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Assessing demand when introducing a new fuel

Natural gas on Java

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The Indonesian government is investing in a gas transmission system on Java. For the evaluation of this investment a forecast of the demand for natural gas by the manufacturing sector is needed. To obtain this forecast the manufacturing sector is divided into subsectors according to energy use in production processes. On the level of production processes the opportunities for natural gas are based on net present value evaluations of its future benefits in production. This results in the desired fuel mix for manufacturing subsectors, from which the gas intensity ratios per subsector for existing production and new investments are calculated. Gas demand can then be forecast by combining the gas intensity ratios with subsectoral (growth in) gross value-added. This approach leads to a flexible forecasting tool that can readily account for changes in economic structure and energy prices, as encountered by rapidly developing economies.

Keywords: Energy demand; Production technology; Netback value

Indonesia is a country endowed with many natural resources (among which are oil, natural gas and coal) and a rapidly growing economy. The growth of non-oil based manufacturing is mainly concentrated on the island of Java, and has led to a strong increase in domestic demand for energy. This demand is mainly met by domestically produced oil products. However, Indonesian oil reserves are not abundant, and without major new findings Indonesia is expected to become a net oil importer within the next 10 years. The Indonesian government therefore wants to know for which manufacturing subsectors it is profitable to replace valuable oil products by more abundant natural gas (17–20 TCF (trillion cubic feet) non-committed reserves). The Indonesian government also wants a long-term forecast of the demand for natural gas by the manufacturing sector. This demand forecast is needed to assess the feasibility of a gas transmission system on Java. Here we restrict ourselves to answering two questions about gas demand; the profitability of natural gas in industrial processes and a forecast of long-term gas demand.

When a new fuel is introduced, the method used to model or describe its demand cannot be validated against historical data, because these data are not available. We could base our demand estimate on the amount of natural gas needed to replace the amount of energy currently used. However, this esti-

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mate would not be based on economic reasoning, and would not take into account what part of the total amount of energy used in production can technically be replaced by natural gas.

The determination of the profitability of natural gas in a single production process is relatively easy. Assuming there is a market for the final product, the profitability of natural gas can be based on the net present value (NPV) of investing in gas technology. The gas demand forecast is obtained by multiplying the expected sales volume by the amount of gas per unit produced. This approach of fuel choice is based on microeconomic reasoning, which is linked to long term growth expectations. An advantage of this approach is that it takes into account the particularities of the production process; a disadvantage is that it covers one plant or one production process only.

Here a method is proposed that generalizes the profitability approach to cover all production processes used in the manufacturing sector. This is feasible only when we can limit the number of production processes.

The starting point for this generalization is the energy intensity ratio per manufacturing subsector, which is defined as the total amount of energy used divided by the real gross value added (*GVAr*) of the subsector. Similar definitions can be given per energy carrier (oil, gas, coal and electricity). Changes in a manufacturing subsector's energy intensity ratio in time can result from many factors (technological change, increasing industrialization, more efficient use of energy etc), and if a subsector uses more than one production process these changes are hard to distinguish on the aggregate level (Jenne and Catell [9]). (For a comparison of different definitions of energy intensity see Ang [1]). If the information on energy utilization in production is detailed enough, on the production process level, the energy intensity ratio per primary fuel is the fuel intensity of the production process used, and represents what Jenne and Catell [9] call the physical intensity ratio.

If available, information on the production processes and the ways primary fuels are used in the processes, can be used to determine for which forms of energy utilization it is profitable to use natural gas. Since a long-term demand forecast is required, we need the profitability of natural gas in conversion as well as in new investments.

A problem is that manufacturing subsectors are normally defined according to the International Standard Industrial Classification (ISIC) [15, 16], and not according to energy utilization in production. Furthermore, the different forms of energy utilization in production are not part of the classification. To obtain this information we survey for Java all ways in which energy is used in production. Based on similarities in energy utilization in production, we then link every ISIC manufacturing subsector as distinguished by the Indonesian Bureau of Statistics to a unique production process. In this way we obtain manufacturing subsectors according to production processes. For these subsectors we can calculate the gas intensity ratios for existing production processes and for new investments based on the profitability of gas in production. These intensity ratios are then linked to the redefined subsectors (growth in) real gross value-added, to forecast the demand for natural gas.

This paper is organized as follows. The next section describes the model used for assessment of the demand for natural gas by the manufacturing sector. The data collection and interpretation process for Java is described. The fourth gives a short review of the results for Java's manufacturing sector and its sensitivity to changes in assumptions; the last section contains some concluding remarks.

Modelling primary energy demand

The following model describes the demand for primary fuels by the subsectors of the manufacturing sector. The demand for fuel f by subsector j in year t is denoted by $D^f_{j,t}$. It depends on the fuel intensity ratio $\epsilon^f_{j,t}$ and the real gross value-added $GVAr_{j,t}$. So by definition we have

$$D^f_{j,t} = \epsilon^f_{j,t}\, GVAr_{j,t} \tag{1}$$

for all $f \in F$, with F the set of all energy carriers; $j = 1, \ldots, J$, with J the number of subsectors of the manufacturing sector. So the total demand for energy carrier f in year t is by definition

$$D^f_t = \sum_{j=1}^{J} D^f_{j,t} \tag{2}$$

The total demand for energy by subsector j in year t is defined as

$$D_{j,t} = \sum_{f \in F} E^f\left(D^f_{j,t}\right) \tag{3}$$

where the functions E^f translate the different forms of energy into a single measure of energy; in our case cubic metre gas equivalent (mge). The energy intensity ratio of subsector j in year t is

$$\epsilon_{j,t} = \sum_{f \in F} E^f\left(\epsilon^f_{j,t}\right) \tag{4}$$

The energy intensity ratio in year t for the total manufacturing sector is by definition

$$\epsilon_t = \sum_{j=1}^{J} \frac{GVAr_{j,t}}{GVAr_t} \epsilon_{j,t} \tag{5}$$

So far the model contains only definitions for year t, because the intensity ratios $\epsilon^f_{j,t}$ are assumed known. To obtain demand estimates for the different fuels in the next year, we need information on $GVAr_{j,t+1}$ and $\epsilon^f_{j,t+1}$. We will formulate on an update of $\epsilon^f_{j,t}$ (based on microeconomic considerations) that changes the descriptive model (1) to (5) into an economic model. However, to assess the opportunities for natural gas we first need to identify for what purposes energy is used in production, and we must determine if this energy can be replaced by natural gas.

Energy utilization in production

Energy utilization in production can be classified into four types. (i) Internal and external transport, for which natural gas can be applied in the form of compressed natural gas (CNG). CNG is feasible only in case of a high annual mileage, and can be neglected here. Note that in our case study some CNG is used in Jakarta in buses and taxis, but these activities belong to the transport sector. (ii) Natural gas as feedstock for production. Feedstock applications are very specific applications; on Java there is one iron and steel factory and two urea plants that use natural gas as a feedstock. (iii) Captive power generation; the conversion to natural gas of existing (diesel) combustion engines for power generation is technically feasible, but in our case it can be precluded in advance for economic reasons (high investment costs). For new investments in manufacturing we assume that the recently extended Java–Bali power grid is able to supply sufficient electricity, so no captive electricity generation is required. (iv) Production of heat for production processes is the most probable application for natural gas. The number of technologies for heat production and application in production processes is limited [7, 17]. Two main principles for heat production can be distinguished: central heat production and *in situ* heat production.

