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ECONOMICS OF ENERGY-CONSERVATION MEASURES IN GREECE

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Abstract—A method is developed for analysing the cost-effectiveness of energy-conservation measures. The method reconciles social preferences with the profit-seeking objectives of private investors. An important externality to the energy system is environmental protection, which is considered through the avoided cost approach. An LP-model is used to examine structural changes to the primary supply side of the system. The employment of an energy engineer (EE), who will implement energy housekeeping procedures for Greek industry, is an example of application of the method. The results show that the measure offers very short payback periods, making its adoption an attractive investment.

INTRODUCTION

Rising energy prices, stagnation of per capita income and serious constraints of scarce capital have forced many countries to implement conservation programs in the last 20 years.[1–5] Techniques such as wall insulation, double glazing, top-up loft insulation, and solar hot-water production were mostly applied to the residential sector because of the high percentage of final energy demand in this sector and homogeneity of the population, which facilitates implementation of policy tools in the promotion of energy-conservation measures. Energy-conservation programs have been adopted by many individual consumers and the potential additional energy savings for the residual sector are expected to be rather small.

As industry increases its share of the final energy demand, the adoption of energy-conservation programs becomes important. Technical options for improving energy-use characterics of the industrial sector fall into two reasonably discrete categories:[6] (i) *Energy housekeeping procedures*—energy auditing and energy management constitute the main components of a housekeeping program. Energy auditing includes extended energy surveys, identification of all important energy wastes, measurements and development of Shankey diagrams. Equally important for energy auditing is set up of energy-management procedures such as routine maintenance, periodic staff training, monitoring, and targeting of energy-efficiency improvements. Such a program usually requires both application of some low-cost items of new or advanced technologies and employment of an EE who is responsible for the design, implementation and review of the program. (ii) *Investments of medium to high initial costs*—these include equipment retrofits, fuel substitutions, shift to less energy-intensive production processes and to new products requiring less energy for their manufacture.

International experience shows that investments in energy-housekeeping procedures could significantly contribute to the reduction of industrial energy demand with little life-time costs.[7–9] In Greece, the government is faced with financial constraints and seeks efficient, low-cost energy-conservation measures. The average industrial consumer has not widely adopted and accepted any energy-housekeeping procedures as part of everyday routine and behaviour. Equipment retrofit has been undertaken by a small number of energy-intensive industries, whereas the prospects for other categories of energy-conservation technologies remain largely unknown. Therefore, energy-housekeeping procedures offer significant energy-saving potentials and should receive special attention.

An important feature of Greek industry is the predominance of small industrial units with average annual employment up to 10 people. These establishments have small energy consumption around 10% of the total energy demand in industry and, therefore, the required funds and their potential energy savings are not sufficiently large to justify employment of an EE. For these reasons, they are not included in further analysis. On the other hand, a few large industrial units (mainly cement plants, refineries, fertilisers, and metallurgical units) use up to 50% of the total electricity consumption.[10] A similar concentration pattern exists in the case of thermal energy. Housekeeping procedures have already been implemented by these large units and are excluded from the industrial samples examined in this paper. The remaining units constitute a population of 2500 establishments that consume 35% of the total energy demand in industry (1200–1300 ktoe).

The Greek government is now considering the promotion of specific energy-conservation programs to overcome the unwillingness of the private investor due to the small size of representative industrial units. A possible approach could be the formation of a new labour market, that of EE, provided that adequate policy instruments will motivate private investors to use their services.

The cost effectiveness of energy-conservation programs and the magnitude of the new labour market are the object of the present study. The methodological approach is formulated using a social cost-benefit analysis coupled with a micro-economic analysis. The most important externality of the energy system, that of the environmental parameter, is incorporated into the social cost-benefit analysis using the avoided cost approach. An LP model is used to analyse differential changes that energy-conservation measures can make in the system. Different scenarios are formed to examine the influence of the overall energy-conservation program on the size of the new labour market. Finally, a brief discussion of the possible policy tools to promote adoption of the EE position by Greek industry is attempted.

METHODOLOGICAL APPROACH

Econometric models and social cost-benefit analysis have been widely adopted for evaluation of energy-conservation measures.[11–15] Their objective is to examine, from a social point of view, the design and implementation of various energy-conservation programs taking into account all relevant life-time costs and associated benefits. A third approach involves the manipulation of simulation models to examine various alternative policies for stimulating energy conservation.[16] The main objectives of the latter are the exploration of the effects that policies have on critical parameters (such as fuel consumption, capital cost, fuel cost, etc.) and the selection of the most appropriate policy tool according to a given criterion.

