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by

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ABSTRACT

When a new fuel is introduced in a large geographical area with many different industries, methods for demand assessment based on the netback value for individual consumers can not be applied. The energy demand forecasts that result from economic models, are not detailed enough to be of any help either. A solution is the formulation of production processes that cover the total energy demand by the manufacturing sector, provided that these processes can be regarded as representative processes. For these production processes the netback value analysis can be applied. Two problems have to be solved: (i) how can a minimal set of production processes be formulated?, and (ii) how can they be linked to national statistics data based on the International Standard for Industrial Classification of economic activities? For both problems a solution is formulated, and this solution is applied to the manufacturing sector of Java in Indonesia.

1 Introduction

Indonesia is one of the newly industrializing economies in Southeast Asia, with a rapidly growing manufacturing sector [23]. The main part of the non-oil industry in Indonesia is concentrated on the island of Java. For their energy supply, most factories use fuel oil or industrial diesel oil from domestic oil production. However, Indonesia also has coal and natural gas reserves. For three reasons the Indonesian government wants to replace the oil products used by the manufacturing sector by natural gas. First, oil products have a higher value at the international market than natural gas has, and can be traded more easily. As the economy grows, domestic energy consumption increases, and efficient use of resources becomes more important. Second, natural gas is less hazardous for the environment, and the environmental problems due to industrialization are growing rapidly on the densely populated island of Java. Third, there are gas reserves in the vicinity of Java that remain unused otherwise. For these reasons the Indonesian government asked Gasunie Engineering in The Netherlands to conduct a feasibility study for gas transmission and distribution on Java. One of the problems encountered during this feasibility study is the estimation of the potential market for natural gas; the major part of this market is potential demand by the manufacturing sector. For the planning of investments in gas transmission and distribution, the Indonesian government needs a realistic assessment of the demand for natural gas after its introduction. For this assessment it must be known which subsectors of the manufacturing sector offer the best marketing opportunities.

An approach often used in case new gas reserves are discovered, is to look for a limited number of large gas based industries that can bear the initial investment costs. By building in some spare capacity, the local market can be served too. However, for a large area such as Java, this concept will not work. Furthermore, in the past several gas based industries (one direct reduction steel plant, and two fertilizer plants) plus some cement production have been constructed, as cheap gas from Liquified Petroleum Gas production became available, and industrialization was at a low level; this gas would otherwise have been flared.

We have to add that, compared with fuel oil substitution, natural gas has a low value in these applications: the fuel oil parity price for natural gas is 154.5 Rupiahs per m^3 (2.50 U$ per million BTU (MMBTU)), whereas the steel plant pays only 38 Rps/m^3 (0.65 U$/MMBTU), the fertilizer industries pay 60 Rps/m^3 (1 U$/MMBTU), and the cement sector can afford 133 Rps/m^3 (2.25 U$/MMBTU). In 1990 the steel plant together with the fertilizer plants used 81% of all the natural gas available; if the cement industry is added 95.8% of the total gas consumption by the manufacturing sector on Java is covered. The share of these industries in the total energy consumption on Java is approximately 50%. Industrial growth is expected to take place in other less energy intensive subsectors of the manufacturing sector.

To forecast energy demand, economists use either economic (normative) or descriptive models that are empirically tested. The consumption model approach is well known in economics [8, 19], but it is not suitable for our problem since it focusses on final energy consumption and has no direct link with the economy's primary energy inputs. The production function and the related cost function approaches are well known economic models that have primary energy as input [3, 9]. However, these approaches do not allow the introduction of a new fuel that can replace (part) of the energy used. In contrast to what the term production function suggests, this approach is not based on a description of the production process, but only links the inputs for production in a mathematical form that allows easy calculation of elasticities. Furthermore, these models assume a constant economic structure, and require many data for estimation; these conditions are not met by a rapid developing economy as Java's.

Descriptive models are often based on energy intensities. Energy intensity is defined as the amount of energy used, divided by production; this production is represented by the gross domestic product or gross value added [1, 2, 14, 17]. If analyzed at a detailed level (e.g. per fuel and per production process), the energy intensities represent the energy intensities of the actual production process [15]. Compared to economic models, descriptive models draw less heavily on data. However, energy intensity models for energy demand forecasts should be treated with caution, because the intensities do in general not take into account changes in the economy's structure [18]. A major drawback of descriptive models is that intensities have no structural relationship with changes in fuel prices, whereas the economic approaches do.

The netback value (or willingness to pay) approach links the demand for natural gas to energy prices at the production process level. The netback value of one fuel compared to another fuel, is defined as the fuel price for which the Net Present Value (NPV) of costs avoided due to the new fuel becomes zero. A netback value larger than the market price of the new fuel, is equivalent to an Internal Rate of Return (IRR) that is larger than the required discount rate. So the netback value of gas with respect to other fuels indicates whether application (in existing and new establishments) is profitable, when gas becomes available. Note that this microeconomic approach requires no data on past gas utilization, whereas the economic and the descriptive approaches do; these data is not available at the moment of planning the introduction of natural gas. What is needed is a description of the roles and costs of energy in the production processes. Note that the energy intensities at the individual production process levels mentioned earlier, are related to the role of energy in the netback value analysis.

A problem is that the netback value analysis is normally applied for a single investment project, by the company that could gain from it, or for a limited number of factories with a similar production process; for instance, the cement industry. In case a new fuel is introduced in a large area (the island of Java), an analysis per establishment is no longer feasible: the number of establishments is too large.

A generalization of netback value analysis can be achieved if we can link the energy intensity ratios per production process and the netback values for natural gas. Then the descriptive approach becomes an economic approach, and can be used to assess future demand for natural gas. Given the fact that the profitability argument on which the netback value approach is based, is also a convincing marketing instrument, it is worthwhile to look for ways to generalize the netback value calculations so that it covers the total manufacturing sector.

Apart from the netback value approach, none of the other approaches takes into account that not every form of energy is suitable for every application in production. As Girod [12] emphasizes, the diagnosis of the role of energy in a system or economy has to take into account the technical (and other) restrictions for the supply and use of every form of energy. The netback value approach does this, since this approach is based on a description of the production process. In this paper we try to link the technical opportunities for natural gas, with the economics of gas utilization at the production process level. We will also show that a limited number of production processes are sufficient from an energy point of view, to analyze the opportunities of natural gas for the total manufacturing sector. Our results can be linked to economic forecasts, to obtain long term forecasts of primary fuels; see [22].

An obvious problem is the data needed for the netback value calculations (these data are not readily available), and their linkage to available statistical sources. Economists mostly use national statistics, which in most countries are based on the International Standard Industrial Classification of all economic activities (ISIC) by the United Nations [20, 21]. ISIC is also the standard for data definition and data collection by the Indonesian bureau of statistics (BPS). The data for the manufacturing sector cover the total sector. ISIC data are categorized according to economic activities, and comprise the different inputs and outputs of production. We will link ISIC data to production processes. Per production process we determine the netback value of natural gas with respect to its main competitors. Through the link between ISIC data and netback values we can determine the profitability of natural gas, in all existing and new production facilities.

This paper is organized as follows. In Section 2 we discuss the ways energy is used in production, and the part that can be replaced by natural gas. In Section 3 we review netback value definitions for different market situations, and the possibilities for more energy efficient techniques. In Section 4 we review the data available from statistical sources, and the extra data that must be gathered for the netback value calculations. The netback data are then linked to the ISIC data, to generalize the approach. Section 5 contains conclusions.

