Impact of cogeneration on integrated resource planning of Turkey

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Received 7 June 2001

Abstract

In most developing countries, difficulties in finding sector-specific data on heat rate and power demands make energy planning a hard task. In some countries, although this data is available, it may be four or five years old. In the present work, a new low-cost method is proposed for developing countries aiming at obtaining such data for the industrial sector quickly. Fifty-two textile factories were selected for a survey to represent the industrial sector. The data were processed and used to generate two scenarios of cogeneration applications in the industrial sector; one sized according to the electrical load of the factories, and the other one according to the thermal load. The costs and primary energy requirements of these programs were compared with that of the nuclear alternative. It was found that the most energy efficient and economical option for Turkey was the cogeneration program, the equipment sizing of which was based on the process heat demand of the industrial sector. Turkey would not only save US$ 72.6-billion by deferring the nuclear program, but it will also reduce the total primary energy demand by 11% in 2020.

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1. Introduction

As developing countries try to raise productivity and improve living standards, their energy needs rise rapidly. In order to meet this rapidly rising demand, they usually prefer to expand their supply base with little attention to the efficiency of energy use.

The primary and non-renewable energy reserves are expected to last 40–230 years at the present level of consumption [1]. Although new reserves of oil and natural gas were reported after the breakup of the Soviet Union, these resources are expected to be sufficient for only the planning
Nomenclature

APDR  average-to-peak demand ratio
AWH  annual work-hours of a factory
\( C_{\text{gas}} \)  specific heat at constant pressure of the exhaust gases, kJ/(kg K)
\( D_{\text{av}} \)  average demand of power or heat rate, MW
\( D_{\text{max}} \)  maximum (peak) demand of power or heat rate, MW
DSM  demand-side management
\( E_{\text{ind,el}} \)  electricity consumption of industrial sector, MTOE
\( E_{\text{nuc,el}} \)  electricity consumption from the nuclear program of MENR, MTOE
FCF  factory-capacity-factor, i.e., operating capacity-to-maximum capacity
GLF  grid loss factor
HPR  heat-to-power ratio
IRP  integrated resource planning
LPG  liquefied petroleum gas
NG  natural gas
\( \dot{m}_{\text{gas}} \)  mass flow rate of the exhaust gases, kg/s
MTOE  mega-tons of oil equivalent, \( 10^6 \) TOE
PHTER  process heat-to-total energy ratio, i.e., the ratio of the fuel consumption to the sum of fuel and electricity consumption at the plants
\( Q_{\text{ex,el}} \)  equivalent primary energy demand for meeting the excess power generated by Program 2, MTOE
\( Q_{\text{ind}} \)  primary energy demand of industrial sector, MTOE
\( Q_{\text{ind,heat}} \)  primary energy demand for process heat applications in industrial sector, MTOE
\( Q_{\text{nuc}} \)  primary energy demand by the nuclear program of MENR, MTOE
\( Q_{\text{nuc,heat}} \)  primary energy demand for process heat of factories using \( E_{\text{nuc,el}} \), MTOE
\( Q_{\text{nuc,tot}} \)  \( Q_{\text{nuc}} + Q_{\text{nuc,heat}} \), MTOE
\( Q_{\text{Pr1}} \)  primary energy requirement by Program 1, MTOE
\( Q_{\text{Pr2}} \)  primary energy requirement by Program 2, MTOE
\( Q_{\text{stack}} \)  process heat delivered by the stack of a cogeneration plant
\( T_{\text{gas}} \)  temperature of the exhaust gases
TOE  tons of oil equivalent
\( TQ_{\text{MENR,nuc}} \)  total primary energy demand (including nuclear energy) projected by MENR, MTOE
\( TQ_{\text{MENR,Pr1}} \)  total primary energy demand projected by MENR and modified to substitute Program 1 for the nuclear program, MTOE
\( TQ_{\text{MENR,Pr2}} \)  total primary energy demand projected by MENR and modified to substitute Program 2 for the nuclear program, MTOE
XFE  the ratio of extra fuel demand for process heat to electricity demand when cogeneration is used in a plant
\( \eta_{\text{el,CG}} \)  electrical efficiency of the cogeneration plant
\( \eta_{\text{el,PP}} \)  electrical efficiency of the power plant or utility
\( \eta_{\text{FS}} \)  fuel-to-steam efficiency of boiler
\( \xi \)  annual energy consumption by a factory, MWh
of the next generation of power plants. Efficient utilization of energy is essential for conservation of the reserves and protection of the environment. Integrated resource planning (IRP) and utility demand-side management (DSM) programs are examples of possible practices that can be utilized by governments to meet future customer energy service needs efficiently and possibly defer new power capacity needs. Before the deregulation and restructuring of the electric utilities, substantial peak reductions and energy savings were enjoyed by the application of DSM programs in the USA. In the early 1990s, an EPRI survey [2] reported summer peak demand reductions of 10.7 GW (based on data from 612 programs) and winter peak demand reductions of 5.4 GW (based on data from 394 programs). Another study [3] reported that utility DSM programs provided capacity equivalent to 39.6 GW in 1993, during which the annual energy savings amounted to 44,300 GW h.