Central heat production is applied whenever solid or liquid fuels are used, unless a temperature of more than 200°C is required (the maximum temperature of steam). In central heat production there are two main steps. First, a fuel is combusted in a boiler or generator to produce a secondary form of energy (say) steam. Then this steam is transported to, and used in, the production process through a steam based technology such as steam injection or mantle heating. In the same way we can start with the production of a hot liquid, mainly hot water.

In situ heat production means that the fuel is combusted either very close to the place where the heat is needed (and the hot gas or liquid is used in the production process through the same techniques as in the case of central heat production) or the fuel is used directly in the production process [7, 17]. Under normal circumstances this is only feasible for gaseous fuels. The main advantage of *in situ* heat production is a reduction in heat losses from 30 to 70% of the gross heating value in the case of central heat production, to losses of 5 to 30% in the case of *in situ* heat production. Another advantage is that natural gas is a clean fuel, so there is no contamination of the production process.

We conclude that the main opportunity for natural gas in manufacturing is in heat production, for which there are four main primary fuels: industrial diesel oil (denoted in our model by d), fuel oil (o), coal (c) and natural gas (g). In central heat production these four fuels are substitutes with respect to net heat production, although coal is not considered an alternative in most production processes. For later use we define two sets: the set of primary fuels for new investments $F = \{d, o, c, g\}$, and the set of fuels for conversion $F_c = \{d, o, c\}$.

Note that central heat production is a putty–(semi-)putty technology, because a boiler or generator can easily be converted to another fuel, whereas *in situ* heating is an example of putty–clay technology, because conversion to another fuel is not possible without considerable costs, and the adjustment needed resembles a new investment [4].

Value of natural gas in heat applications

For existing heat applications a company will switch to natural gas only if the price that the company is willing to pay for natural gas is higher than the actual price. The analytical measure for a consumer's willingness to pay is the netback value, defined as the price at which the NPV of the investment in conversion becomes zero. The netback value for conversion from fuel f to fuel g for production process j in year t is denoted by $NBc^{f,g}_{j,t}$.

Whenever the actual price of natural gas is below the netback value, it is profitable for the company to convert the production process from the current fuel to natural gas. However, to evaluate small investments (such as conversion) companies use a maximum payback period as criterion [8]. In practice a maximum payback period of three years is often used, and is adopted here.

Based on the netback value, we can define an indicator function $\delta^{f,g}_{j,t}$, which has the value one if it is profitable for the company to convert the production process using fuel f to natural gas (g), and which is zero otherwise:

$$\delta^{f,g}_{j,t} = \begin{cases} 1 & \text{if } P^{g}_{j,t} \leq NBc^{f,g}_{j,t},\ f \in F_c \\ 0 & \text{elsewhere} \end{cases} \tag{6}$$

Note that if the choice of fuel was optimal in the past, there is no reason to assume that there will be a fuel other than natural gas to replace the current fuel, unless there is a major change in the country's energy pricing policy.

For new investments we can apply two netback concepts: one based on cost advantages, and one based on the market price of the product produced ([2], pp 67–70 and 84–86). In most production processes the heat application system is only loosely coupled to the actual production process [6], and energy is only a minor input factor; in these cases minimizing costs suffices [4].

In the case where the production process chosen depends strongly on the fuel (a case in point are the feedstock applications), or when the fuel costs are a substantial part (more than 7%) of total input costs, the netback value based on the market price of the final product must be used. Based on the netback value for new investments (denoted by $NBn^{j,g}_{j,t}$), we can define an indicator function (say) $\delta^{f}_{j,t}$, similar to (6) for every fuel $f \in F$. Note that there is only one fuel for which this indicator is 1 for all other fuels.

Forecasting the demand for natural gas

The indicator function for the profitability of natural gas (and other primary fuels) in production can be used to 'estimate' the demand for natural gas by a manufacturing subsector. We assume that for year t_0 data are available that are detailed enough to represent every manufacturing subsector by one production process. With these data we can estimate the gas intensity ratio of subsector j when this subsector converts its existing production to natural gas, provided gas is available and its price is known.

Let $D^{f}_{j,t}$ with $f \in F_c$ denote the amount of fuel f used in subsector j to produce the current amount of heat. In general there will be differences in efficiency among fuels to produce the same amount of process heat; so to replace $D^{f}_{j,t}$ by natural gas, we have to take into account this difference in efficiency. We denote this efficiency difference by $\tau^{f,g}_{c,j}$; if $\tau^{f,g}_{c,j} = 1$, f and g have the same efficiency. The gas intensity ratio in subsector j in year $t (t = t_0 + 1, t_0 + 2, \ldots)$ based on conversion to natural gas $\epsilon^{g,c}_{j,t}$, can be estimated by

$$\epsilon^{g,c}_{j,t} = \frac{\sum_{k=t_0}^{t} D^{g,c}_{j,k}}{GVAr_{j,t_0}} = \frac{\sum_{k=t_0}^{t} \sum_{f \in F_c} \delta^{f,g}_{j,k} \tau^{f,g}_{c,j}\, E^{f}\left(D^{f}_{j,t_0}\right)}{GVAr_{j,t_0}} \tag{7}$$

The demand for natural gas in year t based on conversion is then:

$$D^{g,c}_{j,t} = \sum_{f \in F_c} \epsilon^{g,c}_{j,t}\, GVAr_{j,t_0} \tag{8}$$

The remaining demands for the fuels $f \in F_c$ in year t based on investments before the year $t_0 + 1$ are

$$D^{f,c}_{j,t} = \epsilon^{f,c}_{j,t}\, GVAr_{j,t_0} \tag{9}$$

with $\epsilon^{f,c}_{j,t}$ defined as

$$\epsilon^{f,c}_{j,t} = \left(1 - \delta^{f,g}_{j,t}\right)\epsilon^{f,c}_{j,t-1} \tag{10}$$

$\epsilon^{f,c}_{j,t_0}$ is based on (7) with $t = t_0$ and $\delta^{f,g}_{j,k}\ \tau^{f,g}_{c,j}$ replaced by $(1 - \delta^{f,g}_{j,k})$. Once $\epsilon^{f,c}_{j,t}$ becomes zero, it will remain zero; so equipment converted to natural gas will remain on gas. The model can be easily adjusted to cover switches from natural gas back to other fuels also. However, in case of a consistent energy pricing policy, such a switch is not very likely.

The set of equations (7) to (10) does not suffice to estimate the demand for natural gas, since new investments are not included. Let $\tau^{f,g}_{n,j}$ denote the efficiency of a new investment based on natural gas technology compared with production based on the technology for fuel f. The gas intensity ratio for subsector j based on new investments can be estimated by:

$$\epsilon^{g,n}_{j,t} = \frac{D^{g,n}_{j,t}}{GVAr_{j,t_0}} = \frac{\delta^{g}_{j,t}\ \tau^{f,g}_{n,j}\ E^{f}\left(D^{f}_{j,t_0}\right)}{GVAr_{j,t_0}} \tag{11}$$

Note that in (11) we can substitute any fuel $f_1 \in F$ other than f for g to estimate its intensity ratio.