2 Energy Application in Production

A factory can apply energy for four purposes: (i) for transport, (ii) for captive power, (iii) as feedstock in production, and (iv) for the production of heat for the production process. Not all of these applications are of interest for our fuel choice problem.

Sub (i) For *transport* mainly diesel and gasoline are used, but there are opportunities for alternatives like Liquified Petroleum Gas (LPG) and Compressed Natural Gas (CNG) also. The economics for the application of gaseous fuels are such, that only transport with a high annual milage is of interest; this is especially true for CNG. Note that the transport sector that might meet the requirements for gaseous fuels is not included in the manufacturing sector.

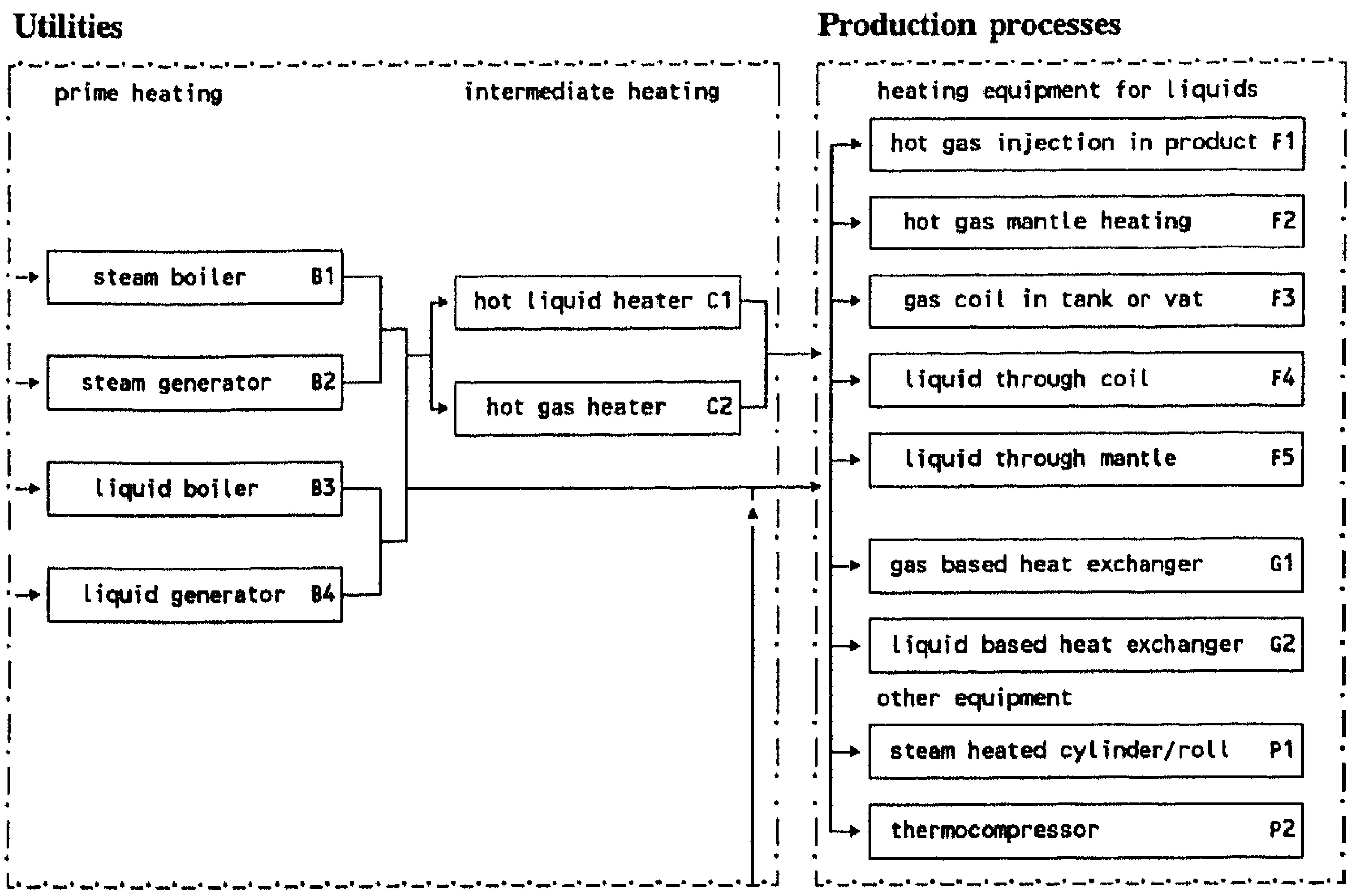
Sub (ii) *Captive power* consists mainly of electricity, but we do not exclude other power applications, such as shaft power for compressors. *Electricity* is mainly bought from the power company. A factory produces its own electricity, only because of a lack of reliable supply. In regions where electricity supply is unreliable we do consider own electricity production. However, with the increase in reliability of the Java-Bali power system (especially in industrialized areas) the captive power system is used only as back up for power failures.

Other power applications are considered, whenever there are favorable conditions for combined production of heat and power, better known as cogeneration. *Cogeneration* can be applied, when heat and electricity are used simultaneously and the operating time is more than 3,500 hours per year. When possible, cogeneration has clear advantages over separate heat and power production. Because of economies of scale the efficiency of primary energy use can be improved with 30 to 35%. The advantage of cogeneration is its utilization of the exhaust heat of power generation; this would otherwise be wasted. The application of cogeneration installations is commercially viable if based on gas turbines with a capacity of 3,6 MW or more, and with a shaft-efficiency of the gas turbines of 30% or more. Smaller installations are available, but their power efficiency is too small to be of real interest, unless these installations are subsidized for environmental reasons. We consider only gas turbine installations with heat recovery for steam and heat recovery for hot water.

Cogeneration has become popular lately, because it improves energy efficiency and as a result reduces the emissions of carbon dioxide, sulphur dioxide and nitrogen oxides. In some developed countries cogeneration is applied, to meet the emission standards agreed upon during the Rio de Janeiro summit. However, cogeneration is also an additional instrument to reach a least cost solution for national energy supply [6]. The reductions in emissions depend on the fuels used in the separate heat and power productions. If natural gas is a substitute for oil, the reduction is less spectacular than in case of coal [14].

Sub (iii) Natural gas as *feedstock* is only of interest for a limited number of products, such as ammonia, nitrogen fertilizers, direct reduction steel production, and basic chemicals. These applications are relatively easy to assess, because the energy needs and the economics of the processes using a fossil fuel as feedstock are relatively well known; see [5] for fertilizer, and [16] for steel. These are also typically processes were only one or a few factories exist in a large area. In these cases netback value calculations can be applied per factory or at the industry level. The technology used in feedstock applications depends heavily on the fuel used, and the products produced are sold on competitive international markets (steel, fertilizer, etc.), so the netback calculations can no longer be based on cost comparison; instead they have to be based on the market price formulation of the netback value.