In order to devise successful DSM programs, it is important to establish a forecast of electric energy consumption and peak demand in the absence of DSM programs [4]. The baseline forecast establishes a reference against which the impact of DSM measures can be assessed. Studies concerning the baseline forecast can be carried out at the sector level.

Energy information administration (EIA) of USA conducts detailed surveys for the manufacturing sector every 4 years. These surveys are intended to collect a detailed data on the energy consumption of the manufacturing industry. The 1994 Manufacturing Energy Consumption Survey (MECS) had a sample size of 22,922, which allowed separate estimates of 52 industries and industry groups [5]. Similarly, Statistics Canada conducts surveys [6] quarterly, targeting almost all establishments in the major energy consuming industries. In these countries, data is usually collected by mail out/mail back method.

In industrialized countries energy auditing of industrialized plants is very common. Data acquisition system (DAS) and monitoring are often used in many plants to obtain the power demand, either for the whole plant or for the end-uses. In these countries, it is usually possible to gather enough data [7,8] to represent the energy use and the demand profile of the industrial sector.

However, DAS and monitoring is expensive. In developing countries, energy audits and end-use data monitoring, by “metering” and “sub-metering”, are usually considered to be unnecessary investments. Detailed equipment inventory is rarely available and building codes and standards are hardly enforced. Lack of this data coupled with the slow process of obtaining accurate and reliable survey data delay long lead in planning. Furthermore, conducting energy surveys by mail may prove to yield inaccurate results in developing countries due to lack of expert knowledge within the establishments. On the other hand, face-to-face surveys in large numbers may be expensive although reliable answers may be obtained by proper guidance of the surveyor.

In this study, a new approach will be presented for quick and inexpensive data generation. The object is two-fold; firstly to show that by designing a simple survey, data can be obtained without requiring investments in DAS, logging, monitoring, and the associated expenses, and secondly, to show how this new method will work through a case study. Turkey is selected for the case study since electricity shortages and blackouts are common and, therefore, there is a desperate need for increasing the country’s electricity generating capacity.
2. Methodology

2.1. Use of available data

Information about primary energy production, consumption and their projections are available from the Ministry of Energy and Natural Resources (MENR) [9]. MENR uses a simulation program, Model for Analysis of Energy Demand (MAED), in order to establish Turkey’s general energy demand. This model requires the input of a wide range of data on social, economical and technological structure of the country. The total energy demand of the country is estimated by adding the demand for the supply-side to the final energy demand obtained from MAED. The demand projections of primary energy sources, estimated by the MAED model, is shown in Fig. 1. According to the MENR reports, the share of the industrial sector in the total demand of primary energy sources will increase from 29% to 40% between the years 2000 and 2020. Similarly the share of the power sector is expected to increase from 21% to 28%. Cogeneration is worth considering in the planning of future power generation, since the prime energy consumers are these two sectors. Furthermore, nuclear power plants are planned to be in use from the year 2007. According to this plan, there would be a 10,000 MW nuclear power capacity by the year 2020. However there are strong public criticism concerning their safety and high expense. On the other hand, wind energy is not included in the projections of MENR, although there are already a few small wind power stations operating in Turkey. At the moment, there are at least 30 projects, which are either under construction or consideration, adding up to 650 MW [10]. Finally, it is not clear how central heating is included in primary energy demand projections of MENR.

