BOFG (Basic Oxygen Furnace Gas) recovery; BOFG WH (Waste Heat) recovery; HS (Hot stove) WH Recovery; SC (Sinter cooler) WH Recovery; SP ME (Sinter Plant Main Exhaust)WH Recovery. Region category uses a definition used at the IPCC SRES (see footnote 13).

Two questions will arise upon application of this MEEP, using diffusion rates for potential estimation. The first question is whether the analysis has really considered all the technologies that can deliver energy efficiency improvements. The complete list of technology t in equation (1) is ideal, but is realistically unattainable due to sparse availability of data. The evaluator must choose certain major technologies. The selection will be based on whether they are commercially deployed (i.e. economically feasible), broadly or at least, in certain regions. The above example inFigure 8 adopted eight representative technologies in Japan which have already been much introduced there (most of diffusion rates are from 80 to nearly 100%). Some of them[14] have short investment cost payback time, less than three years (NEDO, 2001). At the beginning of the evaluation process, it is worth focusing on limited but well-promising technologies in order to grasp overviews of their potentials. Then, a technology list should be expanded and fine-tuned by a subsequent detailed survey, if possible.

The second question is whether a universal set of technologies that represents the best economic solution for everyone actually exists. If the answer is no, then what can the MEEP do? A key advantage of this MEEP is that it allows the evaluation to include barrier analysis. The technical potential for energy saving will be drawn by setting 100% of DR_{Tt}, as shown in Figure 8, although the social, economic or market potential close to the actual case can be calculated by considering reachable DR_{Tt}, through analysing what barriers exist to reach to the technical potential. The barrier analysis needs further discussion among a wide range of stakeholders.

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[13] The business-as-usual case uses "B2", one of future development scenarios of the IPCC Special Report on Emission Scenarios, 2000.

[14] except for CC, SC WH and BOFG WH recovery

Application for political use

Establishment of numerical targets for technology transfer using these diffusion rates may be an area for further work. Political judgement should determine the stringency of these targets. In addition, those target settings should be carefully monitored in the context that the discussion connects to the proposition directly linked with individual technology. Originally, investments are focused to allow prioritized introduction of economically efficient technologies. The set of technology used in the market is influenced by national conditions and the existing policy and framework of the respective country.

In addition to policy and regulation, various background conditions in the respective country affect technology diffusion – the amount, quality and prices of natural resources and energy, market requirements and company strategy, among others. Installation of technologies has been optimized given the particular circumstances, such as energy price and availability, especially in industrialized countries.

One good example is coke dry quenching technology (CDQ). CDQ has been broadly recognized as energy efficient technology, but no consensus exists among members of the International Iron and Steel Institute (IISI, 2007) about the improvement of efficiency if CDQ were to replace conventional wet quenching in every region in the world. CDQ has been introduced in countries and regions with a cold climate and/or high energy prices, such as the former Soviet Union and Japan. The latest plants in China and Korea have installed state-of-art technologies, including CDQ. Moreover, for China, there is a more practical and serious reason behind the choice: water scarcity. However, Europe has not introduced CDQ. There may be several reasons:

1) Under certain plant-wide heat balances, it is believed that wet quenching yields a better quality coke that reduces energy needs in the blast furnaces;
2) The new closed type of wet quenching is preferable under European environment regulations because it eliminates dust emissions;
3) There is less incentive for onsite heat application in cases such as power generation using energy from waste heat recovery.

Taking the above into account, it can be seen that uniform target diffusion rates are difficult to set. Policy makers should carefully set a target based on national or regional circumstances by way of, for example, identifying barriers to attain maximum potentials, as mentioned in the previous page. This is important especially when a technology diffusion target is to play a key role in the future framework of energy efficiency and/or climate policy.

While target-setting of a diffusion rate does not seem to be as straightforward as other economically-based policy measures, as a policy instrument for climate change or energy efficiency, it does have several merits: it is technology-oriented and action-induced and directly facilitates retrofitting and replacing, which are essential efforts for energy efficiency improvement. In this example, policy is not misled by boundary problems and policy makers can consider the possible degree of technology deployment when they set their target diffusion rates, for example, through dialogue with industry.

3 The impact of boundary definitions: a case study of the iron and steel industry

Energy consumption and energy intensity are often estimated based on different definitions of an industry's boundaries, making comparison at best difficult, at worse invalid. To elaborate on the basic points noted in Box 1 (see pages 8-9) this chapter examines the case of the iron and steel industry to illustrate the divergent energy intensity measurements produced by different boundary definitions. The case study relies on actual energy data from the Japanese iron and steel industry.

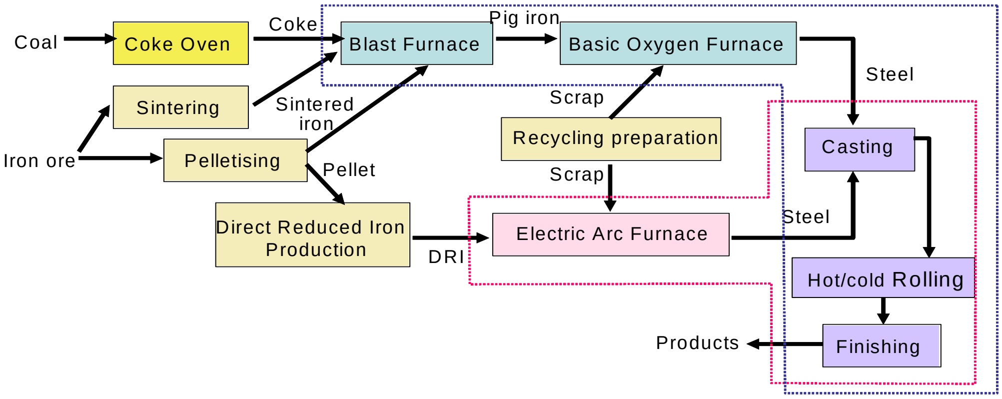
3.1 Issues in boundary definition

3.1.1 In or out? Basic and upstream processes

The basic processes of the iron and steel sector (blast furnace and basic oxygen furnace for integrated plants or electric arc furnace; casting; and hot/cold rolling) are shown inside a boundary in Figure 9. The route of "blast furnace - basic oxygen furnace and latter" and "electric arc furnace and latter" should be separately assessed. In addition to those basic processes, the coke oven, sintering plant, pelletising plant, recycling system, and oxygen plant which supply materials used in those basic processes, are all depicted. It is difficult to set common boundaries according to the possible combination of the components shown in Figure 9. Even in similar enterprises, plants will differ on the exact elements necessary for the process.