Now we are able to estimate for every fuel f the total demand for gas in year $t = t_0 + 1, t_0 + 2, \ldots$ To avoid problems in the initial stage when gas is introduced, we assume that the production capacity of subsector j is fully utilized in year t_0, and that $\Delta GVAr_{j,t} \geq 0$ for $t \geq t_0$. These assumptions are reasonable for the booming economy of Java. The demand for natural gas due to new investments is

$$D^{g,n}_{j,t} = \sum_{k=t_0}^{t} \epsilon^{g,n}_{j,t} \Delta GVAr_{j,k} \tag{12}$$

The total demand for natural gas in year t is

$$D^{g}_{j,t} = D^{g,c}_{j,t} + D^{g,n}_{j,t} \tag{13}$$

Note that the superscript g in (11) to (13) can be replaced by every $f_1 \in F$ other than f; however, here we restrict our analysis to g.

Up to now we assumed that there is no energy saving technical progress that would lead to a decrease in demand for energy in the future. Rogner [13] expects an average saving of 0.5% per year in industrial gas applications. This trend can be easily introduced in Equations (7) and (11).

Data requirements and data construction

To apply (7) to (13) we need the netback values and a division of the manufacturing sector according to production processes. The data required for the application of the NPV criterion are: (i) the investment costs in energy equipment; (ii) the operating and maintenance costs for new and converted energy systems; and (iii) the amounts of fuel used for the different applications in production and their prices. In this section we discuss how these data can be obtained.

Available data

The starting point for our analysis of industrial energy utilization is the 1987 industrial survey conducted by the Indonesian Bureau of Statistics (BPS). BPS surveyed all establishments on Java with more than 20 employees. This survey contains (among others) data at the ISIC five-digit level [15] on: the exact location of the establishments surveyed, their total energy consumption, quantities of the different fuels consumed; financial data on fuel costs, labour costs and other input costs, and on value added.

For our purpose the energy data contained in the BPS survey have one major drawback: it states the total amount of energy used and not the division according to the main forms of energy application in production as described above. To obtain information on the relative importance of the different applications in production, and on the data for netback calculation, Gasunie Engineering conducted a survey, which is discussed next.

The Gasunie engineering survey

To reach maximum coverage of both energy consumption, and energy technologies used in the production processes, we applied the following procedure to select a sample from all 10 167 establishments in the BPS survey. From the set of all establishments we first removed all establishments in ISIC five-digit subsectors for which we know that the application of natural gas in the production process is absent or can be neglected; that is, manufacturing of batiks (code 32 114), production of jewels (code 39 010) etc.

If we randomly selected a sample from the remaining set of establishments, we would most probably end up with a selection of small businesses. For our purposes it is more interesting to study the large energy users, because there is a better chance that they represent Java's state of the art in energy application and that they have more reliable information for our survey data. Therefore we removed all establishments with an energy use of less than 80 000 mge (after deducting the consumption of electricity purchased, automotive diesel and gasoline, and natural gas used).[1] This reduces the set of establishments to 1527.

Java's manufacturing sector is concentrated in a few geographical areas, which are also candidates for investing in gas transmission and distribution. Therefore, the establishments visited should be in West Java either in the industrialized area called JaBoTaBek (Jakarta–Bogor–Tangerang–Bekasi), or in the Bandung area; in East Java in the Surabaya–Gresik area; and in Central Java in the Semarang area. In those three areas almost 90% of the total current industrial activity is concentrated.

A total of 318 establishments were visited by a multidisciplinary team of energy experts. A total of 241 surveys could be completed successfully. Because of their large energy use, eight bulk consumers were studied separately (the iron and steel factory, the two nitrogen fertilizer plants and five cement factories). So in total 249 establishments were surveyed.

Indonesia also has plans to invest in the production of basic chemicals. The demand assessment for this subsector is based on these plans, and will not be discussed here. Currently this subsector is still very small. However, naphtha from Indonesia's oil refineries will be the feedstock, not natural gas. Natural gas will be used only for heat production.

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. If a five-digit subsector in an area was selected for the survey, we always chose the

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[1] In West Java a small gas transmission and distribution system already exists. It supplies gas to the gas based industries (iron and urea), some small industries, and some residential and commercial consumers.

largest establishment still in the set. This was for two reasons: first, we wanted the survey to cover at least 20% of the energy used by the subsector. Second, choosing the larger establishments increases the chance that the technology used will better represent the current state of the art in Indonesia. Indonesia's economic policy is to open its borders [19] for competition, which will force less energy efficient companies to improve their energy use too [14].

The survey also gathered information on the ground plan of the energy utilities and the heating equipment in the establishments visited. This information was used to define a ground plan for a representative production process, which was used to estimate (i) the investment cost for new plants based on different fuels and (ii) the investment costs for conversion of an existing plant to natural gas. For the assessment of the investment costs we also gathered information on prices of equipment and the construction costs.

Data on operational and maintenance costs (O & M) were obtained by including in the survey estimates as a percentage of the total investment costs in utilities; these percentages are based on previous experience. These percentages were checked against the actual figures of the establishments visited, and if necessary adjusted.

The survey was also used to obtain information on the amount of fuel needed in the production processes. The analysis of the energy system included an assessment of the technical state of the equipment used. If energy utilization deviates significantly from what is expected in a similar production process outside Indonesia, the future demand will be gradually reduced with the opening of the domestic market for foreign competitors; also see Warr [19].

Constructing subsectors

In our demand model we defined a subsector as a set of establishments with the same production process from an energy point of view. Using the similarity in energy utilization as the criterion, we can divide the manufacturing sector into 38 different subsectors; see Table 1 (for an example, see the appendix). Table 1 shows how the subsectors based on energy utilization in production are related to the manufacturing subsectors according to ISIC. Note that there is a remarkable difference in the number of ISIC five-digit subsectors represented by one production process. The *GVAr* per production process is obtained by adding up the *GVAr*'s of the ISIC five-digit subsectors that use the same production process.

ISIC two-digit subsector 31 (food and beverages) is subdivided into 11 manufacturing subsectors, according to the use of energy in the production process. (A complete description of all processes is given in [6].) All ISIC five-digit subsectors that are covered by production process 31K use electricity only.

For subsector 34 it suffices to distinguish two production processes, namely paper (34A) and paper products (34B). Processes 34A and 34B are used in the ISIC three-digit subsector 341, and process 34B is sufficient to describe ISIC subsector 342.

For subsector 37 100 the ISIC classification is not detailed enough. The iron and steel factory, using natural gas as feedstock in a direct reduction production process (process 37A) [9] and currently the largest gas user on Java, had to be analysed separately. All other factories in subsector 37 100 produce concrete bars from scrap using electric arc furnaces (process 37B).

Apart from subsector 37 100, there is only one five-digit subsector for which a direct link between data on the ISIC five digit level and a single production process is not possible; see Table 1, processes 35A to 35F. This sector comprises 88 small, often old establishments. Most processes apply energy in reactors or tanks, and for separation of products and byproducts. These technologies are no longer loosely coupled to the actual production process, but depend on the design of the production process (in contrast to most other subsectors).

Note that when the latest revision of ISIC [16] is introduced as the basis for data gathering, it is unlikely that production processes on a level lower than ISIC five-digit are required. Furthermore, some production processes can be used in more than one two-digit subsector; for example, production process 31I is used in the two-digit subsectors 31, 35 and 39; see Table 1.