The present work aims to choose a sample group of factories to conduct a survey in order to determine the potential contribution of cogeneration in the energy-mix of Turkey. State Institute

![Diagram of energy demand projections](image-url)

Fig. 1. The demand of primary energy sources according to the MENR planning [9].
of Statistics (SIS) conducted surveys on energy consumption in large scale manufacturing industries aiming at obtaining information on electricity and fuel consumptions by different industry groups and geographical codes [11–13]. Electricity consumptions of different industry groups for 1992, 1995 and 1998 can be seen in Fig. 2. There is also information on the fuel consumptions of these industry groups.

2.2. Selection of sample industry

Process heat-to-total energy ratio (PHTER) is defined as the ratio of the fuel consumption to the sum of fuel and electricity consumption at the plants. A graph of PHTER for the industry groups is shown in Fig. 3. Selection of only one of these industry groups to form the sample group of our study is preferable, however, it is important to choose one that is representative of the manufacturing industry as a whole. The average PHTER-value of the industry groups, being 0.82 in 1992, 0.78 in 1995 and 0.78 in 1998, meant that the three industry groups, textile, furniture and paper would be the most suitable ones to study for the purpose of this project. It is sought to conduct the survey in a region where a reasonable sample can be formed. The numbers of large-scale factories in 1995 were 244 for textile, 46 for paper and 25 for furniture industries. SIS divided their survey study into seven major geographical regions. As seen in Fig. 4, most of the primary energy consumed by the manufacturing industries is in the Marmara region.

The textile industry is preferred for conducting a survey since not only its electricity consumption is high, but also it is one of the country’s primary export sectors. We chose Bursa, one of the largest industrial cities in Marmara region, to conduct our survey, since there were at least 200 small, medium and large-scale factories according to the records of Textile Institute of Tubitak, Marmara Research Center (SAGEM) in Bursa. Factories are located in organized industrial parks.

Fig. 2. Electricity consumption by the industry groups [11–13].
2.3. Energy survey in Bursa-textile industry

A survey was designed for a sample group of factories to establish their electricity and heat demands, based on their 1997, 1998 and 1999 energy consumptions. In order to collect the necessary data on this energy usage, the survey was conducted with the major textile factories in Bursa. Although a list of 200 factories could be obtained from SAGEM, it was difficult to know the exact number in business. Most of the factories were concentrated in four large industrial parks, namely, Bursa, Demirtas, Inegol and Kestel. A group of well-trained surveyors were sent to these industrial parks, where they met with the energy managers of the factories. Out of the 98 establishments contacted, only 60 agreed to meet with the surveyors. Questions on installed heating and power capacities, monthly electricity and fuel usage, the maximum production capacity...
and the working hours of the factories were asked. The aim of the survey was to establish the maximum heating and power demands of the factories. In some cases, a second and third visit was necessary when the required data was not readily available. After checking the survey reports, out of 60 factories visited only data of the 52 were accepted as valid.

3. Peak demand estimation

In order to evaluate the peak demand, $D_{\text{max}}$, an average-to-peak demand ratio, APDR, was introduced. APDR is the ratio of the average demand obtained from the energy used over a period of time (in this paper 1997–1999) to the maximum demand (see Fig. 5). Electricity and fuel bills data, together with the average factory-capacity-factor (FCF) and the annual work-hours (AWH) were used to estimate the electricity demand and the rate of heat requirement for processes. FCF is the ratio of current working load of the factory to the maximum working capacity. Hence, $D_{\text{max}}$ in MW can be estimated as follows:

$$D_{\text{max}} = \frac{\xi}{(\text{APDR})(\text{AWH})(\text{FCF})}$$

where $\xi$ is the annual energy use in MWh. $\xi$ may refer to electricity consumption or primary energy demand for process heat use at the factory. $D_{\text{max}}$ is summed over all 52 plants to obtain the total demand.