In discussions about boundary definitions, an important division is made between processes which take place *inside* plants and those *outside* plants. These outside processes are called upstream processes (Tateishi, 2007). The major upstream structure differs depending on the company and on the country. In the United States, for instance, oxygen, which is used in basic oxygen furnaces, is provided by an independent third party. Accordingly, the energy cost to produce the oxygen is not included in the steel mill accounts in most cases, whereas most Japanese plants include a chemical plant for oxygen, owned and operated by the mill owner. It is important to take such outsourced materials – and the energy used for their production – into account for an energy efficiency assessment if comparisons are used as the basis for an energy efficiency or CO_2 mitigation policy.[15]

Figure 9: Simplified steel making scheme



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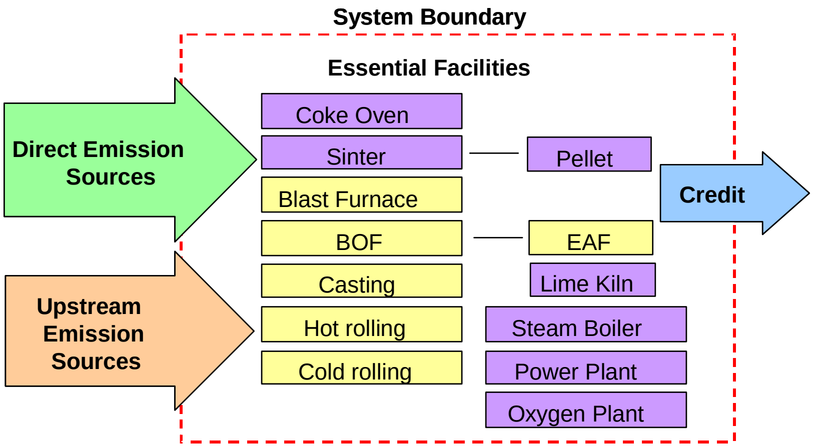
[15] A detailed discussion of a society-wide boundary can be found in Section 2.2.2 (see page 14). - An all-inclusive MEEP: looking beyond the production stage .

Some processes included in the steel sector of one country, do not belong to the steel industry in another country. As indicated in the box in Chapter 1, direct comparison between them is not appropriate, but the outsourcing process can be technically included so as to enable comparison, as seen in recent work of the Asia-Pacific Partnership on Clean Development and Climate (APP) Steel Task Force. Recent discussions there highlighted the importance of counting the energy consumptions and CO_2 emissions of the upstream processes. As agreed during a March 2007 Task Force meeting, it was necessary to gather data in order… *"to prepare common boundary definitions and to solve the problems of boundaries to carry out sector-relevant benchmark and performance indicators."* (APP, 2007). In the survey, "upstream" is counted as energy consumption through energy conversion or material preparation in upstream process beyond the steel plant's boundary, and does not include mining and transportation. Steel plants consume energy, but also supply certain kinds of fuels to other activities, such as tar, by-product gases, and electricity. This energy should be deducted from the amount of gross energy consumption attributed to the plant or process, as illustrated in Figure 10.

Figure 10: The system boundary scheme adopted at the APP Steel Task Force



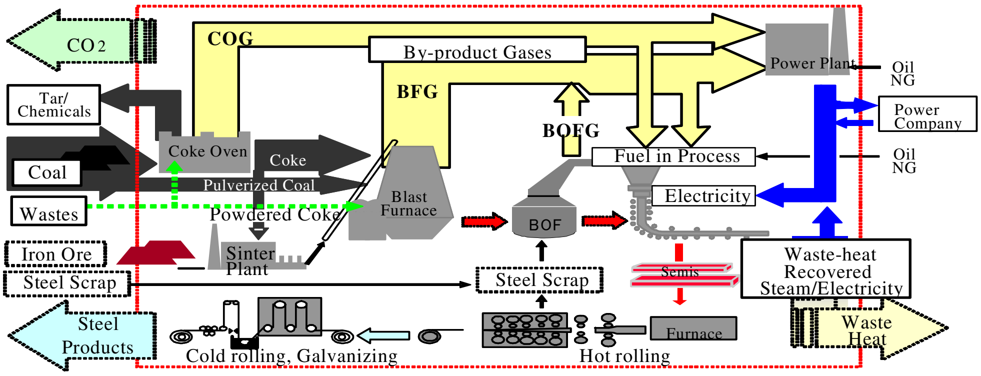
Source: Tateishi, 2007

3.1.2 How and what energy and materials are transferred?

Moreover, as shown in Figure 11, heat and materials are effectively exchanged and used in some cases between processes and/or beyond the mill. The inclusion of these heat and materials in energy performance assessment depends upon the boundary's size. Even with identical components, if a particular process is considered a "small boundary", the means of how heat and material are transferred to the outside should be assessed.

In most Japanese iron and steel plants, blast furnace gas (BFG) is collected and used to generate electricity, with the generation facility included in the plant boundary. Some plants collect waste heat and use it for the generation of electricity and other processes. Each plant or company makes its own decisions about these operations. Heat application should be optimized on the basis of the whole plant's set up and of its environment. In cases where assessment only addresses a blast furnace, considering the energy consumed by the blast furnace as energy consumption on its own can be misleading. Input energy to blast furnace is not necessarily operated at minimum when the BFG used in other processes. The energy passed to such other processes should be deducted from the energy consumption of the blast furnace.