Results

Before we can calculate the netback values of natural gas in the production processes, we need assumptions on fuel prices. Although Indonesia exports oil, it is expected to become a net importer in the next decade; so within the project period there will be a shortage of oil. Therefore we set the price of oil at its border value, and till the year 2000 inflate it with the World Bank estimates on oil price increases [20]. To obtain real prices, we deflate by the expected increase in the Manufacturing Unit Value Index. The prices of oil products are based on the crude oil price adjusted for refinery margins, transport and

Table 1 Production processes and ISIC five-digit subsectors

Process code and name	Corresponding ISIC / BPS codes	No. of establishments
31A Milk powder and sweetened milk	31121	16
31B Coconut oil from coconut	31151, 31159	81
31C Bakery products	31179	225
31D Sugar manufacturing	31181	58
31E Tea processing	31220	148
31F MSG from molasses	31270	16
31G Beer from malt	31320, 31330, 31340	88
31H Tobacco products	31410, 31420, 31430, 31490	784
31I Other products (mainly steam)	31112, 31130, 31140, 31171, 31190, 31241, 31242, 31250, 31280, 35210, 35233, 39090	1 140
31J Other products (mainly furnaces)	31260, 31290	248
31K Other products (mainly electricity)	31111, 31122, 31161, 31163, 31164, 31169, 31210, 31230, 35120, 35140, 35222, 35232, 35290, 36900	730
32A Cloth from fiber	32111, 32112, 32113, 32115, 32120, 32130, 32140, 32160, 32190, 32210, 32290, 32310, 32330, 32400	2 639
33A Manufacturing of plywood	33111, 33112, 33113, 33114, 33190, 33210, 33230	419
34A Paper from board	34111, 34112	51
34B Containers from board	34120, 34190, 34200	442
35A NaOH & Cl_2 from NaCl	35110	11
35B Zinc oxide from zinc ingot	35110	22
35C H_2SO_4 from sulphur	35110	11
35D Inorganic chemicals	35110	11
35E Industrial organic chemicals	35110	11
35F Fatty acids	35110	22
35G Fertilizer	35120	2
35H Resin, plastics and synthetic fibre	35130	7
35I Drugs and medicine	35221	155
35J Soap from palm oil	35231	46
35K Tyres from rubber	35510, 35521, 35523, 35590	239
35L PVC wares from PVC resin	35600	496
36A Clay products	36110	39
36B Pressed and blown glass	36210	28
36C Sheet flat glass	36220	4
36D Cement	36310	5
36E Concrete products	36320	311
36F Quick lime from limestone	36330	66
36G Bricks and tiles from clay	36410, 36420	468
37A Iron and steel from pig iron	37100 PT Krakatau Steel	1
37B Reinforcement bars from scrap	37100 (rest)	22
38A Galvanizing	38190, 38200, 38311, 38330, 38411, 38430	447
38B Surface coating on metal	38111, 38112, 38113, 38120, 38130, 38240, 38320, 38340, 38440, 38450, 38460, 38490, 38500	653
Total		10 167

distribution costs [5], [21]. Java's own gas reserves (5–7 TCF) are insufficient to meet long-term demand, but sufficient to develop the market. After the market has been developed, gas has to be imported from other islands, where uncommitted reserved (11–15 TCF) are available, although not abundant. An alternative use for this gas is LNG export. So the price of gas has to be larger than its net value in LNG export. This is achieved by fuel oil parity pricing (154.4 rupiah/m^3 in 1989). (Pricing gas at fuel oil parity also meets the goal of revenue raising for the Indonesian government.)

We set the price of coal at its border value, since part of the coal used by the cement industry is currently imported from Australia. The low sulphur coal from Kalimantan can easily be exported, and the quality of Sumatra coal is described as insufficient by representatives of the cement industry. After the year 2000 we assume that all real fuel prices grow at an annual rate of 1.5%.

We are now able to calculate the netback values. For 1989 these values are given in columns (3) and (4) of Table 2. Column (5) contains the amount of energy used in 1989, and column (6) the percentage used for heat applications; that is, the amount that can be replaced by natural gas. Column (7) is the *GVAr* (in billions 1983 rupiah) that corresponds to the production process in column (2).

The fuel efficiency of subsector or process $j(\tau_{j,t}^{f,g})$ for new investments is given in column (8) and for

Table 2 Potential and effective demand per million *GVAr* in 1983 prices

ISIC sub-sector	Process		NB value rup / mge		Energy used	Replacement energy	*GVAr* in	Gas / oil efficiency		Potential mge / *GVAr*		Effective mge / *GVAR*	
(1)	No (2)	Name	New (3)	Existing (4)	10^6 mge (5)	% of (5) (6)	10^9 (7)	(8)	(9)	New (10)	Existing (11)	New (12)	Existing (13)
31	31A	Milk	173	138	18.9	58.3	42	0.99	1.00	260	262	260	0
	31B	Coconut oil	236	152	27.8	87.2	47	0.81	0.99	418	510	418	0
	31C	Bakery	232	75	15.2	75.2	18	0.96	0.96	610	610	610	0
	31D	Man. sugar	163	152	132.1	85.7	204	0.98	0.98	544	544	544	0
	31E	Tea	185	132	47.2	65.6	47	0.97	0.97	639	639	639	0
	31F	MSG	216	158	59.7	91.8	29	0.80	0.99	1512	1871	1512	1871
	31G	Beer	243	151	18.3	92.9	105	0.83	0.99	134	160	134	0
	31H	Tobacco	306	152	34.3	69.3	1358	0.72	0.96	13	17	13	0
	31I	Other products	234	152	61.5	83.4	126	0.82	0.97	250	295	250	0
	31J	Other products	183	146	8.7	56.8	15	0.95	0.95	313	313	313	0
	31K	Other products	—	—	109.4	0.7	73	—	—	—	—	—	—
32	32A	Textiles	231	154	633.6	57.4	1056	0.76	0.99	262	341	262	0
33	33A	Plywood	227	150	38.3	10.8	123	0.76	0.94	26	32	26	0
341	34A	Paper	166	146	272.2	78.0	97	0.98	0.98	2145	2145	2145	0
	34B	Paper products	201	153	65.9	70.5	42	0.90	1.00	719	799	719	0
342	34B	Paper products	201	153	17.5	70.5	131	0.89	0.99	84	93	84	0
35110	35A	NaOH and CL2	236	156	2.5	25.0							
	35B	Zinc oxide	173	82	4.7	54.4							
	35C	H_2SO_4	165	145	1.6	99.5							
	35D	Inorganics	199	135	8.1	93.2							
	35E	Organics	224	135	5.6	100.0							
	35F	Fatty acids	205	149	57.0	86.1							
35120	35G	Fertilizer	100	—	664.1	[a]							
35130	35H	Plastics	318	151	1.3	88.2	4	0.62	0.98	161	254	161	0
352	351	Drugs and											
	352	medicines	94	23.4	62.5	222	0.80	0.98	53	65	53	0	
	35J	Soap	181	158	22.9	100.0	49	0.92	0.97	430	453	430	453
	31I	Other products	234	152	85.6	83.4	61	0.82	0.96	96	113	96	0
355	35K	Tyres	176	150	89.0	45.6	115	0.97	0.97	342	342	342	0
356	35L	PVC wares	212	141	61.7	63.1	131	0.88	0.98	262	291	262	0
36	36A	Clay products	169	139	67.0	78.6	26	1.00	1.00	2026	2026	2026	0
(excluding cement)	36B	Blown glass	198	120	106.5	80.4	36	0.91	0.91	2164	2164	2164	0
	36C	Sheet glass	158	146	51.7	100.0	21	1.00	1.00	2462	2462	2462	0
	36E	Concrete											
	225	products	133	21.2	27.0	80	1.00	1.00	72	72	72	0	
	36F	Quick lime	173	76	11.8	0.0	2	0.99	0.99	0	0	0	0
	36G	Bricks	172	133	29.7	84.5	14	1.00	1.00	1793	1793	1793	0
36310	36D	Cement	172	139	908.7	[a]							
37	37A	Iron and steel	108	—	1077.3	[a]							
	37B	Reinforcing bars	163	145	61.9	83.6	42	0.99	0.99	1220	1220	1220	0
38	38A	Galvanizing	326	116	89.8	62.2	518	0.68	0.92	73	99	73	0
	38B	Surface coatings	403	150	86.2	65.9	502	0.62	0.98	70	111	70	0
39	31I	Other products	234	152	68.4	83.4	31	0.82	0.97	152	180	152	0

[a] These sectors comprise only a few companies, and are evaluated at the company level.

existing production in column (9). For existing production $\tau_{j,t}^{f,g}$ is calculated as the weighted average of the efficiencies of industrial diesel oil and fuel oil, using as weights the amounts of fuel oil and industrial diesel oil (both in mge) in the total amount of replaceable energy (column (5) × column (6)).