Sub (iv) Nearly all production processes require *heat*, and this application is the most promising one for natural gas. We distinguish two main systems: (i) utilities to transport forms of energy and utilities to convert one form of energy into another, such as fuel oil into steam or hot water (Figure 1, utilities), and (ii) equipment for the application of energy (mostly in the form of steam or hot air) in the production process (Figure 1, production


Utilities

Production processes

Figure 1a: Central heat production equipment

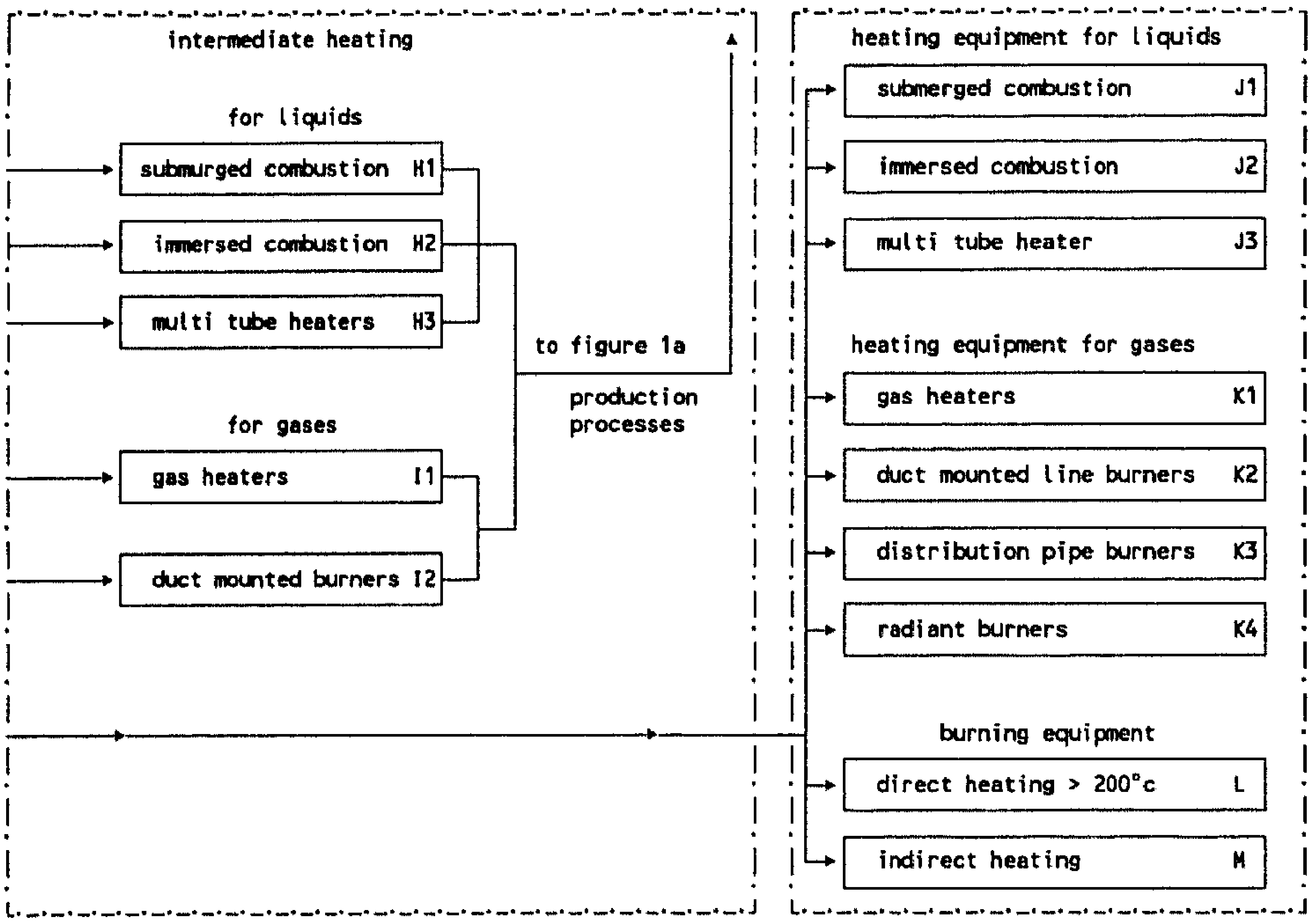


Figure 1b: In-situ heat production equipment

processes). Both, the utility system and the heating equipment in the production process require investments that depend on the fuel chosen.

The number of technologies for fuel application is limited (see Figure 1); for a more comprehensive review see [11]. The general starting point for an energy system for production is either *central heat production* or *in-situ heat production* (Figure 1a and 1b). Central heat production is almost always applied for solid and liquid fuels, which are combusted in a boiler or a generator. In-situ heat production is feasible for gaseous fuels, since these fuels be easily transformed near the point of application (intermediate heaters, Figure 1b) or in the production process (burning equipment in the production process, Figure 1b). The main advantage of in-situ over central heat production is that it reduces the investment costs and the heat losses due to heat transportation. The total heat losses in case of central heat production are 30% to 70% of the gross heating value, whereas in-situ heat production reduces these losses to 5% to 30%.

The arrows in Figure 1 represent energy flows, so an arrow going into a block is a form of energy. If there are no blocks preceding the block, the arrow represents primary energy (coal, oil products, natural gas); otherwise the input is a secondary or tertiary form of energy, such as steam or hot water. In central heat production there are two main steps. First, the fuel is combusted in a boiler or generator to produce a secondary form of energy (say) steam (Figure 1a, block B1). Then this steam is transported to and used in the production process through one of the gas based technologies depicted in Figure 1a (steam injection (F1), mantle heating (F2), steam coil (F3)) for heating liquids, or for heating gases (heat exchanger (G1)). In the same way heat application can start with the production of a hot liquid (block B3; mainly hot water). In some cases the secondary heat carrier is not used directly in the production process, but is fed into an intermediate heater (C1 and C2 in Figure 1a) to heat a tertiary energy carrier. Note that, although technically feasible, some paths are normally not followed; for instance, starting with a hot liquid (say B3) and then producing a hot gas (block C2) is usually not applied; it is only possible if the liquid is thermal oil.

In case of in-situ heat production the fuel is combusted either very close to the place where the heat is needed (intermediate heaters, blocks H and I in Figure 1b) and the hot gas or liquid is used in the production process in the same way as described for Figure 1a, or the fuel is used directly in the production process (blocks J through M in Figure 1b). Figure 1 is used to classify heat application systems on Java.

Figure 1 shows that the technologies for heat application are relatively loosely coupled to the rest of the production process. This is especially the case for central heat production, in which case conversion of an existing plant to another fuel is simple. In case of *in-situ* heat production, however, conversion to a solid fuel is more complicated.

Since steam can be applied for purposes up to 200 °C only, in-situ heating must be applied whenever higher temperatures are required (Figure 1b option L). Our characterization suffices to describe all heat applications on Java (and in many other places); if necessary it can be easily augmented.

Note that several technologies in Figure 1 can be subdivided further. For instance, immersed combustion (H2) comprises immersed combustion in tubes and immersed combustion with spray heaters; direct heating equipment (L) can be further subdivided according to temperature ranges [11]. We use the more detailed descriptions.

3 Netback Value Definitions

Conversion of an existing production process to natural gas is profitable if the NPV of the cost reduction is positive. The netback value of natural gas based on avoided costs is defined as the price of gas that makes NPV zero. The formula for the netback value for conversion of existing facilities to natural gas is

$$\text{(1)} \qquad NBc_t^{f,g} = \frac{\sum_{m=t}^{T-t} (1+i)^{-(m-t)} \left(-I_m^g + (O_m^f - O_m^g) + P_m^f D_t^f \right)}{D_t^g \sum_{m=t}^{T-t} (1+i)^{-(m-t)} \prod_{n=t}^{m} (1+\dot{p}_n^g)} ,$$

f and g denote the current *f*uel and natural *g*as respectively, I stands for investment, O for operation and maintenance costs, D for the amount of fuel needed, P for the fuel price, i for the discount rate, and T - t is the evaluation period. The product term in the denominator reflects the effect of anticipated changes in the price of gas. For most production processes, energy is only a minor input; the choice of fuel is then based on an evaluation period of three years or less ($T - t \leq 3$). Notwithstanding much criticism, a maximum payback period is still widely used to evaluate small investments; in all cases it is a constraint to be met before evaluation by means of other criteria takes place [13].