Figure 11: Energy flows of a typical iron and steel plant in Japan



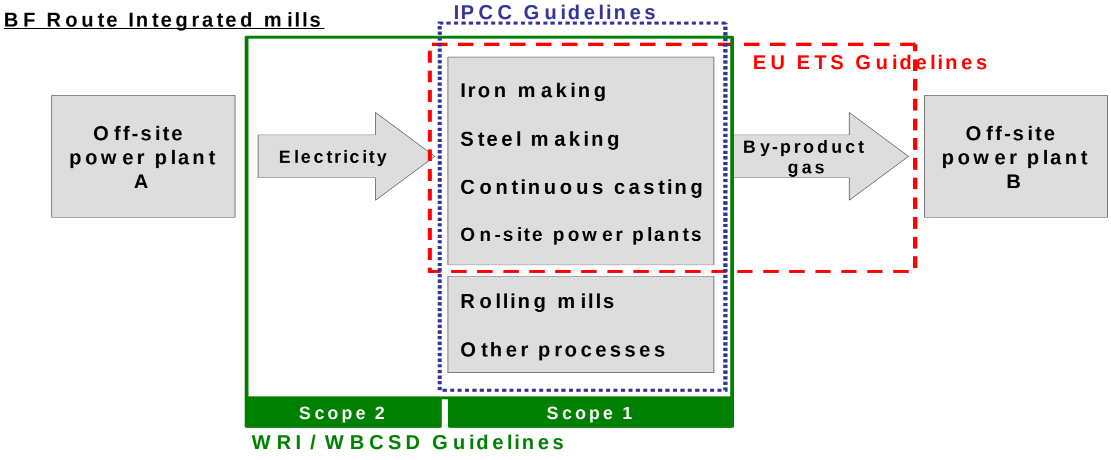
Source: Nippon Steel, 2007

3.2 Varieties of energy efficiency in different boundary settings

Policies or frameworks around the globe require different reporting formats for industrial energy use.

The first example to show the variability of these definitions is shown here. IISI summarised the differences of boundary definitions among three existing international guidelines for green house gas (GHG) emissions of the blast furnace integrated mills (Figure 12). IISI has been discussing how to employ a guideline which will cover processes covered by all other exiting schemes in Figure 12. The EU ETS guideline, for example, considers GHG emissions from iron making, steel making, continuous casting and on-site power plants, and also counts emissions from by-product gas. On the other hand, IPCC guideline includes rolling mills and other processes, but not count emissions from by-product gas. From and energy point of view, almost 80% of total energy is consumed from coke making[16] to casting, just before the hot rolling processes, and 90% is consumed before the cold rolling processes in the case of Japan (JISF, 2006). EUETS guideline should also include these finishing processes for more accurate estimations.

Figure 12: Various boundary definitions by international guidelines for GHG emissions of blast furnace integrated mills



Source: IISI, 2007

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[16] Figure 12 does not include coke making. The ratio of energy consumption of process after rolling will increase without coke making.

The next section illustrates the importance of the defining appropriate boundaries when measuring energy consumption in a given sector.

3.2.1 Various methods to report energy consumption of Japanese iron and steel industry

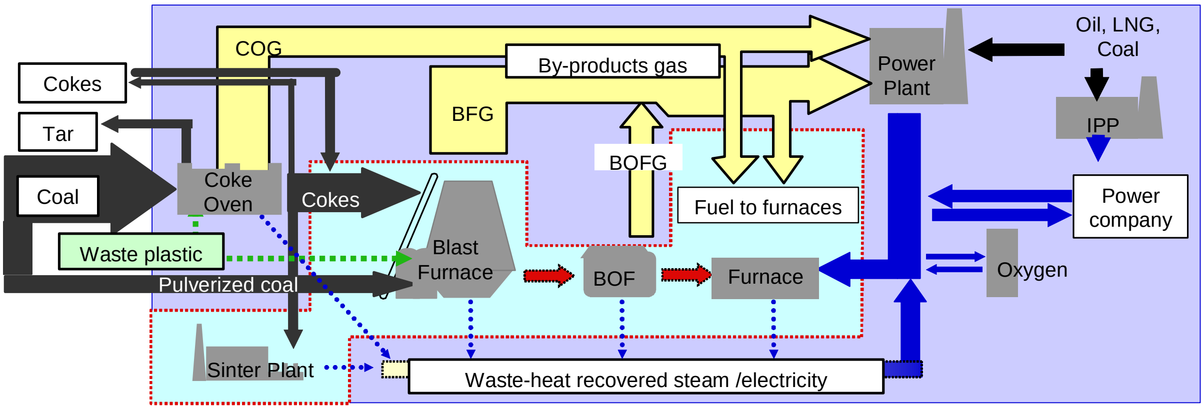
The following subsections include energy statistics from Japan and the IEA. Different characteristics among these methods cause differences of boundary definitions.

- **General Energy Statistics (GES)**

The Japanese government publishes GES, a basic energy database that synthesizes statistics from various official sources of economics statistics (ANRE, 2005) The GES database shows how different kinds of energy sources imported to or produced in Japan are converted and consumed and in which forms, to which sectors, and for which purposes. The energy conversion sector statistics are arranged to highlight final energy consumption.

In the iron and steel industry, each mill reports its energy use every month to the statistics bureau of the Ministry of Economy, Trade and Industry (METI), which aggregates information for the database. Iron and steel industry data includes on-site oxygen plant and energy conversion sectors, such as coke ovens, on-site power plants, waste-heat recovery, and independent power producers (IPP).[17] Energy consumption for oxygen production from external sources (outside the iron and steel boundary) is not counted. The energy from/to those energy conversion facilities/processes is summarized separately in the statistics. To provide a clear picture of total energy consumption, the database counts waste plastic as energy. Electricity produced from waste heat has been translated into primary energy equivalent with 9.0 MJ/kWh, while 3.6 MJ/kWh is used for the final electricity consumption. Figure 13 shows a schematic view of boundary definitions for GES.

Figure 13: Boundary definitions of iron and steel industry for statistics in Japan



Source: Nippon Steel, 2007

Note: The light blue section represents the boundary definition for the final use of iron and steel in as defined in Japan's General Energy Statistics. Elements in the violet section are sorted in energy conversion sectors. Blue solid arrows are electricity, blue dotted arrows are waste heat from processes, light yellow arrows are by-product gas, black arrows show fuel input including coal/cokes, and heat transferred within iron or steel is shown with red arrows.