In the past much diesel oil was used because the prices of fuel oil and diesel oil in Indonesia were the same. Since the early 1990s fuels have been priced according to their real value to the economy [21]. This leads to the use of fuel oil instead of diesel oil for heat production in new investments.

We use process 38A to illustrate the calculations for the last four columns. The amount of gas per million *GVAr* for new investments is $(89.8/518) \times 0.622 \times 0.68 \times 1000 \approx 73$ (column (10)), and for conversion $(89.8/518) \times 0.622 \times 0.92 \times 1000 \approx 99$ (column (11)). These potential demands become effective demand (columns (12) and (13) respectively) if the price of gas (154.4 rupiah/m^3 in 1989) is less than the netback values in columns (3) and (4).

Column (12) shows that gas will be used in new investments. From this one might conclude that the fuel oil parity price is too low. However, a gas price increase of 10 rupiah/m^3 (to 165 rupiah/m^3 and keeping the price of oil products constant) induces a drop in demand; processes 31D (sugar), 36E (concrete products) and 37B (iron from scrap) will use fuel oil instead of natural gas; also see column (3). So a price of gas larger than fuel oil parity will reduce demand.

A second increase of 10 rupiah affects the fuel choice for paper (process 34A), clay products (36A), and bricks (36F). With every price increase the number of processes using natural gas reduces; a last large drop in demand to less than 5% of the original demand occurs when the price of gas becomes larger than 225 rupiah/m^3, and natural gas is no longer feasible for production process 32A (textiles).

Column (13) shows that existing production is hardly every converted. However, analysing column (4) shows that an initial lowering of the price for gas by five rupiah/m^3 is incentive enough for eleven more processes to switch to natural gas. This is an interesting result for the marketing department of Indonesia's gas distribution company.

We do not use the results for the production processes 35A to 35E. Because process 35F dominates ISIC five-digit sector 35 110 (see columns (5) and (7)), and the subsector is small, we assume that the combined result based on the last row of the block (35 110 in column (1)), is sufficient to forecast demand. Furthermore, the Indonesian government has extensive plans (many already under construction) for this subsector using naphtha as feedstock. For these investments natural gas can be used in heat production, where it has clear advantages.

For the processes 35G (fertilizer), 36D (cement) and 37A (iron and steel) we use estimates of future production based on investment plans and estimated future demand for final products, instead of growth in *GVAr*. No new production facilities for fertilizer (process 35G) will be established on Java. The current price of gas for Java's fertilizer industry is 60 rupiah/m^3. Given the fact that natural gas is relatively scarce on Java, the netback value of gas in fertilizer production is too small to increase capacity profitably. For the cement industry (process 36D), the use of gas is profitable in new investments; however, after 1995 the netback value of gas compared to coal becomes less than the price of natural gas, and coal is the optimal fuel. Currently the Indonesian government forces the cement industry to use coal. Since there are no plans for new investments in cement before 1995, we assume that cement will remain on coal. The netback value of natural gas in iron and steel production (process 37A) is also below the market value of gas; see Table 2. The existing production units are under revision to boost capacity, but new gas based production units are not feasible from an economic point of view. If more steel is needed than can be produced, import of steel seems a more viable option.

Demand forecast

Before we can apply Equations (7) to (13) to forecast the demand for natural gas, one other variable is needed: sectoral growth. The main assumptions for *GVAr* are given in Table 3; they are based on Indonesia's sectoral investment plans, and on private communication with the Indonesian Bureau of Planning.

If we substitute the results of Tables 2 and 3 into the model we can forecast effective demand for natural gas by the manufacturing sector (see Figure 1). Figure 1 shows that demand from gas based industries will grow only moderately (from 2.4 billion m^3 in 1993 to 3.8 billion in 2013), which is due to improvements in efficiency of existing capacity and new investments that started before 1993. The gas demand for heat applications will grow from 1.3 billion m^3 in 1993 to 10.4 billion m^3 in 2013, and by the year 2000 is the largest market.

Note that not every establishment will convert to natural gas, when gas becomes available. Experience with the introduction of natural gas in other countries shows that if fuel costs are less than 2% of the input costs, management is not interested in conver-

Table 3 Summary of the assumptions for demand forecast

	Average growth (%) Process	1989–93	1993–2000	2000–13
GVAr		7.0	5.8	5.2
Manufacturing		10.6	7.2	5.9
Food and beverages	(31A-31K)	8.3	6.3	5.5
Textiles	(32A)	13.0	8.3	6.1
Fertilizer	(35G)	8.0	8.5	0.0[a]
Basic chemicals	(35A-35F)	26.3	8.4	5.3[b]
Cement	(36D)	5.8	6.2	5.3[c]
Krakatau steel	(37A)	9.6	7.2	5.9
Metal products	(38A-38B)	13.5	7.8	6.4
All other processes		10.5	6.8	7.2

[a] No new investments in fertilizer production after the present plans have been realized.
[b] Also includes Indonesia's plans for investment in production of chemicals.
[c] The cement industry uses coal as fuel.

sion; if the fuel costs exceed 7% of the input costs, they will always convert. For the subsectors for which the fuel costs as a percentage of total input costs are in the 2–7% range, say $a\%$, we assume that $a/5 \times 100\%$ of the subsector will convert. This approximation is in line with what gas application specialists experienced. Furthermore, this assumption hardly affects our long-term demand forecast, since the demand arising from conversion is small.

Sensitivity analysis

Our gas demand forecast is an input for Indonesian decision makers, who have to decide on investment in gas transmission. The forecast is based on the most likely or base case scenario. However, the decision makers are also interested in alternative scenarios, that is, in the effect of changes in assumptions. Practitioners translate this information request into questions, such as, 'what is the effect of a change in the relative price of gas and oil?' Although this sort of (one factor at a time) sensitivity analysis helps us to understand our model, it is not very useful for decision makers. Decision makers need realistic limits within which gas demand will be. To obtain this information it is necessary to conduct a more comprehensive sensitivity analysis, based on all relevant factors simultaneously. Simultaneously, because one factor at a time analyses do not take into account interactions between factors.