The formula for new investments (say) $NBn_t^{f,g}$ is obtained by replacing $-I^g$ in (1) by $(I^f - I^g)$. The evaluation period for new investments is not restricted to three years; in most of our calculations we used ten years. Note that the actual values of the symbols in case of conversion differ from the values in case of a new investment.

To evaluate the choice of fuel we can apply (1) for most heat applications. For feedstock applications or whenever energy costs are a substantial part of the total input costs (rule of the thumb, 7% or more), the netback value of a fuel depends on the market value of the sales (instead of the avoided costs), assuming that the market price of the final product can not be set (there is competition). The formula based on the market value of sales (say PS) minus the operating and maintenance costs of total production (including material cost) minus the investment costs is

$$(2) \qquad NB_t^g = \frac{\sum_{m=t}^{T-t} (1+i)^{-(m-t)} \{P_m - (O_m + I_m)\}}{D_t^g \sum_{m=t}^{T-t} (1+i)^{-(m-t)} \prod_{n=t}^{m} (1+\dot{p}_n^g)} .$$

If this netback value is smaller than the price of natural gas, then production is not feasible without (explicit or implicit) subsidies. We will apply (2) for the feedstock applications. For other energy intensive subsectors (for instance, cement) the validity of (1) is checked by also calculating (2). In most cases, however, the share of energy costs in the total costs is small and (1) suffices. (See for a discussion on when to apply which netback value definition [7].)

If cogeneration is possible, then (1) and (2) are not sufficient, since they only indicate if gas is feasible. Demand for gas by the manufacturing sector could increase if cogeneration is applied. (In the total demand for gas this increase can be offset by a decrease in demand by the power sector.) To see whether further search for cogeneration is necessary, we calculate the simple payout time (SPOT) of investment in cogeneration; the formula for the case where no electricity is delivered back to the power grid is

$$(3) \qquad SPOT = \frac{I}{h(Pe - ((\eta_t + \eta_e)^{-1}(y+1) - \eta_b^{-1} y) \frac{3600}{LHV} Pg - O)},$$

where the investment costs I are in Rupiahs per kWh, h is the number of hours per year that the installation is used, Pe is purchase costs of electricity (in Rupiahs per kWh), y is the heat power ratio of the production process, η_t is the thermic and η_e the electric efficiency of the cogeneration plant, η_b is the efficiency of the steam boiler that is the alternative for cogeneration (all efficiencies are expressed as fractions of the lower heating value of the fuel considered), 3600 is the conversion factor from kWh to kJ (kilo Joule), LHV is the lower heating value of natural gas in kJ per m^3, Pg is the price of natural gas per m^3, and O are the maintenance costs (in Rupiahs per kWh).

(3) should be interpreted as a necessary condition to be met before further evaluation [10]; it only indicates if the application of cogeneration is possible. The feasibility of cogeneration depends on many factors, which have to be evaluated case by case. For instance, the most efficient form of cogeneration is a combined cycle, but the minimum electrical power required is 20 MW (economies of scale). There are many different cogeneration installations, and an optimal choice can be made only if the exact data of the production facility are known. Note that the capacity of a cogeneration plant depends on the amount of heat needed for production, and not on the amount of electricity.

From (1) through (3) we can deduct the necessary data:

(i) Amount of investment in energy utilities and heat application equipment. We need a blueprint of the production facilities for the calculation of the investment costs in energy transport, in combustion or intermediate heating equipment, and the kind of heating equipment needed in the production process; also see Figure 1. Furthermore, we need the current prices of the equipment and appliances needed.

(ii) Operation and maintenance costs for the total energy system.

(iii) Amounts of fuel used in the different applications, and their prices. These data are needed for the conversion of existing plants to natural gas, and per fuel for new investments.

4 Data Available

The Indonesian bureau of statistics (BPS) uses the 1971 international standard industrial classification ISIC [20] as a basis for its data collection. ISIC 1971 divides the manufacturing sector into nine two digit subsectors (31 through 39). (The 1990 revision distinguishes more subsectors (called divisions); but this revision is not yet used in Indonesia.) Every two digit subsector is divided into three digit subsectors or major groups according to, among others, similarities in the production process and products produced. For instance, 34 is the subsector "Manufacture of paper and paper products; printing and publishing", and is divided into two three digit subsectors or major groups, namely 341: Paper and paper products, and 342: Printing, publishing, and allied industries. The three digit subsectors are divided into four or five digit subsectors, called groups. BPS uses a five digit description; for instance, 341 is divided into 34111 (manufacture of paper), 34112 (paper board and fiber board), 34120 (containers and boxes of paper and board), and 34190 (articles of pulp, paper and board, not classified elsewhere).

As the example shows, the five digit ISIC classification for data collection is based on comparable economic activities; for instance, the production of paper. As far as possible establishments (or kind-of-activity units) form the basis for data collection. The establishments in one five digit ISIC category are relatively homogeneous, since the classification is based on product character, production technology, and production organization, characteristics that define a production process; see [20, 21].

The question is whether a separate analysis of all ISIC five digit subsectors is required, if we want to classify energy utilization. Economic models are often based on a higher ISIC aggregation level (say three digit) to reduce the number of subsectors. The data of similar economic activities are then added up, but this similarity in economic activities does not necessarily imply similar energy systems. With respect to energy, other combinations of five digit subsectors may be more appropriate. Furthermore, not all five digit subsectors are equally important from an energy point of view. For a parsimonious and manageable analysis of energy demand we would like to combine less important ISIC five digit subsectors with the same energy system, whereas we analyze in more detail those subsectors that use large amounts of energy, and are therefore more sensitive to the energy technology applied.

We define a subsector as the set of establishments that have a common production process, from an energy point of view. For each production process we need data for our netback calculation. This redefinition of subsectors can be achieved, if we realize that not every production process has a unique energy supply and heat application system. So from an energy application point of view we can treat as one different products with the same energy supply and heat application system.

4.1 The Indonesian Bureau of Statistics Survey

BPS distinguishes 120 five digit subsectors on Java, which cover the full range of manufacturing activities on that island. At the five digit level we have available: total primary energy and electricity consumption, quantities of the different fuels consumed, energy input costs, and value added. Not available are the data required for netback value calculations.

The starting point for our analysis is the basic data of the 1987 industrial survey conducted by BPS, which are the basis for the 1987 five digit data. BPS surveyed all Java's establishments that have more than 20 employees.

We use the 1987 data on energy consumption to make a preliminary division of the manufacturing sector into a number of subsectors (see Table 1). The division is based on subsectoral energy consumption, and on previous research [4]. Our reasoning is that the more important energy in the production process is, the more detailed the information required is. The result of this preliminary classification is that for some subsectors (for instance, subsector 31: food & beverages) we start our analysis of energy consumption at the two digit level, whereas for more energy intensive subsectors we start at a more disaggregated level; for instance, the analysis of subsector 34 (Paper & Pulp) starts at the three digit level, because the differences in energy consumption in paper and pulp production and the downstream activity of printing are well known. We know in advance that our analysis requires even more detailed information for other industries; for instance, the subsectors 35120 (two nitrogen fertilizer factories) and 36120 (five cement factories). Sector 37100 is divided even further, namely into the genuine iron and steel factory using natural gas in the reduction process [16], and all other steel factories producing mainly concrete bars from scrap using electric arc furnaces.