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[17] It is operated by the iron and steel company, and supplies power not only to the iron and steel industry, but also to the grid.

Coke oven gas (COG) and BFG (depicted with light yellow arrows in Figure 13) are by-product gases regarded as fuel generated from processes and are deducted from the energy consumption amount. However, in cases in which waste heat is also used for power generation (depicted with blue dotted arrows in Figure 13) and electricity use is counted within final energy consumption, the power generated by waste heat is counted as well – in other words, *double counting*.

The total energy consumption related to the iron and steel sector as reported by the latest GES (ANRE, 2005), are shown in Table 3. Numbers of on-site electricity and steam include waste-energy, 66 PJ and 69 PJ, respectively, already accounted for as the energy used at prior processes. Secondary energy use by waste heat recovery should be deducted from the total value.

Table 3: Total energy consumption of iron and steel industry in Japan FY 2003

(PJ)	Energy consumption at energy conversion sectors which related to iron and steel industry			Final energy consumption
	On-site electricity generation	On-site steam generation	Coke production	
Consumption				
Coal and coal products	218	37	196	1253
Petroleum products	22	3	10	88
Gas	10	1	0.3	63
Recovered waste heat	66	69		
Electricity			4	243
Heat			4	104
Production				
Electricity	-112			
Heat		-104		
Net Consumption	**204**	**7**	**215**	**1750**

Source: ANRE 2005

Note: The coke production figure is a sum of coking related data for iron and steel in the statistics: coking production; coking production at steel-chemical plant; and own use at coking process.

- **JISF Report to Nippon Keidanren Voluntary Action Plan**

There exists another collection of data on industrial energy consumption in Japan. The Voluntary Action Plan by the Japan Business Federation (Nippon Keidanren) encourages members of the iron and steel industry to declare CO_2 emission reductions achieved by energy efficiency improvement (Keidanren, 1997).

After each company reports data to the Japan Iron and Steel Federation (JISF), JISF prepares a summary to submit to Keidanren.

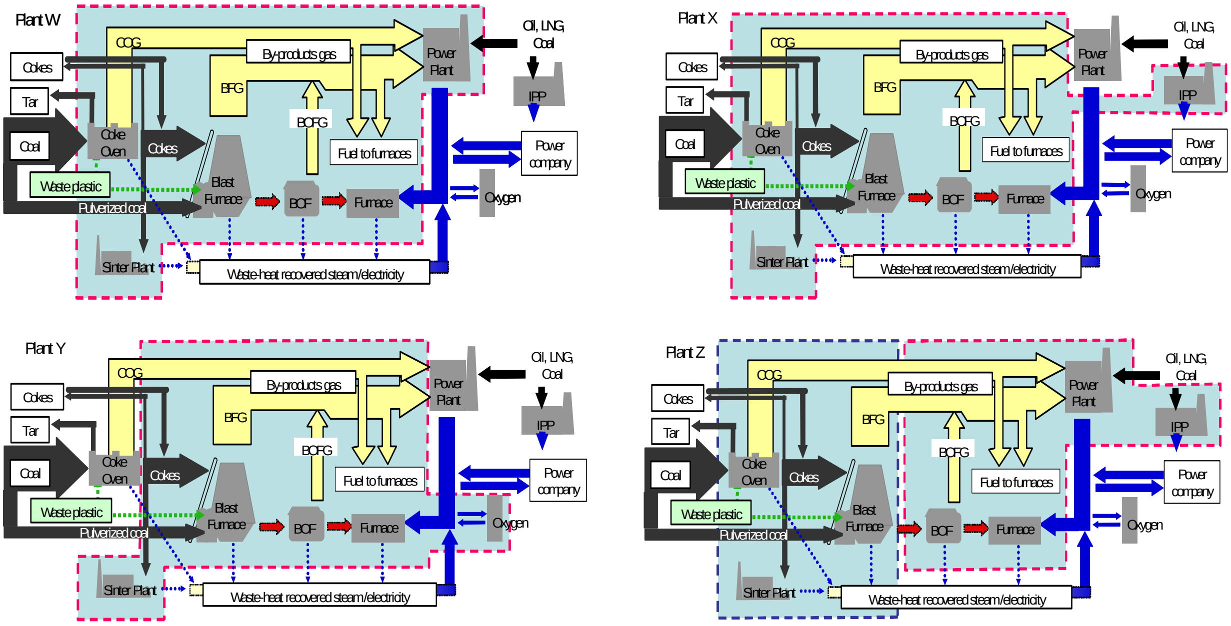
In JISF figures, the boundary is defined to clarify the challenges attributed to the iron and steel industry. All energy input/output related to iron- and steel-making in the plant is taken into account within the boundary, including the same energy conversion sectors as used within GES, except for independent power producers (IPP). Primary energy consumption related to electricity use from grid power is calculated using the coefficient 10.26 MJ/kWh, as based on the value of the year 1990[18] for JISF calculation; and the fixed value which is annually decided for Keidanren calculation. Energy consumption for oxygen from outside is also counted, unlike the treatment of GES. The double counting of electricity produced by waste-heat recovery was avoided and the reported total energy consumption was adjusted downward.

The difference between the Keidanren method and the GES, which shows the energy balance in Japan, is whether each sector's contribution can be separated. The Keidanren agreement initially seeks to measure the iron and steel industry's energy consumption and CO_2 emissions reduction. The guideline of the Keidanren method therefore has a clear boundary definition and can also facilitate MEEP of the iron and steel industry. For the purpose of MEEP of each sector, the indices drawn by the Keidanren method is an example of success.

- **Periodical reporting of factory-level energy use**

As compelled by the Law Concerning the Rational Use of Energy, industry, including iron and steel producers, periodically reports to METI. The purpose of such reports is to promote the energy conservation of the designated energy-using factory, using an energy intensity index to measure conservation. The report does not aim for consistency with statistics covering the schematic energy balances in Japan. It is imposed on the plant/mill, based on a legal entity basis, so that the report does not necessarily cover the "iron and steel industry" and the covering range of boundary of each plant/mill differs greatly.