Fig. 5. The definition of APDR. (An appropriate time scale can be chosen in order to represent the typical energy use over a period of time. The time units can be hours, days or months. In this work, the time unit is months and the data of years 1997–1999 are used to estimate $D_{\text{max}}$.)
4. Survey results

4.1. Summary of the results

The survey results were used to estimate the energy saving potential of cogeneration applications in industry. The installed electric supply capacities (transformer sizes) and heat equipment capacities of the factories were grossly oversized. Therefore, actual energy bills were used to estimate the demands. It was discovered that most of the factories operated almost all their departments for two to three shifts so that production continued for 24 h. For this reason, an average APDR-value of 0.85 was assumed in our calculations. Maximum demands of electricity and heat, in MW, were calculated by substituting the survey information, APDR, FCF and AWH into Eq. (1).

Peak power demand for all 52 factories, obtained by the substitution of annual electricity consumption into Eq. (1), was estimated to be 85.6 MW. It was estimated that 305.71 MW of primary power was required at the utility, for meeting this demand (assuming electrical efficiency, $\eta_{el,PP}$, to be 35% and a grid-loss factor, GLF, of 0.8).

The rate of process heat requirement of the 52 factories was calculated by using their monthly fuel bills. The total primary heating (fuel) demand by the boilers was estimated to be 426.28 MW. Assuming fuel-to-steam efficiency, $\eta_{FS}$, to be 84%, the total rate of heat used in processes was estimated to be 358.08 MW.

A summary of heat and power demands for the 52 plants is shown in Fig. 6. The ratio of primary energy consumption for process heat to electricity consumption was found to be 4.98. The PHTER-value was therefore evaluated to be 83%, which is in good agreement with the industry-wide average of 78–82% shown in Fig. 3. The total fuel rate used by the 52 factories was 732 MW. In other words 42% of this was used for power, and 58% for process heat generations.

4.2. Cogeneration sized on electricity load

It is assumed that the electrical efficiency of the cogeneration plant, $\eta_{el,CG}$, is 40% and with a requirement of both steam and hot water, the total efficiency of the cogeneration plant is approximately 90% (or heat-to-power ratio, HPR=1.25). Therefore, total heat producing capacity of the
Fig. 7. Summary of the cogeneration application based on satisfying the electricity load. (It is assumed that reciprocating engines would be the most popular choice for cogeneration in Turkey for their simple operation and high efficiencies, ranging from 38% to 43%. Therefore an average electrical efficiency of 40% is used in the calculations.)

cogeneration systems would be 107 MW as shown in Fig. 7. In order to meet the total demand of 358.08 MW, extra heat generation will be needed to supply the remaining 251.08 MW. The rate of heat requirement (fuel) for the operation of these boilers would be 298.90 MW. The cogeneration application described here requires 30% less primary energy than the present system of using utility electricity and producing heat by boilers (Table 1).

<table>
<thead>
<tr>
<th>Current rate of primary heat requirement</th>
<th>Proposed rate of primary heat requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel used at the utilities</td>
<td>Fuel required at cogeneration</td>
</tr>
<tr>
<td>85.6 MW</td>
<td>85.6 MW</td>
</tr>
<tr>
<td>0.8 x 0.35 MW</td>
<td>0.4 x 251.08 MW</td>
</tr>
<tr>
<td>Fuel for process heat</td>
<td>Fuel required for extra heating</td>
</tr>
<tr>
<td>426.28 MW</td>
<td>0.84 x 298.90 MW</td>
</tr>
<tr>
<td>Total</td>
<td>Total</td>
</tr>
<tr>
<td>731.99 MW</td>
<td>512.90 MW</td>
</tr>
</tbody>
</table>