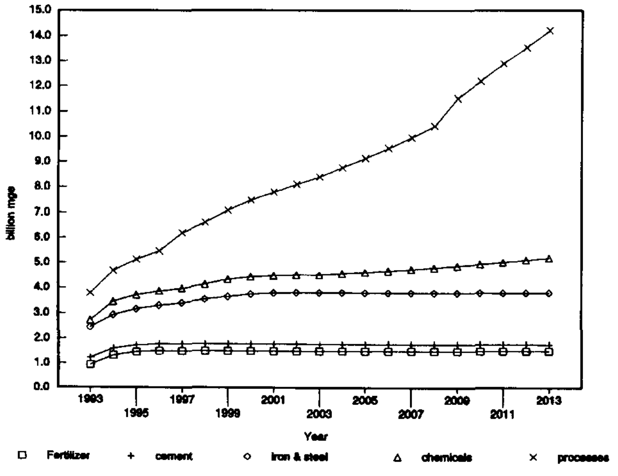

Figure 1 Gas demand forecast

In the gas demand model (7) to (13) there are four important factors. To see this we first note that the netback value can be written as $NBc = a + bP^f$, where a is based on the discounted investment plus operation and maintenance costs, and b on the ratio of the amount of fuel f and the amount of natural gas needed to produce one unit of output (also see [17]).

With this formulation of the netback value in mind, it is easy to see which four factors are important: (i) the discounted investment plus operation and maintenance costs in the netback value calculation (further denoted by x_1); (ii) the ratio of the amount of fuel oil and the amount of natural gas in the netback calculation (denoted by x_2); (note that both x_1 and x_2 affect the gas intensity ratios; see Equations (7) and (11)); (iii) the relative gas/oil price scenario (denoted by x_3), which affects the fuel choice; and (iv) the *GVAr* growth scenario (x_4), which affects the growth in energy demand through equations (8) and (12). Changes in one or more of these factors will affect our gas demand forecast.

We use statistical design theory to analyse the effect of simultaneous changes in factors, because a correct design covers all possible alternatives. Since there are only four factors, we can apply a 2^4 full factorial design ([11], pp 172–175). In a full factorial design every factor ($x_1, \ldots, x_4$) is changed positively and negatively with respect to its base case value. With each of these two changes we can (arbitrarily) associate +1 and −1 respectively. In a full factorial design we conduct $2^4 = 16$ experiments, so in total we generate 16 gas demand forecasts (say) $(y_1, \ldots, y_{16})$. The pattern of factor changes that correspond with these 16 experiments is given in columns (1) to (4) of Table 4.

In cases where factors interact, these interactions affect the simulation results. Possible two, three, or four factor interactions can be identified with the columns (5) to (15) of Table 4. If we call the matrix of +1's and −1's in Table 4 X, and augment it with a vector of 1's for the constant, we can estimate all 15 possible effects with the model

$$\underline{y}_m = \beta_0 + \sum_{i=1}^{4} \beta_i x_i + \sum_{i=1}^{4} \sum_{j=i+1}^{4} \beta_{ij} x_i x_j + \sum_{i=1}^{4} \sum_{j=i+1}^{4} \sum_{k=j+1}^{4} \beta_{ijk} x_i x_j x_k + \beta_{1234} x_1 x_2 x_3 x_4 + \underline{\epsilon}_m \tag{14}$$

Equation (14) is also referred to as metamodel. We assume that the deviations $\underline{\epsilon}_m$ between the simulation results and the metamodel predictions are identical and independently distributed, so we can apply ordinary least squares; also see Kleijnen and Van Groenendaal ([17] p 154).

If we choose the actual values we associate with changes in x_1, x_2, x_3 and x_4 correctly, the magnitudes of the estimated β's show the importance of the effects. We choose these values such that the experimental area is as large as possible; that is, the borders of the experimental area are the extreme values for the variables considered.

With $x_1 = -1$ we associate a change of +40% in investment costs of the NPVs on which the netback values are based, and with $x_1 = 1$ we associate a change of −40%. The size of these changes is based on our survey results, which indicate that all alternatives are within these limits. For x_2 (fuel ratio) and x_3 (real gas/oil price) we use ±10%. These values are chosen somewhat arbitrarily; however, we consider them large but still realistic. For economic growth (x_4) a low and high growth scenario are used similar to the base case scenario of Table 3. For the low growth scenario the average *GVAr* growth rates are 6.5%, 4.8% and 4.3% for the time periods 1991–93, 1994–2000, and 2001–13 respectively, and for the high growth scenario the *GVAr* growth rates are 7.2%, 6.4% and 6.0%. The subsectoral growth figures will not be presented here, but show the same pattern as the figures for the base case; see Table 3. (Note that all growth scenarios are based on discussions with the Indonesian Bureau of Planning and the Jakarta World Bank Office.)

We are interested in the effect of factor changes on total gas demand over the forecast period (1991–2013), not in the exact demand development per year. Therefore we use $y = \sum_{j=1}^{J} (D^g_{j,2013} - D^g_{j,1991})$, the difference between gas demand in 2013 and 1991, as an endogenous variable for our sensitivity analysis. If we estimate (14) and delete all insignificant effects, we obtain the following result:

$$\begin{aligned} \hat{y} = {} & 10\,961 + 1052x_2 - 1013x_3 + 2400x_4 \\ & t{:}87.0 \quad 8.4 \quad -8.0 \quad 19.1 \\ & -961x_{23} + 298x_{24} + 310x_{34} \\ & -7.6 \quad -2.4 \quad 2.5 \end{aligned} \tag{15}$$

With $R^2_{cor} = 0.98$, we have a good fit. The subscript *cor* means corrected for the number of regressors ([18], p 181). All t-values are significant at the level

Table 4 2^4 **full factorial experimental design (+means +1 and −means −1)**

Run	1	2	3	4	5 = 12	6 = 13	7 = 14	8 = 23	9 = 24	10 = 34	11 = 123	12 = 124	13 = 134	14 = 234	15 = 1234
1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2	−	+	+	+	−	−	−	+	+	+	−	−	−	+	−
3	+	−	+	+	−	+	+	−	−	+	−	−	+	−	−
4	−	−	+	+	+	−	−	−	−	+	+	+	−	−	+
5	+	+	−	+	+	−	+	−	+	−	−	+	−	−	−
6	−	+	−	+	−	+	−	−	+	−	+	−	+	−	+
7	+	−	−	+	−	−	+	+	−	−	+	−	−	+	+
8	−	−	−	+	+	+	−	+	−	−	−	+	+	+	−
9	+	+	+	−	+	+	−	+	−	−	+	−	−	−	−
10	−	+	+	−	−	−	+	+	−	−	−	+	+	−	+
11	+	−	+	−	−	+	−	−	+	−	−	+	−	+	+
12	−	−	+	−	+	−	+	−	+	−	+	−	+	+	−
13	+	+	−	−	+	−	−	−	−	+	−	−	+	+	+
14	−	+	−	−	−	+	+	−	−	+	+	+	−	+	−
15	+	−	−	−	−	−	−	+	+	+	+	+	+	−	−
16	−	−	−	−	+	+	+	+	+	+	−	−	−	−	+

$\alpha = 0.025$. The F-test on model reduction ([11], p 157) resulted in an F-statistic of 0.07, so the model reduction is clearly accepted.

Because our experimental area is based on extreme factor changes, the magnitude of the coefficients in Equation (15) also rank the effects. Equation (15) shows that *GVAr* growth (x_4) is the dominant factor, followed *ex aequo* by the fuel ratio per unit produced (x_2) and the relative gas/oil price (x_3). Changes in investment plus operation and maintenance costs (x_1) have no significant effect on gas demand.

Furthermore, three two-factor interactions are significant. The positive effect that an increase in the fuel ratio (x_2) has on the demand for gas can be almost totally offset by an increase in the relative price of natural gas (x_{23}). This is as expected, since the fuel ratio (which is 1 where both fuels have the same efficiency) affects the netback value of gas through the price of fuel oil, and so does the change in the real gas/oil price.