Figure 14: Examples of boundary definitions for periodical reports from iron and steel industry to the government of Japan



Information source: Nippon Steel, 2007, modified by author

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[18] That is because the objective of this accounting is to evaluate individual sector's contribution for CO_2 reduction, so the energy efficiency improvement in power generation since 1990 should be separated from the energy efficiency efforts in the iron and steel sectors.

Figure 14 shows some examples from Japanese plants now in operation. While Plant W might report a power plant within a boundary, Plant Y might not report a power plant but an oxygen plant, even though both plants have energy input *from* or *to* those plants. Plant X has generation facilities but is registered as IPP. Plant Z is divided into two corporate bodies: first, pig iron production and blast furnace (as shown by the blue dotted line); second, steel-making and finishing processes (as shown by the pink dotted line). The energy intensity indices in this scheme are interesting from the point of view of the performance of each plant or mill, but they are obviously unsuited for comparisons across plants.

Some policies, using company-wide energy intensity targets common to the whole industry, are not particularly useful in an industry characterized by its variety and combination of components.

- **OECD/IEA Energy Statistics and Balances**[19]

These databases have been used in a range of analyses because they represent a unique set of homogenous data for most countries. The energy balance is a presentation of the basic supply and demand data for all fuels in a common energy unit. These characteristics allow easy comparison between fuels. Here, electricity consumption is accounted for with its final energy content (11.6 MJ/kWh) not the primary energy equivalent (3.6 MJ/kWh).

The Japanese data is reported after rearrangement in the IEA format, based on data submitted to General Energy Statistics (stated above). Coal and oil are reported in physical units and gas is expressed in energy units. When converted to energy from a physical unit, a set of conversion coefficients submitted by Japan is used for coal and crude oils; a common coefficient is used for oil products, resulting in slight differences of numbers appearing in data.

A more critical problem concerns the difference in database structure between the GES and the IEA statistics. The IEA statistics feature distinct categories of blast furnace, basic oxygen furnace and coke ovens in the energy conversion sector, though among those three categories, only coke ovens are separated in the case of the GES. Moreover, on-site power and steam production for iron and steel are individually categorized in the GES, but not in the IEA statistics, which shows an aggregated category of on-site generation for all sectors as energy use at *autoproducer plants.*

IEA's energy balance provides a coherent framework for a complete picture of energy flows from supply down to the consuming sectors of activity. It is, however, important to understand that such an energy balance framework provides limited information on the potential use of waste heat recuperated from industrial processes.

Within the energy balance framework, if the recuperated waste heat is the result of industrial processes without energy combustion (e.g.: chemical process), or if the heat is from an energy combustion process and is sold to a third party, then the heat is defined as an energy flow and National Administrations are to report it as such. However, if the recuperated waste heat from an energy combustion process is used within plant gates (not sold to a third party) the framework defines this heat as an "efficiency" gain and such heat is not to be reported. In situations where recuperated waste heat is used as an input to on-site electricity generation, National Administrations are to report the share of the energy input to the industrial

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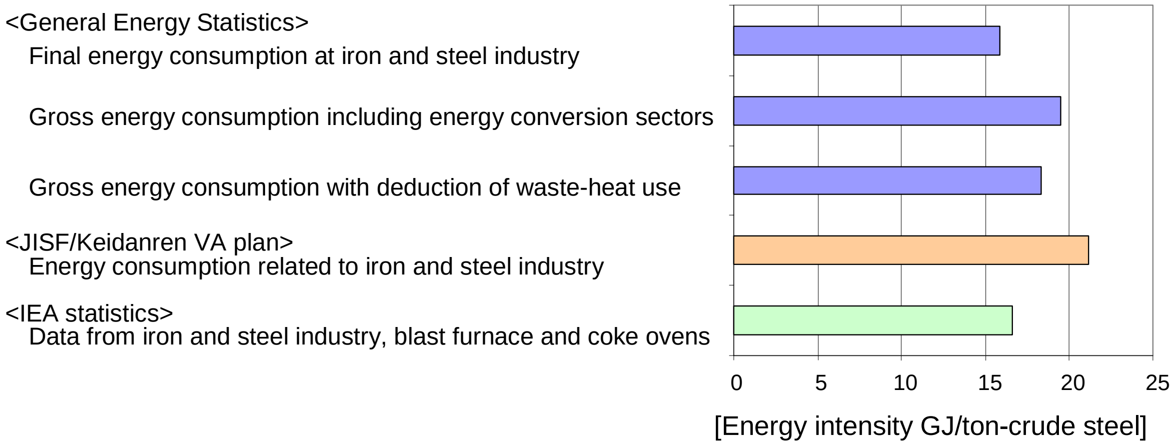
[19] See on-line database at http://data.iea.org .

combustion process that corresponds to the generated electricity is reported as an input to electricity generation in the transformation sector along with its electricity output.

3.2.2 Comparison of results from boundary definitions

This section considers calculation of energy consumption of the iron and steel industry in Japan, utilizing the various reporting formats described in the previous section. Figure 15 shows the results from five different boundary definitions for the three data sources described above: GES, JISF/Keidanren and the IEA database.

Figure 15: Energy intensity of steel production in Japan based on different boundary definitions



Source: JISF 2006b, 2007a; ANRE, 2005; IEA, 2007a.
Note: Data covers FY 2003 for General Energy Statistics and JISF/Keidanren data and calendar year 2003 for the IEA.

Use of the JISF/Keidanren boundary produces the highest value of energy consumption, mainly due to a higher conversion coefficient of electricity,[20] while energy consumption from IEA statistics seems low because items related to iron and steel include 'iron and steel industry, blast furnace and coke ovens', but steam or electricity generation plants in iron and steel sectors are not included. They are not as wide-ranging as ranges applied by the other two data sources, GES and JISF/Keidanren.[21] When the application of waste heat is properly categorized in the statistics, energy intensity drops by 1.2 GJ/ton of crude steel (as shown by the difference between the second and third GES bars in Figure 15), but what remains is relatively small compared to the differences in the conversion coefficient of electricity (as shown in the difference between the JISF/Keidanren bar and the third GES bar). Short-term growth in waste heat would produce a greater potential for difference.