For our purpose the energy data contained in the BPS survey have one major drawback: they are not organized according to the main forms of energy application in production, mentioned in Section 2.

Table 1: Manufacturing subsectors for gas utilization

Code	Subsector	No of establ.	energy cons. > 80,000 mge	establish. in survey	(3)/(2) in %
31	Food & Beverages	3 111	484	58	11
32	Textiles	2 619	367	46	12
33	Wood & Furniture	393	32	7	22
341	Paper & Pulp	120	40	14	32
342	Printing	381	22	4	18
35120	Fertilizer	2	2	2	100
351 rest	Industrial Chemicals	140	64	18	26
352	Other Chemicals	409	87	14	16
353	Petroleum Refineries	-	-	-	-
355	Rubber products	241	64	9	14
356	Plastics	481	72	9	11
36120	Cement	5	5	4	80
36 rest	Mineral products	1 019	118	16	14
371A	Iron & Steel	1	1	1	100
371B	Rest Basic Metals	20	15	2	13
38	Metal products	1 086	237	44	20
39	Others	139	15	-	-
	Total	10 167	1 527	248	

4.2 The Gasunie Engineering Survey

To obtain information on the data for netback calculation and on the link between production processes and ISIC five digit sectors, we (Gasunie Engineering) conducted a field survey. To reach maximum coverage of both energy consumption and energy technologies used in production processes, we applied the following procedure to select a sample from the 10,167 establishments in the 1987 BPS survey (see the last row in Table 1). First we removed from the set of all subsectors all five digit subsectors (such as, manufacturing of batiks (code 32114) and production of jewelry (code 39010)) for which we know that the application of natural gas in the production process can be neglected.

If we would randomly select a sample from the remaining set of establishments, we would most likely end up with a selection of small businesses. For our purposes it is necessary to study the larger energy users; we also expect that they will have more reliable information for our survey. Therefore we remove all establishments with an energy use of less than 80,000 m^3 gas equivalents (mge), after deducting the consumption of electricity purchased, automotive diesel and gasoline (transport), and natural gas used. This reduces the set of establishments to 1,527 (see again the last row of Table 1).

Since the industrialization of Java is concentrated in a few geographical areas, and these areas are also candidates for investing in a gas distribution, the establishments visited should be in the industrialized areas, that is, JaBoTaBek (Jakarta-Bogor-Tangerang-Bekasi) and Bandung in West Java, Surabaya-Gresik area in East Java, and in Central Java in the Semarang area. In those three areas 90 to 95% of all current industrial activity is concentrated.

In these areas a total of 318 establishments were visited by a multi-disciplinary team of energy experts. A total of 241 surveys could be completed successfully. Seven bulk users (two nitrogen fertilizer plants, four cement factories, and one iron and steel factory) were studied separately and in great detail, because of their large energy use. The stratification of the survey over the different subsectors is given in Table 1, column 4. Of the completed survey forms, 115 were from the JaBoTaBek area, 29 from the Bandung area, 54 from the Surabaya-Gresik area, and 43 from the Semarang area. The last column gives the number of establishments successfully visited, as a percentage of the number of establishments considered.

If a five digit subsector in an area was selected for the survey, we always chose the largest establishment still in the set. This was done for two reasons. First, we wanted the survey to cover at least 10% of the primary energy used by a subsector. Second, choosing the larger establishments will improve the chance that the technology used represents the current state of the art in Indonesia. In a competitive market, efficient energy use will force smaller less efficient companies to improve their energy use too. This improvement will be stimulated by the more restrictive environmental legislation that is currently introduced in Indonesia.

The survey also gathered information on the physical outline of the energy utilities and the heating equipment in the production processes in the establishments visited, and on the state of the equipment used. The information on the outline of the processes can be used to estimate (i) the investment cost for new plants based on different fuels, and (ii) the investment costs for conversion of existing plants to natural gas. For the assessment of the investment costs we had to gather information on prices of equipment and the construction cost too.

Data on the operating and maintenance costs (O&M) were obtained by including in the survey a set of figures based on previous experience. For the utilities in Figure 1 the O&M was set as a percentage of the total investment costs in utilities: 7% for natural gas, 7.5% for diesel fuel oil, and 8.5% for heavy fuel oil. For the heating equipment in the production processes these percentages were 5% of the costs for the equipment for the application of gasses (mainly steam), and 3% of the costs for equipment for applying hot liquids. These assumptions were checked during the survey, and whenever necessary adjusted. Note that the heat losses are included not in the O&M, but in the efficiencies of the heat application.

The survey includes information on energy application in production (see Section 2). For heat in production the survey also contains information on the amounts of and forms in which energy is used, in the different stages in production processes. Based on Figure 1 we identified the energy technologies per establishment visited.

Analyzing the data of the Gasunie Engineering survey leads to the definition of a number of production processes, according to energy utilization. In most cases these production processes can be linked to one or more of the ISIC five digit subsectors. Whenever several ISIC five digit subsectors are linked to one energy system, our method is more parsimonious than analyzing all five digit subsectors separately. Not all different choices will be explained here; we restrict ourselves to two example: one in which a large number of ISIC five digit subsectors can be described by a single production process, and one subsector for which cogeneration is possible.

4.3 Example 1: ISIC subsector 38, Manufacture of Metal Products

How the data of the Gasunie survey can be made to represent a larger set of products is illustrated for the ISIC two digit subsector 38: Fabricated metal products, machinery, and equipment. This subsector is divided into five three digit subsectors, and twenty five-digit subsectors; see Table 2. Subsector 38 produces a wide variety of products, including wire (ISIC code 38112), pipe (ISIC code 38130), assembled cars (ISIC 38430), spectacle frames (BPS code 38500). At first glance it might not be expected that all these different kinds of products can be described by only two energy systems. However, after carefully analyzing the descriptions of the production processes for these products there appear to be only two relevant forms of heat application: hot galvanization of steel parts and applying surface coatings on metals respectively. Note that Table 2 shows that some five digit subsectors are not surveyed; we left some additional five digit subsectors out. For subsectors 38330 and 38340 we did so, because we can neglect heat application in the production and repair of toasters, food mixers, ironers, etc. These production processes use electricity.

Table 2: Division of industry group 38

sub-group	description	group	description	# surveyed
381	fabricated metal products, except machinery and equipment	38111	hand tools, agric. equipment	1
		38112	cutlery, nails, etc.	2
		38113	kitchen app.	3
		38120	metal furniture and fixture	1
		38130	structural metal products	16
		38140	metal containers	2
		38190	other metal products	1
382	Machinery excl. electrical	38200	machinery and repair	2
383	electrical machinery, apparatus, appliances, and supplies	38311	storage batteries	2
		38312	dry cell batteries	2
		38320	radio, TV, communication eq., etc.	2
		38330	electrical apparatus and supplies	0
		38340	repair of electrical appliances	0
384	transport equipment	38411	ship building and repair	2
		38430	motor vehicles	2
		38440	motor cycles and three motor vehicles	1
		38450	bicycles	1
		38460	motor vehicle body and equipment	5
		38490	other transport equipment	0
385	measuring and controlling equipment	38500	scientific, optical, etc. equipment	1

The Gasunie Engineering survey covers 21.2% of the total energy used by subsector 38; the shares of the different forms of energy application are 4.6% for transport, 23.7% for electricity generation, 0.0% for feedstock, and 71.8% for heat production.