There is also a negative relation between the fuel ratio and economic growth (x_{24}); however, this is difficult to explain. This negative effect suggests that economic growth is stronger in gas efficient subsectors.

The positive interaction between the relative gas/oil price and economic growth (x_{34}) suggests that the negative effect of a relative gas price increase is mitigated by the faster growth of subsectors that use gas as fuel.

To test the robustness of our sensitivity analysis we apply cross-validation ([11], pp 156–157); that is, we delete every simulation run y_m from the total set of simulation runs $\{y_1, \ldots, y_{16}\}$, and delete the corresponding row (say) x_m^T from the matrix of regressors $(x_2 x_3 x_4 x_{23} x_{24} x_{34})$. We then reestimate (15), and use the vector of coefficients (say) $\hat{\beta}_{(-m)}$ to predict y_m by $\hat{y}_m$ by $\hat{y}_m = x_m^T \hat{\beta}_{(-m)}$. If our model is robust the predictions $\hat{y}_m$, $m = 1, \ldots, 16$, and the simulation results y_m must be close. The scatter-plot in Figure 2 shows that this is the case; so our sensitivity analysis is robust.

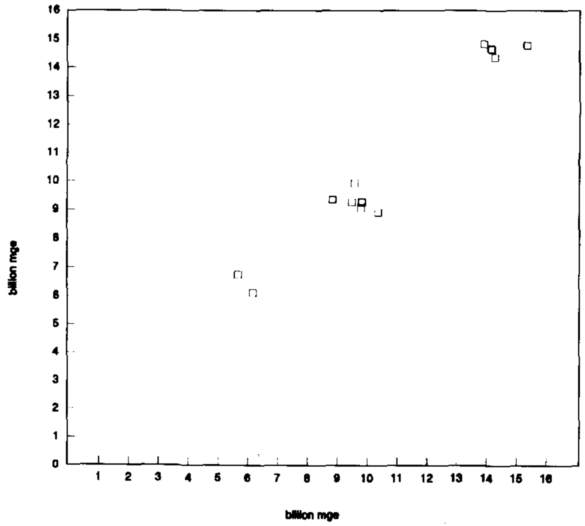

Figure 2 Scatter plot of $\hat{y}_m / y_m$

Note that $\hat{\beta}_0$ in (15) is relatively large (10 961), so even for the worst scenario ($x_2 = -1$, $x_3 = +1$, and $x_4 = -1$) the change in demand is according to (15) only -4112 or -37.5% of $\hat{\beta}_0$. Our approach is also easy to interpret, since the estimated coefficients are in million cubic metres of gas. Furthermore, factor changes smaller than the boundary values used in the sensitivity analysis can be evaluated as fractions of $+1$ or -1.

Conclusions

Forecasting the demand for natural gas by the manufacturing sector when gas is not available yet is a difficult problem. The main opportunities for natural gas in manufacturing are in heat application in production. Therefore, we first identified the technologies used to produce and apply heat in production processes. We showed that a limited number of processes (38) suffice to cover all heat applications in manufacturing. To every production process we linked manufacturing subsectors in the ISIC five-digit level (120 in total). In this way almost the total manufacturing sector is covered, and the processes can be interpreted as manufacturing subsectors.

The process descriptions were also used to estimate the profitability of natural gas compared to other fuels, which in turn was translated into the netback values of gas in the different production processes. We distinguished two situations: new investments and conversion of existing production. By linking the potential gas intensity of the subsectors to these netback values we were able to forecast which subsectors will use natural gas in new investments, and whether or not existing production will convert to natural gas and when this switch will take place. By multiplying the gas intensity for conversion with the expected *GVAr* of a subsector in the year of conversion and adding to this the gas intensity for new investments times the growth in *GVAr*, we obtained demand forecasts for all manufacturing subsectors.

The redefinition of manufacturing subsectors allows comprehensive and reliable analysis of energy pricing policies, since changes in relative fuel prices show exactly which subsectors are affected. Therefore it is more than a model for gas demand forecasts; it is also an adequate tool for the design of energy pricing policies and how price changes affect the fuel mix.

Our redefinition of subsectors did not work for two ISIC subsectors (basic chemicals (ISIC 35 110), and iron and steel (ISIC 37 000). For these ISIC subsectors more detailed analyses were required. However, when the 1990 revision of ISIC is introduced as the basis for data collection, the problems encountered will disappear.

A drawback of the approach is that there is no link between sectoral economic growth and input costs. However, this link can be included when the model is embedded in an overall economic model.

Our sensitivity analysis shows which factors affect future demand. By applying statistical experimental design theory, we obtained more detailed results than are obtained through the more frequently applied 'one factor at a time' or *ceteris paribus* approach.

The demand forecast has been used as an input for Indonesia's domestic energy policy. The forecast, in combination with the long-term plans for the electricity sector, led to investments in gas transmission and distribution (financed by the World Bank) in West and East Java. Furthermore, the production process descriptions are used by the Indonesian gas distribution company as input for energy audits of industrial companies to market natural gas.

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Appendix

An example: metal products

The Indonesian Bureau of Statistics BPS distinguishes 25 ISIC five-digit subsectors within the ISIC two-digit subsector 38. The products produced range from wire for spectacles to steel pipe. However, the establishments in this subsector use energy either to galvanize their products or to coat the surface. So from an energy point of view, two subsectors instead of 25 are sufficient to analyse this two-digit sector at the production process level. For a more comprehensive discussion on production processes and statistical data see Brown *et al* [3] and van Groenendaal and de Gram [17]. The sequel of this example is restricted to galvanization, denoted as production process 38A.

A flow chart of production process 38A based on central heat production is given in Figure 3. Since the actual galvanization requires a temperature of more than 400 °C, *in situ* heating is required; see block L2. All other heat applications use steam from a central boiler. The technologies used are indicated in the bottom left corner of Figure 3. A flowchart for the same production process based on natural gas is given in Figure 4; technologies are again indicated in the left-hand bottom corner.

The costs for a galvanizing production unit are displayed in Table 5. The first column indicates the different energy consuming phases of Figures 3 and 4. The symbols B1, F1 etc denote the technologies also displayed in the figures. For the fuel supply system and for the heat application equipment Table 5 contains investment costs, operating and maintenance costs, and the amount of fuel needed. The conversion to natural gas is based on converting a production process using fuel oil. The data are for a plant of average size, but the actual size of a reasonably designed plant has no large influence on the netback calculations. The efficiencies of natural gas (symbol g) in process 38A relative to fuel oil (o) and diesel oil (d) are for new investments $\tau^{o,g}_{38A} = 475/720 = 0.66$ and $\tau^{d,g}_{38A} = 475/696 = 0.68$, and for conversion: $\tau^{o,g}_{38A} = 644/720 = 0.89$ and $\tau^{d,g}_{38A} = 644/696 = 0.93$.

Production process 38A can be used to evaluate the opportunities for natural gas in the ISIC five-digit subsectors 38 190, 38 200, 38 311, 38 330, 38 411 and 38 430.

With respect to the different forms of energy used in total production, Gasunie's survey showed that on average 8.3% is used for road transport, 0% for feedstock, 29.5% for electricity production, and 62.3% for central heat production in boilers or other central heating equipment; so 62.3% of the total energy used can be replaced by natural gas.