Energy consumptions or indices feature particular boundary definitions to suit an original policy purpose. As far as total energy consumption of a certain sector in Japan is concerned, application of Keidanren methodology is more appropriate than others, *i.e.* using GES or IEA.

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[20] The conversion coefficient of electricity possibly includes: coefficient of physical energy conversion of electricity, *i.e.*, 3.6 MJ/kWh; and calculated coefficient by using actual generation efficiency, e.g. 9.0 MJ/kWh, to show primary energy consumption at generation.

[21] The result of IEA statistics shows the summation of *coke production* and *final energy consumption* in Table 3 as energy consumption of iron and steel industry in Japan.

This is because the Keidanren method is a tailor-made method which has the original purpose of estimating end-use energy consumption (CO_2 emissions).

The energy statistics published from these sources in Section 3.2.1 and secondary indices derived from them, including energy consumption per unit of output, are frequently cited. Given their differing conclusions, an evaluator could note the multiple values for energy consumption of iron and steel industry in Japan. This is the case in several instances, not only in Japan. Without a proper understanding of the background, evaluations could be misleading.

If the evaluator only considers the trend of energy consumption data given by one data source, *e.g.*, trend of energy consumption of iron and steel industry in Japan using the JISF/Keidanren method, the above boundary definition difference does not matter. However, there are cases where an evaluator might try to compare energy consumption beyond the assessment boundary of data from country-by-country or company-by-company, or tries to analyse trends in one country from several sources because of insufficient data in a series from a single data source. In such cases, where more detailed analysis is required, the conclusions which one could draw might be very misleading if evaluators do not use one single homogenous set of data. Cases where this could be relevant would include comparison of the Japanese iron and steel industry based on Keidanren data, and then based on IEA data for developing countries. Another example might be when an evaluator extracts values for the past 10 years from GES data, but takes more recent data from the Keidanren data source because of issues with publication timing, for instance. Such data cannot be shown in the same trend figure without relevant data treatment.

3.3 How to achieve more accurate estimated values of energy consumption

As explained, it is important to define the boundaries of a study when charting energy consumption of industries or countries in using the measures of energy efficiency performance of *energy intensity* or *absolute amount of energy consumption*, especially as when those values are used for comparison. To avoid difficulties on boundary definitions, the *diffusion rate* or *thermal energy efficiency of equipment* can be used, as they focus on technology which is not as concerned with boundary problems. This section, however, discusses what further steps can be taken to achieve more accurate estimated values of energy consumption There are several conceivable ways, as explained below:

- *Preparing a detailed energy input/output database*

  A more detailed explanation appears in a subsequent paragraph.

- *Consensus in defining fundamental processes (components) within boundaries and upstream processes out of boundaries, and matching boundary definitions of objects to be compared*

  As shown in Section 3.1.1: *In or out? Basic and upstream processes*", delineation of fundamental and upstream processes is critical to assessment. Two examples of existing schemes of trying to clarify these boundary conditions through surveys on energy consumption can be found in the Appendix.

- *Focusing on and confirmation of key elements within the system boundary*

  Several factors are essential in assessing energy efficiency performance. Varying by country and often otherwise qualified, these factors include fuel availability, electricity prices, policies and regulations (energy efficiency *and* non-energy efficiency). While s not easy to quantify, all these effects on energy efficiency performance, should nonetheless be considered, for example, when grouping energy consumption data into categories under a particular set of critical elements.[22]

- *Preparing a detailed energy input/output database*

  Data sufficiently detailed to track the whole input and output of energy related to a targeted industry and countries or regions enables most estimations necessary to MEEP. In an ideal situation, detailed data would facilitate the relation of energy input and output for a targeted industry and to particular countries or regions, furthering the possibility of accurate and necessary estimations for energy efficiency.

  IEA *Energy Statistics and Balances* (IEA, 2007a) apply many fuel/energy categories in columns and sectoral or process categories in lines. This can become a good starting point. However, current IEA statistics do not have a breakdown of specific categories in detail, such as the processes within each industrial sector, because they involve national-level data collection.

  In Table 4, horizontal lines might represent processes where energy is consumed or produced. Sector-level on-site electricity and steam generation should be separately categorized too. Columns might represent similar kinds of fuel or energy, as used in IEA statistics,[23] with clear indications of input and output (consumption and production). Additional categories would be necessary to substantiate information about energy and fuels, including waste heat. This energy data collection provides information on more accurate energy in-and-out among processes and from or to the outside. When evaluators compare energy efficiency of specific processes of a country with another, they can identify their process boundaries more easily. Proper understanding on boundary definitions would be facilitated.

In the chemical and petrochemical industries, for example, many processes are integrated by the combination of supply of various products, with the entire process operated to minimize the energy cost. In such integrated systems, even assuming that sufficient detailed data are gathered, it is difficult to compare energy consumption by product of one factory with the product of another factory. In addition, such detailed energy reporting may reveal strategic information about the cost allocation structure of a company to its competitors.

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[22] Most simple examples would be electric furnace ratio in the case of the iron and steel industry, paper/pulp production ratio or recycle use ratio in paper and pulp industry, clinker ratio in cement industry, and so on.

[23] IEA statistics includes in their fuel/energy kinds: hard coal, brown coal, peat, patent fuel, coke oven coke, gas coke, coal tar, BKB/peat briquettes, gas works gas, coke oven gas, blast furnace gas, oxygen steel furnace gas, industrial waste, municipal waste, primary solid biomass, biogas, liquid biomass, charcoal, natural gas, crude/NGL/feedstocks, other hydrocarbons, refinery gas, ethane, LPG, kerosene, gas/diesel oil; residual fuel oil, naphtha, white spirit & SBP, lubricants, bitumen, paraffin waxes, petroleum coke, renewable, and electricity.