For the two production processes hot galvanization and surface coating, the technical possibilities for heat application are limited. We further restrict this example to hot galvanization, denoted as production process 38A. This production process is basically the same for all products that require galvanizing. The results of the survey for the galvanization process are given in Table 3. The data are for a representative establishment, galvanizing 12,000 mt per year. The yearly amounts of energy needed are 696,000 mge of industrial diesel oil and 1,404 MWh of electricity.

Table 3: Investment, O&M, and energy use for production process 38A.

	heavy fuel oil					diesel oil				
equipment		inv.[1]	O&M[1]	eff.[2]	fuel[3]		inv.[1]	O&M[1]	eff.[2]	fuel[3]
fuel supply acc.		37.4	1.3				29.8	1.0		
heat transport		36.1	1.8				36.1	1.8		
steam boiler	B1	261.6	11.2	59%	473	B1	254.9	9.0	61%	457
degreasing	F1	10.9	0.4			F1	10.9	0.4		
acid pickling	F1	21.8	0.8			F1	21.8	0.8		
fluxing	F1	21.8	0.8			F1	21.8	0.8		
drying	G1	23.4	0.8			G1	23.4	0.8		
galvanizing	L2	68.0	3.4	103%	247	L2	68.0	2.4	100%	239
quenching	F1	10.9	0.4			F1	10.9	0.4		
Total plant		492.2	20.8		720		477.8	17.6		696
Per metric ton[4]		41.014	1.736		0.060		39.819	1,470		0.058
	natural gas					conversion to gas				
fuel supply acc.		14.9	0.4				7.9	0.2		
heat transport							-	1.8		
steam boiler						B1	30.0	7.8	61.5%	453
degreasing	J2	25.6	0.9	80%	37	F1	-	0.4		
acid pickling	J1	53.6	1.8	90%	65	F1	-	0.8		
fluxing	J1	53.6	1.8	90%	65	F1	-	0.8		
drying	K3	39.7	1.4	90%	33	G1	-	0.8		
galvanizing	L2	68.0	2.4	100%	239	L2	-	2.4	80%	191
quenching	J2	25.6	0.9	90%	37	F1	65.0	0.4		
Total plant		281.0	15.4		475		102.9	15.4		644
Per metric ton[4]		23.4	0.8		0.040		8.6	1.3		0.054

[1] In million rupiahs.
[2] Energy efficiency.
[3] Energy use in 1,000 mge per year.
[4] Investment and O&M in 1,000 rupiahs.

The first column of Table 3 contains the different steps in the galvanization process. The first column *per fuel* links the production process to the fuel utility system and the heat application equipment of Figure 1; for instance, B1 for fuel oil corresponds with the box B1 (steam boiler) in Figure 1a. The technology indication in Table 3 is the one most frequently used in the establishments surveyed. The technology choices in case of natural gas are our own, and correspond with Figure 1b.

Note that production process 38A is an example of a production process that requires temperatures over 200 °C, and thus in-situ heating is required. In Table 3 galvanizing is indicated by L2, which stands for direct heating equipment with a temperature in the range of 400 to 850 °C.

Based on this survey, we made an outline (not presented here) of a production site to locate the different production utilities, the energy utilities, transport facilities for fuel and heat, and the heating equipment within the production process required. This outline of the plant is used to calculate the investment costs per type of fuel for both a new plant and conversion of an existing plant to natural gas. The resulting investment costs are displayed in the second column per fuel ("inv").

The third column per fuel type contains the operating and maintenance costs (O&M), based on the assumptions of Section 4.2.

The fourth column per fuel type shows the efficiency ("eff") of the heating equipment, that is, the amount of heat available at the outlet as a percentage of the lower heating value of the inlet; for instance, a steam boiler with an efficiency of 59% means that of the lower heating value of 100 mge, 59% is available in the form of steam for heat applications, and 41% is lost. For in-situ heating we define efficiency as the amount of energy used in the process, divided by the lower heating value of the amount of energy combusted. To make the processes better comparable, we give the amount of a fuel needed for galvanizing (L2) as a percentage of the amount of natural gas needed; so the number 103% means that 3% more energy is needed in the form of fuel oil than in case natural gas is used. Note that the amount of heat used in a part of the production process, can be larger than 100%, namely, when exhaust heat (for instance, in the form of condense) is utilized.

The last line per fuel type in Table 3 gives the data per metric ton produced. Note that the forms of the different products galvanized can vary widely; therefore the amount of energy per metric ton can vary. A better measure would be the surface of the product galvanized, since the shape has some influence on the speed with which the process can be applied. For practical reasons it is not feasible to use the shape as measure. The economics of the heat application process, however, are only slightly influenced by the form of the products.

The ISIC five digit subsectors covered by process 38A are 38190, 38200, 38311, 38411, and 38430. If in the future new technologies or new products will emerge, it might be that all these subsectors can no longer be presented by one production process only; a redefinition of subsectors is then necessary. Given our analysis, this redefinition is relatively simple.

4.4 Example 2: ISIC subsector 341, Paper and Fiber Board

Subsector 341 covers ISIC five digit subsectors 34111, 34112, 34120, and 34190. The subsectors 34111 and 34112 produce paper and fiber board. The subsectors 34120 and 34190 use paper or board as input, and the production process can be clearly distinguished from production process 34A. The survey data showed that the subsectors 34120 and 34190 can be combined with subsector 34200, and can be represented by one production process, namely 34B (containers from board).

The size of subsector 34111 is large, compared with subsector 34112. The amount of energy used in subsector 34112 is only 1% of that in subsector 34111. Given this difference and the fact that from an energy point of view the production of paper and fiber board is quite similar, one production process (34A) is sufficient to represent the two subsectors.

The production process is simple, and requires a steam boiler (Figure 1: B1); its steam is used for steam injection (F1) in the early stage of the process, and for steam heated cylinders (P1) in the drying section of the production process (drying consumes about 95% of all the steam produced, and the temperatures required are 60 to 120 °C). Almost all production units operate full time; that is 8,500 or more hours per year (a year has 8,760 hours).

Five out of a total of 32 establishments were visited, covering 25.7% of the total energy consumption. Of the total amount of energy consumed 0.8% is used for transport, 21.7% for electricity, and the remaining (77.5%) in boilers. The technologies used, process 34A is the same for all fuels; natural gas does not have specific advantages. The main investments are in a fuel supply system and two steam boilers (one for back up).

We base our netback value calculations on a plant producing 25,000 mt per year, and consuming 7,95 million mge for heat and 16.5 million kWh. The costs of the fuel supply system for this plant differ with the fuel type, about 4.5% of the total investment costs for fuel oil, and 1.5% for natural gas. The investment costs for one steam boiler are 883 million Rupiahs for fuel oil, and 860 million Rupiahs for industrial diesel oil and natural gas. The amount of natural gas per ton of paper is 316 m^3; for diesel oil and fuel oil this amount is 318 mge and 327 mge respectively. The amount of electricity needed is 660 kWh. Consequently, natural gas in conversion has no advantages, unless the price of natural gas relative to fuel oil is extremely low. In new investments, however, natural gas has certain advantages over oil products.