It has recently been realised that decisions on energy conservation are highly decentralised.[17,18] Conservation cannot be effective unless a large proportion of the consumers, mobilised by relevant and specific government decisions, reduce their energy consumption, change their life styles and invest in more energy-efficient devices. Evaluation of energy-conservation programs must take into account both social preferences and individual consumer responses to the measures.

The algorithm designed to assess the economics of energy conservation measures uses three interrelated approaches: (i) *A micro-economic analysis* to investigate if the measure is of economic benefit to individual consumers. (ii) *An energy-environmental analysis* to establish the differential changes the measure can cause to the flow of energy from the supply to the demand side of the energy system. These changes influence both the energy bill and the cost associated with environmental control. (iii) *A social cost-benefit analysis* to examine if the measure is of value to society and if there are any opportunities of providing financial incentives to the consumers to make the program more attractive. The graphical portrayal of the algorithm may be seen in Fig. 1.

Micro-economic analysis

At the **first stage,** the proposed measure is analysed using a micro-economic model. The model inputs are energy consumption and economic data. The net present-value (NPV) approach is used and the economic efficiency of the program, assuming that all establishments in sector i will employ an EE, is evaluated as follows:

$$\mathrm{NPV}_i = (1-\varphi)\sum_{t=1}^{n} \frac{p_\mathrm{h}\, V_{\mathrm{h},i,\mathrm{t}} + p_\mathrm{e}\, V_{\mathrm{e},i,\mathrm{t}} - aN_i}{(1+\mathrm{r})^\mathrm{t}} + \sum_{t=1}^{n} \frac{\varphi g a N_i}{(1+r)^t} - (1-\varphi)[I_i + (1+s)aN_i]\ \forall i, \qquad (1)$$

where φ = the marginal tax rate, p_h = price of heavy fuel oil (GDR/toe), $V_{\mathrm{h,i,t}}$ = annual fuel conservation of heavy fuel oil (toe/year), p_e = price of electricity (GDR/toe), $V_{\mathrm{e,i,t}}$ = annual fuel conservation of electricity (toe/year), a = annual remuneration of EE (GDR/year), N_i = number of EEs, g = proportion