Energy saving potential = \(\frac{731.99 - 512.90}{731.99} = 0.299\) (or 30%)
4.3. *Cogeneration sized on heat load*

If the cogeneration systems are sized according to the process heat requirement of the 52 factories (estimated to be 358.08 MW), there will be excess (more than factories’ need) electricity production. Using an HPR-value of 1.25 the electrical capacity of the 52 factories is estimated to be 286.46 MW. Since we require only 85.6 MW of this capacity at the factories, the remaining 200.86 MW is to be exported to the grid (Fig. 8). Considering that 20% of this will be lost in the grid, the total power consumed would be 246.3 MW. This cogeneration application (sized according to the heating load) requires 45% less primary energy than generating the same electricity by utilities and producing the required heat at the plants (Table 2).

<table>
<thead>
<tr>
<th>Current rate of primary heat requirement</th>
<th>Proposed rate of primary heat requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel used at the utilities</td>
<td>Fuel required at cogeneration</td>
</tr>
<tr>
<td>246.3 MW</td>
<td>286.46 MW</td>
</tr>
<tr>
<td>0.8 × 0.35 MW</td>
<td>0.4 MW</td>
</tr>
<tr>
<td>Fuel for process heat heat</td>
<td></td>
</tr>
<tr>
<td>426.28 MW</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Total</td>
</tr>
<tr>
<td>1305.90 MW</td>
<td>716.15 MW</td>
</tr>
</tbody>
</table>
| Energy saving potential = \(\frac{1305.90 - 716.15}{1305.90}\) = 0.452 (or 45%)
5. Proposed DSM programs

In this section, installation of cogeneration plants in the industrial sector, are proposed to be a part of DSM programs. There are two options of applying the cogeneration plan. The first option requires the cogeneration sizing to be made according to the electricity needs of the factories, which will be referred to as Program 1. In the second option the cogeneration sizing will be based on the process heat requirements. This will be named as Program 2. In both of these programs half of the total installation cost (equipment, construction, etc.) of the cogeneration systems is targeted to be covered by DSM rebates. The majority of the factories visited in Bursa were using natural gas for their heating purposes, as shown in Table 3. Considering Turkey’s long-term energy plans, in this study it is assumed that the cogeneration systems would be natural gas-fired.

5.1. Cogeneration scenarios based on sizing

It is estimated by MENR that the industrial primary energy demand will be 127.13 MTOE in 2020. Let $Q_{\text{ind}}$ be the expected primary energy demand of the manufacturing industry for a particular year as estimated by MENR. MENR’s projections for $Q_{\text{ind}}$, show an exponential growth with time. The electricity consumption in the industrial sector is estimated by using the survey results, which indicates that 42% of the primary energy is used for electricity generation. In order to estimate the electricity consumption by the sector, $E_{\text{ind,el}}$, power plant efficiency and the grid losses are taken into account, such that

$$E_{\text{ind,el}} = 0.42Q_{\text{ind}}\eta_{\text{el,PP}}(\text{GLF})$$

(2)

The electricity consumption from the nuclear program can also be estimated by a similar approach, such that

$$E_{\text{nuc,el}} = Q_{\text{nuc}}\eta_{\text{el,PP}}(\text{GLF})$$

(3)

Here, $Q_{\text{nuc}}$ is the primary energy demand by the nuclear program projected by MENR. In order to estimate the primary energy demand for process heat applications in industry ($Q_{\text{ind,heat}}$), 58% (obtained from the survey results) of $Q_{\text{ind}}$ was computed. Similarly, in order to estimate the primary energy demand for process heat generation ($Q_{\text{nuc,heat}}$), of industrial plants using the nuclear electricity, $E_{\text{nuc,el}}$ was multiplied by 4.98 (see Fig. 6). The projections of $E_{\text{ind,el}}, Q_{\text{ind,heat}}, E_{\text{nuc,el}}$ and $Q_{\text{nuc,heat}}$ for the years 2000–2020 are shown in Fig. 9. It is clear that one of the industrial cogeneration programs, described in this paper, can be planned to replace the nuclear energy program of MENR. First option is a program (Program 1) where the electricity demand, $E_{\text{nuc,el}}$, is fulfilled. According to the survey results extra heat generation will be required for this program.