Because of the large amount of energy consumed and because factories produce more for than 8,000 hours per year, cogeneration might be attractive. If we express all energy required by process 34A in kJ (318 mge = 11,270 MJ and 660 kWh = 2,359 MJ), the heat-power ratio y (see equation (3)) becomes 11,270/2,359 = 4.78. The best technology is a gas turbine with an exhaust gas boiler with supplementary firing. The investment costs I for such a gas turbine are 2 to 2.5 million Rupiahs per kWe, the operating and maintenance costs O are 10 Rupiahs per kWh, the price of electricity Pe is 106.6 (Rupiahs per kWh) and the price of natural gas (with a lower heating of 35.4 MJ) Pg is 154.5 (Rupiahs per m^3). The plants visited achieve a boiler efficiency η_b of 75%. The proposed cogeneration can achieve a combined thermal and electricity efficiency ($\eta_t + \eta_e$) of more than 90%. If we substitute these figures into equation (3), a SPOT of 3.0 years can be achieved. This solution is quite robust; changes of 25% in the variables of (3) still keep the SPOT below five years.

4.5 Overall Results

If we apply the method outlined and illustrated for all manufacturing subsectors in Table 1, we get Table 4, column 2. All ISIC five digit subsectors are linked to production processes, and there is a remarkable difference in the number of ISIC subsectors represented by one production process. One reason is that the larger the amount of energy used in the production process, the more specific the energy utilization technology will be.

For ISIC two digit subsector 31 (food & beverages) eleven production processes are needed for twenty nine ISIC five digit subsectors; see Table 4, column 1. Note that production processes 31I and 31K are used for more than one two-digit subsector.

Table 4: Production processes and ISIC five digit subsectors

Process code and name (1)	Corresponding ISIC/BPS codes (2)	Total energy (in million mge) (3)	Replaceable as % of (3) (4)	Potential demand natural gas (5)	netback value gas/fuel oil	
					new (6)	conv. (7)
31A Milk powder & sweetened	31121	18.9	58.3	11.0	173	138
31B Coconut oil from coconut	31151,31159	27.8	87.2	24.2	236	152
31C Bakery products	31179	15.2	75.2	11.4	232	75
31D Sugar manufacturing	31181	132.1	85.7	113.2	163	152
31E Tea processing	31220	47.2	65.6	30.1	185	132
31F MSG from molasses	31270	59.7	91.8	54.8	216	158
31G Beer from malt	31320,31330,31340	18.3	92.9	17.0	243	151
31H Tobacco products	31410,31420,31430	34.3	69.3	23.8	306	152
31I Other products (steam)	31112,31130,31140,31171,31190,31241,31242,31250,31280,35210,35233,	61.5	83.4	51.3	234	152
31J Other products (furnaces)	31260,	8.7	56.8	4.0	183	146
31K Other products (electr.)	31111,31122,31163,31164,31210,31230,35120,35140,35222,35232,35290,36900	109.4	0.7	0.8	-	-
32A Cloth from fibre	32111,32112,32113,32115,32120,32130,32140,32160,32190,32210,32290,32310,32330,32400	633.6	57.4	365.0	231	154
33A Manufacturing of plywood	33111,33112,33113,33114,33210,33230	38.3	10.8	4.1	227	150
34A Paper and fibre board	34111,34112	272.2	78.0	212.3	166	146
34B Containers from board	34120,34190,34200	65.0	70.5	45.8	201	153
35A NaOH & Cl_2 from NaCl	35110	2.5	25.0	0.6	236	156
35B Zinc Oxide from zinc ingot	35110	4.7	54.4	2.6	173	82
35C H_2SO_4 from sulphur	35110	1.6	99.5	1.6	165	145
35D Inorganic chemicals	35110	8.1	93.2	7.5	199	135
35E Organic chemicals	35110	5.6	100.0	5.6	224	135
35F Fatty acids	35110	57.0	86.1	49.1	205	149
35G Fertilizer	35120	664.1	88.2	664.1	100	-
35H Resin, plastics and fibre	35130	1.3	62.5	1.1	318	151
35I Drugs and medicine	35221	23.4	100.0	14.6	352	94
35J Soap from palm oil	35231	22.9	100.0	22.9	181	158
35K Tires from rubber	35510,35521,35523,35590	89.0	45.6	40.6	176	150
35L PVC wares from PVC resin	35600	61.7	63.1	38.9	212	141
36A Clay products	36110	67.0	78.6	52.7	169	139
36B Pressed and blown glass	36210	106.5	80.4	85.6	198	120
36C Sheet flat glass	36220	51.7	100.0	51.7	158	146
36D Cement	36310	908.7	100.0	908.7	172	139
36E Concrete products	36320	21.2	27.0	5.7	225	133
36F Quick lime from limestone	36330	11.8	0.0	0.0	173	76
36G Bricks & tiles from clay	36410,36420	29.7	84.5	25.1	172	133
37A Iron and Steel	37100 PT Krakatau Steel	1,077.3	99.3	1,069.8	108	-
37B Reinforcement bars	37100 (rest)	61.9	83.6	51.7	163	145
38A Galvanizing	38190,38200,38311,38411,38430	89.8	62.2	55.9	326	116
38B Surface coating on metal	38111,38112,38113,38120,38130,38240,38320,38440,38450,38460,38490	86.2	65.9	56.8	403	150
	Total	4,990.8		4,181.7		

The textile industry (ISIC 32) is presented by one production process only (32A); its fuel profile holds for an integrated plant (spinning, weaving, and finishing). The main energy utilization is in the wet parts of this production process. The profile for this sector is based on 44 surveys and covers 35% of the current energy use.

From the start of our study it was clear that five digit subsector 37100 could not be presented by a single production process. The energy system in the production of genuine iron differs from the other processes, such as forging and casting. In the latest revision of the ISIC classification, this subsector is divided into four separate subsectors. If the data were based on the 1990 revision, the different processes could have been linked to the separate five digit subsectors, and no lower level classification would have been necessary.

Apart from ISIC subsector 37100, there is only one five digit subsector for which a direct link between the ISIC five digit data and a single production process is not possible; see Table 4, processes 35A through 35F. The reason is that the chemical industry is energy intensive, and the optimal design of production facilities becomes rather specific. In the latest review of ISIC subsectors [21], subsector 35111 (manufacture of basic chemicals except fertilizers) is also split into several five digit subsectors, which offer better opportunities for classification according to type of production processes.

For the basic chemical sector, Indonesia has planned large investments, which offer opportunities for feedstock applications. Indonesia, however, has abundant naphtha produced in its oil refineries, and this naphtha will be used as feedstock (instead of natural gas). Natural gas will be used for heat production, because it is profitable and it is less contaminating in production.

Using a discount rate of 12%, the netback values for conversion and new investments, based on a price for natural gas at fuel oil parity (both 154.5 Rupiahs per mge) are shown per production process in the last two columns of Table 4; the only exception is the netback value for cement, which is based on coal. For the production processes 35G and 37A the netback values must be based on equation (2) and conversion is not possible; for all other processes equation (1) suffices.

Column (6) shows that at fuel oil parity pricing, natural gas has clear advantages in new investments; the only exceptions are fertilizer production (35G) and genuine steel production (37A). In case of industrial diesel oil, the same picture emerges; however, we show only the netback values for fuel oil, because fuel oil is the main competitor for natural gas under an efficient pricing policy. Sensitivity analysis showed that the netback values are quite robust.