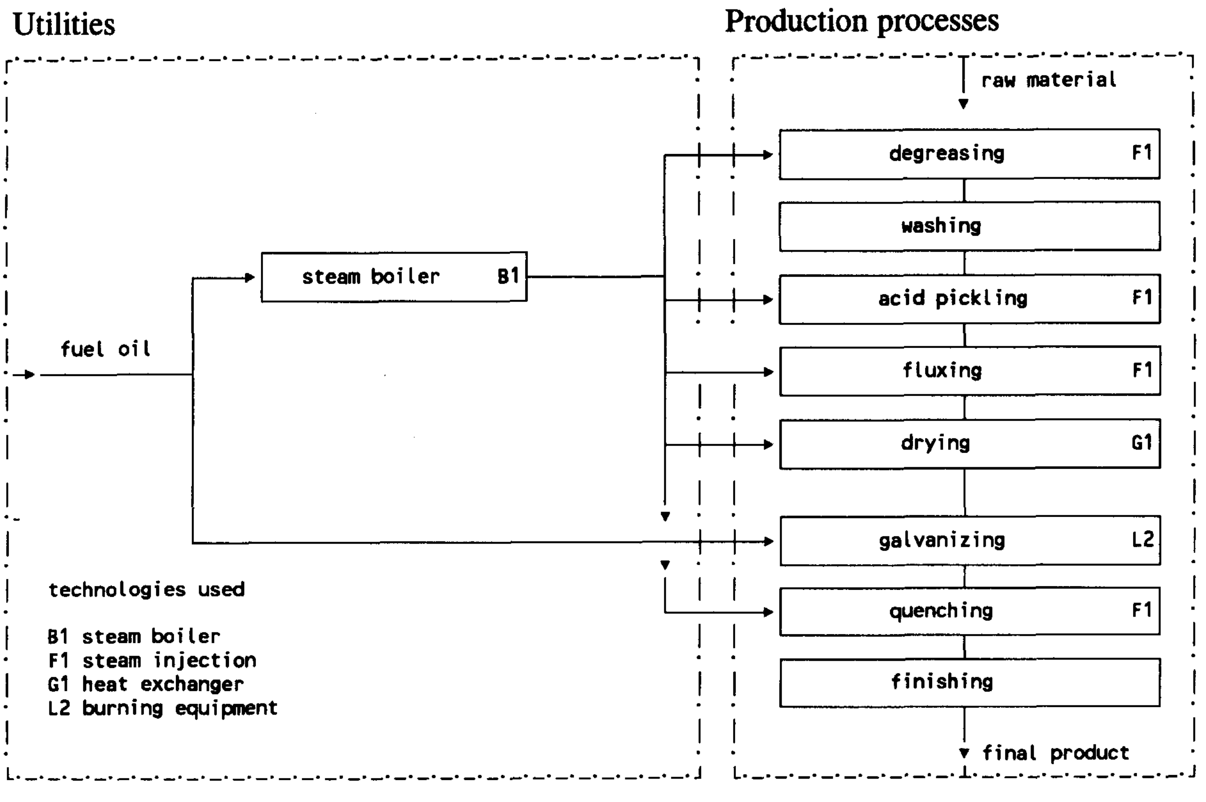

Figure 3 Central heat production for galvanization of metal products

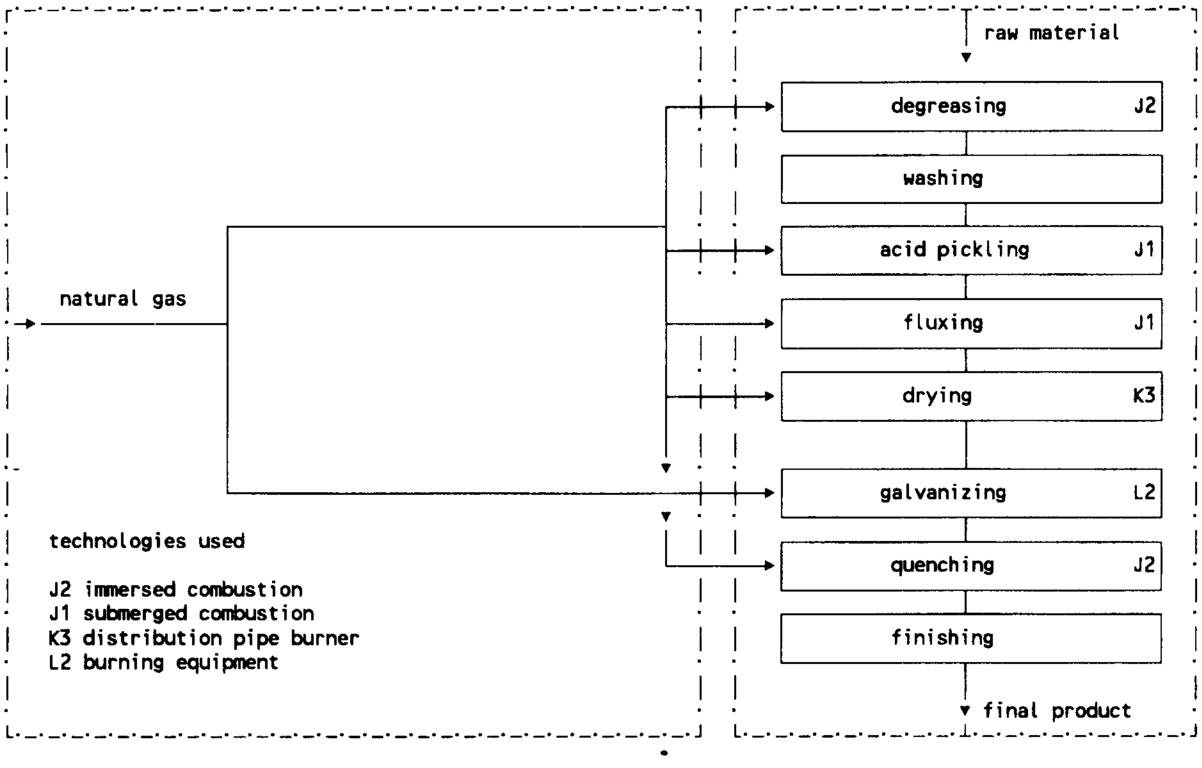

Figure 4 *In situ* heating for galvanization of metal products

Table 5 Investment, O & M, and energy use for production process 38A

Equipment		Investment[a] Fuel oil	O & M[a]	Fuel[b]		Investment[a] Diesel oil	O & M[a]	Fuel[b]
Fuel supply		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	473	B1	254.9	9.0	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	247	L2	68.0	2.4	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 1000 kg[c]		41.014	1.736	0.060		39.819	1.470	0.058
Equipment		**Natural gas**				**Conversion to gas**		
Fuel supply		14.9	0.4			7.9	0.2	
Heat transport						—	1.8	
Steam boiler					B1	30.0	7.8	453
Degreasing	J2	25.6	0.9	37	F1	—	0.4	
Acid pickling	J1	53.6	1.8	65	F1	—	0.8	
Fluxing	J1	53.6	1.8	65	F1	—	0.8	
Drying	K3	39.7	1.4	33	G1	—	0.8	
Galvanizing	L2	68.0	2.4	239	L2	—	2.4	191
Quenching	J2	25.6	0.9	37	F1	65.0		
Total plant		281.0	15.4	475		102.9	15.4	644
Per 1000 kg[c]		23.4	0.8	0.040		8.6	1.3	0.054

[a] In million rupiah
[b] Energy use in 1000 mge per year.
[c] Investment and O & M in 1000 rupiah.