Table 4: Example of detailed energy balances of iron and steel industry

				Input				Output			
Processes	Preparation	Coking									
		Sintering									
		Pelletizing									
	Iron making	Blast furnace									
	Steel making	Basic Oxygen Furnace									
		Electric arc furnace									
	Casting	Continuas casting									
		Ingot casting									
	Hot-rolling	Hot strip									
		Plate									
	Cold-rolling	Cold strip									
		Electric sheet									
		Galvanizing									
		Pipe									
	Chemical processes	Gas treatment									
		Chemical products	Nitrogen								
			Oxygen								
			Others								
	Other utilities	Boiler	For generator								
			For process								
		Pump									
		Generator	Steam turbine								
			Gas turbine								
		Blast blower									
	General operation										

When planning to collect energy data detailed by process, potential problems may arise with respect to the Antitrust Law. If the law is interpreted very strictly, two points can be argued, which may be related to price manipulation by enterprises. Sharing of the energy data only by an industrial body, without third party involvement, is connected to sharing cost information. Aligning energy efficiency with certain target that industry may set for itself may correspond to the specific arrangement which also relates to cost. Here again, most importantly, anonymity should be a priority to avoid these possible problems.[24]

Policy makers are possibly misguided in their assessment when boundary definitions are not properly understood as already mentioned. It is, however, a time- consuming process to check every single definition behind published data on every occasion. The detailed database would be one approach for to establish ideal data environment in the future. Evaluators can use clearer data once the database has been established. On the other hand, the establishment of the collection scheme for these data requires time and cost.

Conclusions and Recommendations

Measuring industrial energy efficiency performance (MEEP) takes various forms, purposes and applications. As discussed in this paper, the four kinds of MEEP, *thermal energy efficiency of equipment*, *energy consumption intensity*, *absolute amount of energy consumption*, *diffusion rates of energy efficient facilities*, are unique in their advantages and disadvantages, and roles within policy frameworks. Policymakers and future analysts of MEEP should carefully consider the suitability of their measurements against criteria such as *reliability*, *feasibility* and *verifiability*. There is no ideal and established MEEP that can be applicable to every case. It is not feasible to select the best index for every set of circumstances, but it *is* possible to choose an appropriate gauge for the individual policy or measure. Different indices may be used for different applications or use. A number of different indices may provide insights regarding the robustness of rankings.

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[24] Matter related to anonymousness was also mentioned in section 2.3 "Criteria for assessment of MEEPs for policies and measures".

Boundary definition is a key to proper comparison of energy consumption, which generates *energy consumption intensity*. In the case of Japanese iron and steel industry, differing boundary definitions produce a greater than 25% difference between highest and lowest energy consumption. When energy consumption data is used for a policy purpose, the boundary should be set in a way that is relevant for specific policy. For any further assessment, this purpose behind the data value should be considered.

MEEP application at the international level is hampered by the paucity of data on the energy efficiency indices of industry (IEA 2007b). Accordingly, the IEA presented the following policy recommendation to the G8 2007 Summit, Heiligendamm, "*In order to develop better energy policies for industry, urgent attention is needed to improve the coverage, reliability and timeliness of industry's energy-use data*." As long as each government or international body contributes to the data, they should carefully check the balance between required data for policy making/implementations and available data currently or in future, and also the balance of *feasibility* and *reliability*. Proper reporting and monitoring mechanisms should also accompany sound and coherent policies.

Here, participants should consider the confidentiality of the information on technology as a possible barrier to the collection of perfect information. Confidence between the policymaker and industrial company is a key to an efficiency policy's success. Industrial federations/associations may here play an important role in maintaining data confidentiality. This case, however, needs strong leadership, convening power or reasonable incentive for industry's voluntary participation. The government can promote this scheme too by sharing information and providing positive recognition of compliant industrial firms.

More global homogenous action is better carried out under a strong international industrial body, such as IISI for iron and steel or WBCSD, which currently exists for cement and paper and pulp, or industry-government body such as APP. IEA can be also nominated as the repository of industrial data. The cost of creating additional and elaborate energy reporting formats of industry worldwide, in addition to the existing IEA statistics would be overwhelming, but more realistic than attempting to create entirely new formats. The IEA will ensure the data is compiled with care, since it does not have a unique boundary definition for industry data, and can not predict which definitions are accurate. The future role of IEA should be carefully discussed.

In successfully measuring energy efficiency performance to raise industrial efficiency, government can play several important roles and should be especially aware of its influence on policy development and data collection. Proper use of MEEP, international sharing of policy information and practical cooperation with industry are critical to the society-wide conservation of energy.

APPENDIX

Two Examples of Questionnaire Formats for Measuring Energy Consumption

(1) Example of a questionnaire used by the International Aluminium Institute (IAI)

The questionnaire is sent to IAI member companies so that IAI take stock of their electricity consumption in the primary aluminium production process (smelter). This requires information on production, major technology (cell technology) applied, and electricity, along with their primary sources, such as hydro, coal, oil and/or gas both for power from the grid and from self-generation. The Institute also tries to clarify the breakdown of the use of electricity self-generated to other sources than the smelting process. Fuel conversion factors to calorific values are indicated as a default value by regions and can be used when the actual value is not known.

International Aluminium Institute Confidential Return **IAI**

ELECTRICAL ENERGY USED IN PRIMARY ALUMINIUM SMELTING **FORM ES001**

1. Smelter
   Location of Smelter ____________________
2. Cell Technology
   Cell Technology Category ____________________
3. Primary Aluminium Production
   Production Relating to this Smelter and Cell Technology ☐ Tonnes
4. Electrical Energy Used for Smelting
   Table 1 – Relating to this Smelter and Cell Technology
   (Exclude electrical energy used in anode production and casting. Include electrical energy lost in AC/DC rectification, and the electrical energy used by associated auxiliaries e.g. pollution control equipment, compressed air generation, heating and lighting. See Reporting Guidelines 2 and 3.)