Column (5) shows that the potential demand for natural gas is 4,181.7 million m^3 per year; potential demand is defined as the maximum amount of gas that can be utilized in existing establishments. From this number we subtract the gas already committed in earlier contracts (at fixed prices) for steel (1,069.8 million m^3), fertilizer (664.1), and some cement production (0.319*908.7 = 289.9). We then get the potential new demand for gas in existing industries: 2,157.9 million m^3 per year. This demand, however, will not be realized. The netback value for conversion of most production processes is below the price of 154.5 Rupiahs per m^3 (see column (7)). Only the processes 31F, 35A, and 35J (with a demand of 78.3 million m^3) will convert at that price. Demand can be increased by reducing the price of natural gas in the first three years (the payback period for conversion). A reduction by 5 Rupiahs per m^3 will make natural gas profitable in the conversion of fourteen more processes; this conversion will increase demand to 821.2 million m^3. A further reduction by 5 Rupiahs per m^3 will increase demand to 1,191.6 million m^3. Only a special offer for the cement industry can increase the last figure substantially (by 618.8 million m^3). Note that the conversion of the cement industry will also have a large environmental impact.

There are favorable conditions for the application of cogeneration in 10 of the 38 processes: 31A, 31D, 31F, 31G, 32A, 34A, 35D, 35E, 35F and 35I. The simple payout times range from about 2 years (for 35F and 35I) to 5,5 years (for 31A).

Note that the energy consumption per production process can be adjusted for energy saving technical progress by introducing this progress in the characterization of the technologies used in the processes.

We know that profitability as expressed by the netback value is only one of the factors that will induce conversion to another fuel. Other factors are also important, e.g. the share of energy costs in the total costs and the availability of investment capital. A problem is that even if capital is available, a company in a growing economy is more interested in investing in new capacity than in improved energy utilization. So to achieve conversion in case of capital shortage, the Indonesian government will have to reach some form of agreement with the manufacturing sector.

5 Conclusions

Our engineering approach has clear advantages over traditional (economic and descriptive) models, when evaluating the opportunities for natural gas in the manufacturing sector. Traditional models for energy demand are rather abstract and are based on total energy use, whereas our method is based on concise descriptions of fuel applications in production processes. By linking the process descriptions per fuel type to their costs and benefits, we can calculate the netback value per fuel to determine the choice of fuel. This netback value evaluation takes into account the technical restrictions for fuel application in production. Furthermore, we require no historical data on gas utilization to apply our model; these data are not available when gas is introduced.

The production process descriptions plus the economics of these processes are the basis for the marketing strategy of the Indonesian gas distribution company, upon gasification of an area. Of course, our general outline of a production process should be adjusted when applied at the plant level. The distribution company currently uses the process descriptions to analyze new client's fuel utilization and to suggest improvements. Our results show which manufacturing subsectors are most promising for the distribution company's general marketing strategy. For example, we can analyze the effects that a more comprehensive tariff structure will have on the demand for natural gas, given the prices of other fuels.

Our technical descriptions of the production processes are linked to regional statistical data at the ISIC five digit level, to obtain the manufacturing's sector total demand for natural gas. Because of this link our method is a good starting point for macroeconomic policy evaluations as well. At the macro level, our analysis allows the Ministry of Energy to evaluate the effects of comprehensive energy pricing policies. The link of the technical data for the netback calculations with the ISIC five digit subsectors enables easy evaluation of the effects of pricing policies for all fuels. Furthermore, our analysis can be combined with a more general least cost approach for energy planning, including the opportunities for cogeneration in the overall electricity system.

Our analysis shows that 38 significant production processes suffice to analyze the demand for energy by the total manufacturing sector on Java. In case new production processes emerge, these processes can be easily added and a complete reevaluation is not required. Furthermore, information on new technologies can be added to every production process. This information will indicate the technological state of existing industries, and set the path for future energy demand management.

References

[1] Ang B.W., Structural change and energy demand forecasting in industry with applications to two newly industrialized countries, *The Energy Journal*, 1987, 12(2):101-11.

[2] Ang B.W., A statistical analysis of energy coefficients, *Energy Economics*, 1991, 13(2):93-110.

[3] Blackorby C., D. Primont and R.R. Russel, *Duality, separability, and functional structure: theory and economic applications*, North Holland, New York, 1978.

[4] Brown H.L., B.B. Hamel, and B.A. Hedman, *Energy analysis of 108 industrial processes*, Fairmont Press, U.S.A., 1985.

[5] Constant K.M. and W.F. Sheldrick, An outlook for fertilizer demand, supply, and trade, 1988/89-1993/94, World Bank Technical Paper No. 137, Asia Technical Department Series, World Bank, Washington, D.C., U.S.A., 1991.

[6] Davison A., Least cost planning, Oxford Institute for Energy Studies, EV6, Oxford, United Kingdom, 1991.

[7] DeAnne Julius and A. Mashayekhi, *The economics of natural gas: pricing, planning and policy*, Oxford University Press, Oxford, England, 1990.

[8] Feibig D.G., J. Seale and H. Theil, The demand for energy: evidence from a cross-country demand system, *Energy Economics*, 1987, 9(3):149-53.

[9] Fuss M., D. McFadden and Y. Mundlak, A survey of functional forms in the economic analysis of production. In M. Fuss and D. McFadden (ed.) *Production Economics: a dual approach to theory and applications*, North Holland, New York. 1978.

[10] Gasunie, Kleine en middelgrote warmte-kracht-installaties (Small and medium sized heat-power plants), N.V. Nederlandse Gasunie, Groningen, The Netherlands, 1982.

[11] Gasunie Engineering, Study for a gas transmission system on Java: present industrial energy utilization, Gasunie Engineering B.V., Report Nr: GUE-R06, volume II, Jakarta, October 1990.

[12] Girod J., Diagnosis of energy systems in developing countries, Commission of the European Communities, Luxembourg, 1992.

[13] Hajdasinsky M.M., The payback period as a measure of profitability and liquidity, *The Engineering Economist*, 1993, 38(3):177-91.

[14] Homer J., Natural gas in developing countries: evaluating the benefits to the environment, World Bank Discussion Paper 190, The World Bank, Washington, D.C., U.S.A., 1993.

[15] Jenne C.A. and R.K. Catell, Structural change and energy efficiency in industry, *Energy Economics*, 1983, 5(2):114-123.

[16] Kendrick D.A., A. Meeraus and J. Alatorre, *The planning of investment programs in the steel industry*, John Hopkins University Press, Baltimore, Maryland, U.S.A., 1984.

[17] Nguyen T.H., On energy coefficients and ratios, *Energy Economics*, 1984, 6(2):102-109.

[18] Ramain P., The energy demand elasticity in relation to gross domestic product: a relevant indicator?, *Energy Economics*, 1986, 8(1):29-38.

[19] Seale J.L., W.E. Walker and I.M. Kim, The demand for energy: cross country evidence using the Florida model, *Energy Economics*, 1991, 13(1):33-40.

[20] United Nations, Indexes to the international standard industrial classification of all economic activities, Statistical Papers, Series M No. 4, Rev. 2, Add. 4, Department of Economic and Social Affairs, Statistical Office of the United Nations, United Nations, New York, 1971.

[21] United Nations, International standard industrial classification of all economic activities, Statistical Papers, Series M No. 4, Rev. 3, Department of Economic and Social Affairs, Statistical Office of the United Nations, United Nations, New York, 1990.

[22] Van Groenendaal W.J.H., Assessing and forecasting the long-term fuel mix for the manufacturing sector when a new fuel is introduced. In: Energy, environment and sustainable development: challenges for the 21st century, Proceedings of the 16th Annual Conference of the International Association for Energy Economics, Nusa Dua-Bali, Indonesia, July 27-29, 1993, pp 4_35-4_46.

[23] World Bank, *The East Asian miracle: economic growth and public policy*, Oxford University Press, Oxford, England, 1993.

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