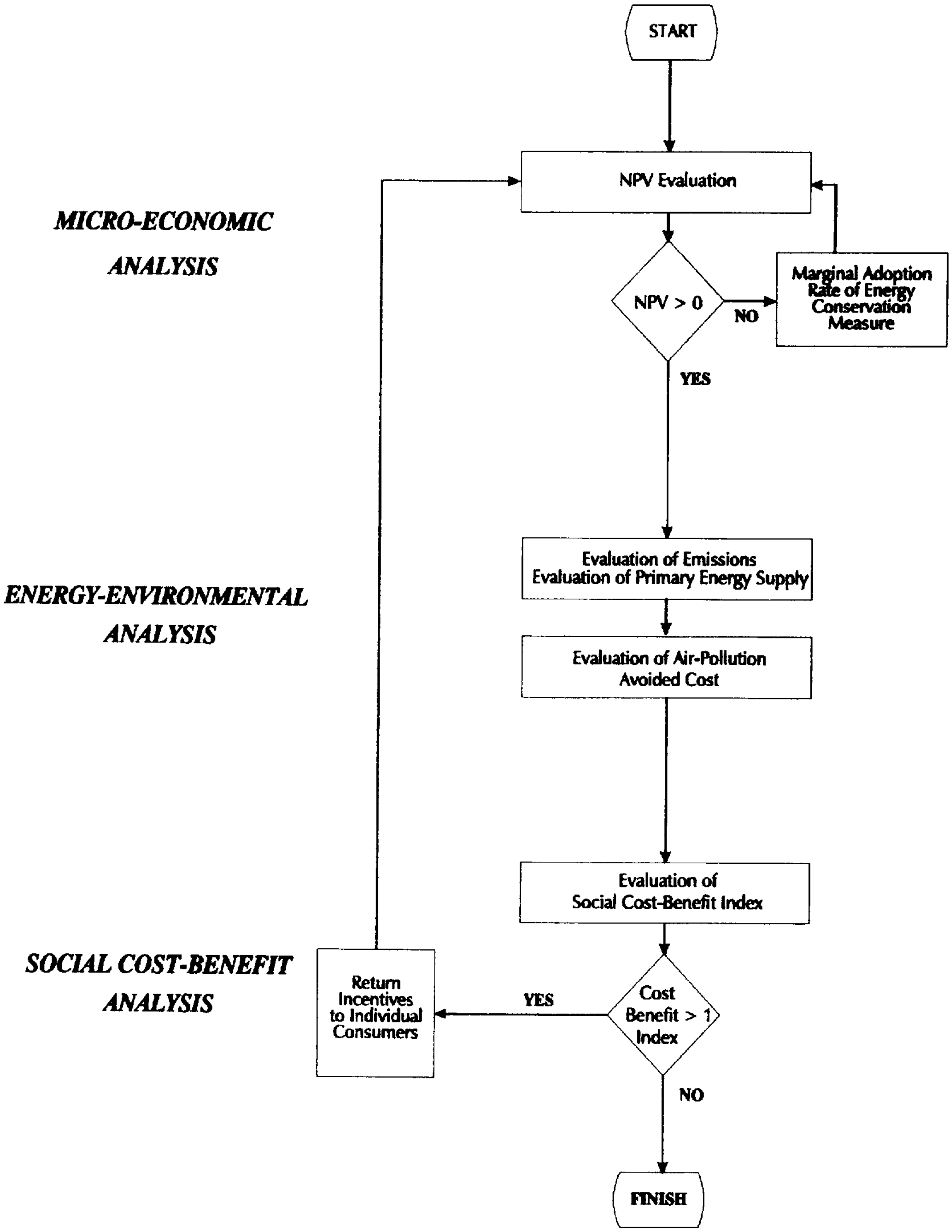

Fig. 1. Method for the cost-effectiveness evaluation of energy-conservation measures.

of engineer's salary that is tax credited, I_i = initial cost for various equipment (GDR), s = proportion of engineer's salary that is used for training, r = individual discout rate, n = economic time horizon of the project.

If the NPV becomes positive, the number of EEs is equal to the number of establishments and use of the algorithm proceeds to the next stage. Otherwise, a marginal number of EEs is estimated by setting the NPV equal to zero. The procedure is applied to all of the industrial sectors examined.

Energy-environmental analysis

At the **second stage,** the algorithm calculates the reduction of primary energy forms attributed to the corresponding reduction of final energy demand. For this purpose an LP model is used which represents the Greek energy system as a set of linear constraints describing the energy flow from the supply to the demand side. The evaluation process consists of one simulation run representing the energy conservation measure under consideration, a baseline simulation run that excludes the measure, and a comparison of the structural changes projected by the two runs.

Model inputs are exchange and environmental cost of each energy form and the technical parameters describing the structure of the Greek energy system (capacities, efficiencies, load factors, etc.). Using the avoided cost approach the total environmental cost is calculated as a social parameter. This approach is based on the assumption that an equivalent reduction of the air pollution from burning, caused by energy conservation, could be achieved through the adoption of pollution-free technologies. The economic data refers to initial investments and operating costs of advanced technologies for SO_2 through the *Flue Gas Desulphurisation method* which achieves a 90% reduction of emissions and for NO_x through the use of *Selective Catalytic Reduction* with 80% efficiency.

The variables of the LP-model are the energy flow across the whole energy system from the supply to the demand side. The objective function is the foreign exchange cost of primary energy forms

$$\mathrm{COST} = \sum_{s \in S} \mathrm{FY}(s,l,t)\mathrm{ct}(s,l,t)\ \forall l,t\,, \tag{2}$$

where S = the set of all those primary energy forms that are supplied (that is, they are imported and/or extracted), $\mathrm{FY}(s,l,t)$ = required primary energy form s at transformation process l in period t (toe/year), $\mathrm{ct}(s,l,t)$ = foreign exchange cost of energy form s at transformation process l in period t (USD/toe). The constraints of the model are grouped into five main categories.

(a) Demand-balance constraints. These constraints state that the sum of all feasible (to that end use) final energy forms must meet the demand of the end use

$$\sum_{r} L(r,k,t) = \mathrm{DEM}(k,t)\ \forall k,t\,, \tag{3}$$

where $L(r,k,t)$ = the final consumption of form r by end use k in period t (toe/year), $\mathrm{DEM}(k,t)$ = exogenously given energy demand of end use k in period t (in terms of delivered energy, toe/year).

(b) Energy-balance constraints. These constraints state that final energy consumed by all end uses must equal the total energy required as input to various transformation processes of the system taking into account all losses through the energy efficiency coefficients

$$\sum_{p} \mathrm{EC}(p,l,t)\mathrm{FY}(p,l,t) = \sum_{k} L(r,k,t)\ \forall r,l,t\,, \tag{4}$$

where $\mathrm{EC}(p,l,t)$ = energy efficiency coefficient of primary energy form p at transformation process l in period t.