Table 3
Fuel usage of the factories visited in Bursa

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Natural gas</th>
<th>LPG</th>
<th>Fuel oil no. 2</th>
<th>Fuel oil no. 4</th>
<th>Fuel oil no. 6</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of factories</td>
<td>48</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>33</td>
<td>2</td>
</tr>
</tbody>
</table>
Fig. 9. Projections of electricity and fuel consumptions of the industrial sector and the nuclear program, estimated from MENR figures [9] and the survey results.

The second option, Program 2, takes process heat demand, $Q_{nuc,heat}$, into account and cogeneration-sizing is made accordingly. However, in this program more electricity is generated than needed which will be exported to the grid to be used elsewhere. In Fig. 10, the primary energy requirement for the nuclear program added on the primary energy requirement for the corresponding process heat requirement is compared with that of Programs 1 and 2. In other words, if the nuclear program was allocated to the industry, then the total primary energy needed, $Q_{nuc,tot}$, would be the addition of $Q_{nuc}$ and $Q_{nuc,heat}$, whereas for Programs 1 and 2, the total primary energy needed, are evaluated from the following equations respectively:

$$Q_{Pr1} = \frac{E_{nuc,el}}{\eta_{el,CG}} + (3.5E_{nuc,el})$$

$$Q_{Pr2} = \frac{Q_{nuc,heat} \eta_{FS}}{(HPR)\eta_{el,CG}}$$

In Eq. (4) the extra primary energy needed for process heating is evaluated using the survey results. Fig. 7 implies that, the extra primary energy needed is 3.5 times the electricity consumption. This ratio is dependent on HPR and will be referred to as the ratio of extra fuel demand for process heat to electricity demand, XFE.

Although, $Q_{Pr1}$ is lower than the other two options, it does not mean that it is the most efficient option for Turkey. The aim is to evaluate the effect of these programs on the overall primary energy consumption of Turkey. The total primary energy demand (including the nuclear energy) projected by MENR, $TQ_{MENR,nuc}$, is compared with the scenarios in which the nuclear option is replaced by Programs 1 and 2. In the first scenario, the MENR-projection of total primary energy
The total primary energy demand of Turkey would be the lowest with Program 2. The total primary energy demand, estimated by MENR, is decreased by 11% in 2020 by replacing the nuclear program by Program 2.

5.2. Natural gas resources

Turkey’s natural gas demand is projected to increase rapidly in the near future, with the prime consumers to be industry and power plants. At the moment, nearly all of the imported natural gas comes from Russia, while the rest is from Algeria via LNG ships. However, when these sources are compared with the natural gas projections of MENR, it is realized that the import sources must be diversified quickly. Turkey has signed gas import deals with Egypt, Iran, Iraq, Russia and Turkmenistan. A recent large natural gas reserve found in Azerbaijan’s Shakh Deniz field is also considered seriously for an import deal. In Fig. 12, both the purchase of natural gas under signed agreements and the projections of natural gas demand for the programs discussed in this paper are shown.
Fig. 11. Total energy demand projections for Turkey in the application of nuclear and cogeneration programs.