Energy Source	Electrical Energy Used for Primary Aluminium Smelting (GWh)			
	Self generated	Purchased		Total
		From National or Regional Grid	From Other Sources	
	(a)	(b)	(c)	(d) = (a) + (b) + (c)
Hydro				
Coal				
Oil				
Natural Gas				
Nuclear				
Total				

5. Self-Generated Electrical Energy
   (Only complete this Section if appropriate)
   a. Table 2 – Total Electrical Energy Self-Generated (See Reporting Guideline 4)

Energy Source	Electrical Energy Self-Generated (GWh)			
	Used in Operating the Smelter		Used for Other Purposes	Total
	As Reported in Table 1 for Smelting	Other Smelter Operations		
	(a) From Table 1	(e)	(f)	(g) = (a) + (e) + (f)
Hydro				
Coal				
Oil				
Natural Gas				

Note that "Other Smelter Operations" include anode production and casting

b. Table 3 – Quantities of Fuel Used (See Reporting Guidelines 5 and 6)

Energy Source (Fuel)	Total Electrical Energy Self-Generated (GWh) (g) From Table 2	Quantity of Fuel Consumed In Generating Electrical Energy (h)	Calorific Value Of Fuel (j)	Fuel Energy Consumed In Generating Electrical Energy (k) = (h) x (j) x 10^{-9}
Coal		kg	kJ/kg	TJ
Oil		kg	kJ/kg	TJ
Natural Gas		m^3	kJ/m^3	TJ

IAI ENERGY RETURNS DATA SHEET

1. Fuel Calorific Values
   (Default values to be used when precise values are not known)

Energy Source	Default Calorific Value (kJ/kg or kJ/m^3 for Gas)							
	Area 1 Africa	Area 2 North America	Area 3 Latin America	Area 4 East Asia	Area 5 South Asia	Area 6A West Europe	Area 6B East/Central Europe	Area 7 Oceania
Coal	25 728	23 497	23 312	21 422	23 238	24 237	18 386	21 515
Heavy Oil	42 176	41 868	42 860	42 077	42 695	41 868	42 287	41 868
Diesel Oil	42 176	41 868	42 860	42 077	42 695	41 868	42 287	41 868
Gas	40 000	38 200	38 000	39 300	39 300	37 800	37 700	38 200

2. Electrical Energy Generation Conversion Factors
   (Default values to be used when precise values are not known)

Electrical Energy Source	Default Electrical Energy Generation Conversion Factor (kJ/kWh)							
	Area 1 Africa	Area 2 North America	Area 3 Latin America	Area 4 East Asia	Area 5 South Asia	Area 6A West Europe	Area 6B East/Central Europe	Area 7 Oceania
Coal	12 758	10 680	12 939	8 321	12 107	13 498	18 784	15 286
Oil	9 033	8 156	11 776	8 335	12 103	9 018	27 180	11 140
Natural Gas	8 962	6 533	16 837	8 756	10 899	10 529	28 360	10 806

3. Unit Conversion Factors
   (Specific Gravity values for oil are default values to be used when precise values are not known)

Category	Conversion Factors		
Weight	1 kg	=	2.20462 lb
	1 lb	=	0.4536 kg
Volume	1 m^3	=	35.3147 ft^3
	1 ft^3	=	0.0283168 m^3
	1 US Gallon	=	3.7854 litres
	1 UK Gallon	=	4.546 litres
Energy	1 J	=	0.2388 cal
	1 cal	=	4.187 J
	1 kJ	=	0.948 Btu
	1 Btu	=	1055 J
	1 Therm	=	100 000 Btu
	1 kWh	=	3600 kJ

Source: IAI, 2007.

Note: The IEA slightly modified the formats (not the contents), from the original questionnaire. “Reporting Guideline” was omitted.

(2) The APP approach: Indicator Analysis Based on a Common System Boundary to Evaluate Performance

The APP Steel Task Force has tried to survey the details of energy consumption in order to establish a consensus of boundary definitions. The draft of the questionnaire survey questionnaire below shows the attempt to get information on energy consumption from countries from both direct use at site and upstream consumption, as well as from credit (*i.e.* energy sources produced to be used outside of the iron and steel industry).

Consumption Data

Items			Intensity over crude steel	Energy Conversion Factor
Direct Emission	Coal	for coking	kg/t	MJ/kg
		for BF injection	kg/t	MJ/kg
		for BOF, sinter	kg/t	MJ/kg
		for Boiler	kg/t	MJ/kg
		for EAF	kg/t	MJ/kg
	Purchased Coke(Physical)		kg/t	MJ/kg
	Natural Gas	for BF injection	m3/t	MJ/m3
	City Gas	fuel	m3/t	MJ/m3
	Heavy Oil	for BF injection	l/t	MJ/l
		fuel	l/t	MJ/l
	Coal Tar		kg/t	MJ/kg
	Oil Coke		kg/t	MJ/kg
	Light Oil		l/t	MJ/l
	Kerosene		l/t	MJ/l
	LPG		kg/t	MJ/kg
	Lime Stone		kg/t	
	Dolomite		kg/t	
	Others (Specify)			
Sub total				MJ/t-steel
Upstream Emission Source	Purchased Electricity		kWH/t	MJ/kwH
	Purchased Oxygen		m3/t	MJ/m3
	Purchased Nitrogen		m3/t	MJ/m3
	Purchased Steam		kg/t	MJ/kg
	Purchased Coke(Upstream)		0 (Auto input)	MJ/kg
	Purchased Pellet		kg/t	MJ/kg
	Purchased DRI	Natural Gas roots	kg/t	MJ/kg
		Coal roots	kg/t	MJ/kg
	Purchased Pig-Iron		kg/t	MJ/kg
	Burnt Lime		kg/t	MJ/kg
	Burnt Dolomite		kg/t	MJ/kg
	Others (Purchased fuel gas)			
Sub total				MJ/t-steel

Credit Data

Credit		Intensity over crude steel	Energy Conversion
Byproduct Gases	Blast Furnace Gas	m3/t	MJ/m3
	Coke Oven Gas	m3/t	MJ/m3
	BOF Gas	m3/t	MJ/m3
Electricity		kWH/t	MJ/kwH
Other Sources	Coke	kg/t	MJ/kg
	Coal Tar	kg/t	MJ/kg
	Coal Light Oil	l/t	MJ/l
	Steam	kg/t	MJ/kg
	Oxigen	m3/t	MJ/m3
	Nitrogen	m3/t	MJ/m3
	Pig Iron	kg/t	MJ/kg
	Others (specify)		
Sub total			MJ/t-steel

Total	kt-steel	MJ/t-steel

Source: JISF, 2007b

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