Fig. 12. Natural gas demand projections compared with that of its planned purchase (based on international agreements [10] and MENR projection [9] of natural gas demand).
Program 1 requires more natural gas than the present forecast of MENR, since replacing the nuclear program with cogeneration would bring extra burden on the existing natural gas demand. However, in the application of Program 2, the extra electricity generated can either be used to replace prospective capacities fired by fuels other than natural gas or to replace that of natural gas-fired capacities. The first option seems to be a good opportunity to reduce electricity generation by coal and petroleum-fired power plants and hence to reduce the carbon emissions, but natural gas demand is expected to reach 88.9 MTOE, which is the highest among all four options. Since this would widen the already existing natural gas deficit even more, selection of this option depends very much on the success of diversifying the natural gas import sources. If the efforts fail, however, it would be to the best interest of Turkey to keep the natural gas demand at its lowest possible level. In this case, the second option is chosen, since the natural gas demand will be below the present projections of MENR, reducing the deficit to more manageable levels (Fig. 12).

5.3. Biomass as an alternative fuel

While most cogeneration capacity is fired by natural gas, there are a number of installations and the potential for many more that are fired by biomass or by industrial or municipal wastes. There is a great potential in utilizing the residues in industries such as pulp and paper [14], wood and furniture [15], and sugar [16] for electricity production. Turkey has great aptitude for landfill gas extraction from the municipal wastes. Unfortunately the modern biomass usage is not included in the MENR projections. It is highly recommended to consider pilot projects before a more detailed plan of using biomass and especially for industrial applications.

6. Sensitivity analysis

In Fig. 11, Program 1 and the nuclear program have very close effects on the total primary energy demand projections of MENR; the difference is 4.2% in 2020. Therefore, it would be appropriate to carry out a sensitivity analysis with respect to process heat temperature for Program 1.

In Program 1, the XFE ratio is dependent on the temperature of the process heat. The process heat delivered by the stack, \( Q_{\text{stack}} \), is expressed as:

\[
Q_{\text{stack}} = \dot{m}_{\text{gas}} C_{p_{\text{gas}}} \Delta T_{\text{gas}}
\]

In this equation, \( \dot{m}_{\text{gas}} \) is the mass flow rate and \( C_{p_{\text{gas}}} \) is the specific heat at constant pressure of the exhaust gases. Temperature drop in the exhaust gases, \( \Delta T_{\text{gas}} \), depends on the temperature of the process heat.

It is possible to find data on the process heat temperatures for the Turkish food, textile, chemical and cement industries in the literature [17,18]. The distribution of heat requirement for different temperature ranges for the textile and the chemical sectors are summarized in Fig. 13. The mean process heat temperatures for the two sectors are evaluated as 113.48 and 398.13 °C, respectively. The cement sector, on the other hand, requires 1477 °C for 99.4% of its process heat. In such sectors, using bottoming cycle cogeneration systems is inevitable. In order to make the analysis simple, the textile and the chemical industries will be compared in this section.
If the energy calculations of Program 1 were repeated for the mean process heat temperature of the chemical industry (approximately 400 °C), the XFE ratio would change according to a simple analysis using Eq. (8) and the data in Fig. 7. The temperature of the exhaust gases is assumed to be 550 °C. In Fig. 7, the waste heat recovery will drop to 36.8 MW (HPR = 0.43) and the need for extra heat generation would increase to 321.2 MW. The XFE ratio will therefore increase to 4.47. When this value is used in our calculations, the total primary energy demand projection with Program 1, shown in Fig. 11, is increased by 1.66%, from 301.2 MTOE to 306.2 MTOE in 2020.

For Program 2, HPR is modified since the heat recovery from the stack would drop for higher temperatures of process heat. As HPR drops to 0.43 in Fig. 8, the electrical power exported to the grid will increase to 746.96 MW. This implies that the total primary energy required for MENR program would decrease by 4% from 279.1 MTOE to 267.9 MTOE.

The deviation in the total primary energy demand determined here is a conservative one, since the manufacturing industry is replaced completely by the chemical industry in the analysis. However, even then, the error would not lead the policy maker into misjudgment during the decision making process.

7. Economical analysis

Turkey’s first 1300 MW nuclear power plant, estimated at US$ 4-billion, is postponed [19] for financial reasons, although there also had been some public opposition. If the planned 10,000 MW nuclear power plants were to go ahead and built by 2020, the total cost (including the operation, maintenance, decommissioning and disposal costs) would have amounted to approxi-
approximately US$ 47.8-billion. The proposed programs of promoting cogeneration in industry, costs considerably less than the nuclear program. The price of cogeneration systems may vary according to the types of systems employed. In this study, it is assumed that mostly gas engines would be preferred, the unit cost of which may be taken as US$ 650/kW on average. If Program 1 were implemented and 10,000 MWe capacity of cogeneration systems were installed at the factories, the capital cost would be US$ 6.5-billion. With the operation and maintenance costs, this amount rises to US$ 22.7-billion in 2020 (which is 47.5% of the cost of nuclear program). Alternatively, Program 2, which would require an installed capacity of 33,500 MWe of cogeneration, would cost US$ 76-billion by the year 2020. A cost analysis is made in Table 4. The total savings of switching from the nuclear program to the cogeneration programs are estimated by evaluating the difference between the costs of avoided programs (such as the nuclear plants and boilers for process heating) and the costs related to Programs 1 and 2. Turkey’s savings are estimated to be as much as US$ 36.8-billion with Program 1 and US$ 72.6-billion with Program 2, if any of them was to go ahead instead of the nuclear program.

8. Conclusion

In this work, it is not intended to show that cogeneration applications can be an alternative to nuclear power. However, in developing countries, where lack of capital hinders implementation of the nuclear option, cheaper alternatives to nuclear power plant hopes should be emphasized for quick implementation.

Turkey is falling short of electricity as the water levels in major hydroelectric power plants, Ataturk, Karakaya and Keban, are dropping to critical levels with lessening rainfalls. Urgent energy programs are needed for quick implementation. The grid losses are too high and they need to be updated. Application of DSM programs, such as the ones discussed in this paper, could be a good way of establishing a more energy efficient and economical way of energy generation and easing the imminent energy crises. By this way, it is possible to defer capacity expansion as well. However, in order to make the cogeneration programs even more attractive, the extra electricity generated by the establishments should be purchased with a reasonable price.

It is determined that application of a cogeneration program, based on the process heat requirement of the participating factories, i.e., Program 2, is the most efficient and economical option amongst the programs considered. If Program 2 is designed to replace the nuclear program, the avoided costs will amount to US$ 148.6-billion and the savings due to this change of plan would be US$ 72.6-billion. This program could be subsidized by the government in the form of giving rebates to completed projects. The government would need US$ 10.9-billion until the end of 2020.

Acknowledgements

The authors express sincere gratitude and appreciation to F.F. Yildirim and M.A. Kostem (Textile Institute, Marmara Research Centre, Bursa, Turkey) for their assistance and advise during the conduct of energy survey at the textile factories.
Table 4
Cost analysis comparing the savings at the end of 2020 due to switching from the nuclear program to Programs 1 and 2

<table>
<thead>
<tr>
<th></th>
<th>Unit cost</th>
<th>Cost (billion US$)</th>
<th>Avoided costs (billion US$)</th>
<th>Savings (billion US$)</th>
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<tr>
<td><strong>Program 1</strong></td>
<td></td>
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<tr>
<td><strong>Cogeneration plants to be installed (10,000 MWe)</strong></td>
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<tr>
<td>Capital cost (US$/kW)</td>
<td>650</td>
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<tr>
<td>Fuel + O&amp;M (US$/kWh)</td>
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<tr>
<td><strong>Boilers to be installed for extra heat generation (35,000 MW)</strong></td>
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<td>Capital cost (US$/kW)</td>
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<td><strong>Nuclear power plants to be deferred (10,000 MWe)</strong></td>
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<td>Fuel + O&amp;M (US$/kWh)</td>
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<td>Decommissioning (% of capital cost)</td>
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<td><strong>Total</strong></td>
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<td>87.06</td>
<td>36.79</td>
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<td><strong>Program 2</strong></td>
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<td><strong>Cogeneration plants to be installed (33,500 MWe)</strong></td>
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