(c) Substitution constraints. These constraints state that upper and lower bounds of final energy forms exist which can be used for each end use determined by technological, economic, and policy factors

$$\mathrm{LB}(r,k,t) \leqslant L(r,k,t) \leqslant \mathrm{UB}(r,k,t)\ \forall r,k,t\,, \tag{5}$$

where $\mathrm{LB}(r,k,t)$ and $\mathrm{UB}(r,k,t)$ are respectively the lower and upper bounds of using the energy form r for end use k in period t (toe/year).

(d) Installed-capacity constraints. These constraints state that the installed capacity at a transformation activity of the system, up to the period of concern, is adequate to produce the energy required

$$\mathrm{FY}(p,l,t) \leq \mathrm{CAP}(p,l,t)\ \forall p,l,t\,, \tag{6}$$

where $\mathrm{CAP}(p,l,t)$ = installed capacity of primary energy form p at transformation process l in period t (toe/year).

(e) Policy constraints. These constraints state that the exploitation concerning indigenous primary energy forms must not exceed an upper bound due to security of supply

$$\mathrm{FY}(p,l,t) \leq \mathrm{UBR}(p,l,t)\ \forall p \in S,\, l,t\,, \tag{7}$$

where $\mathrm{UBR}(p,l,t)$ = upper bound of supplying indigenous primary energy form p at transformation process l in period t (toe/year).

The model gives the differential demand of all primary energy forms as well as the reduction of foreign exchange of energy bill, investments of the power system, and total environmental cost.

Social cost-benefit analysis

Finally at the **third stage,** shadow prices are used and all the benefits and associated costs are evaluated. The number of EEs, estimated at the first stage, is the crucial parameter. The social cost-benefit index (SCBI) is used as an indicator of the social preference of the measure.

The SCBI is defined as the ratio of discounted benefits of the program to life-time costs evaluated using shadow prices

$$\mathrm{SCBI} = \frac{\displaystyle\sum_{t=1}^{n} \frac{E_{\mathrm{t}}^{*} + P_{\mathrm{t}}^{*} + M_{\mathrm{t}}^{*} + \sum_{i=1}^{m} F_{1,i,\mathrm{t}}}{(1 + r_{\mathrm{e}})^{t}}}{\displaystyle\sum_{t=1}^{n}\sum_{i=1}^{m} \frac{s_{1}aN_{i} + F_{2,i,\mathrm{t}} + \varphi gaN_{i}}{(1 + r_{\mathrm{e}})^{t}} + \sum_{i=1}^{m} s_{\mathrm{c}}(1 + \varphi)[I_{i} + (1 + s)aN_{i}]}\,, \tag{8}$$

where E_{t}^{*} = reduction of foreign exchange cost of all primary energy forms in shadow prices (GDR/year), P_{t}^{*} = cost of avoided air pollution in shadow prices (GDR/year), M_{t}^{*} = reduction of investments of the power system in shadow prices (GDR/year), $F_{1,i,\mathrm{t}}$ = benefit from increased income of sector i (GDR/year), r_{e} = social discount rate, s_{1} = shadow price ratio of labour, $F_{2,i,\mathrm{t}}$ = cost from decreased fuel consumption of sector i (GDR/year), s_{c} = shadow price ratio of capital, m = number of industrial sectors examined.

As a result of the fuel conservation industries will realise an increased income and therefore government revenues will grow up according to:

$$F_{1,i,\mathrm{t}} = \varphi(p_{\mathrm{h}}\, V_{\mathrm{h},i,\mathrm{t}} + p_{\mathrm{e}}\, V_{\mathrm{e},i,\mathrm{t}} - aN_{i})\ \forall\ i,t\,. \tag{9}$$

The decreased fuel consumption leads to lower taxes on fuel consumption and therefore government revenues will decline by:

$$F_{2,i,\mathrm{t}} = \frac{p_{\mathrm{h}}\, V_{\mathrm{h},i,\mathrm{t}}\varphi_{\mathrm{h}}}{1 + \varphi_{\mathrm{h}}} + \frac{p_{\mathrm{e}}\, V_{\mathrm{e},i,\mathrm{t}}\varphi_{\mathrm{e}}}{1 + \varphi_{\mathrm{e}}}\,, \tag{10}$$

where φ_{h} = the tax rate of heavy fuel oil consumption, φ_{e} = the tax rate of electricity consumption.

If SCBI is greater than one, then life-time benefits are greater than associated costs and the government has the opportunity to return some of these extra benefits to individual consumers using financial incentives. These incentives will, in their turn, promote the adoption rate of the measure up to the point where SCBI becomes marginally equal to one.

APPLICATION OF THE MODEL

Scenarios of energy-conservation

Economics of housekeeping procedures and the possibility of adopting an EE position is examined for individual consumers and government. The sectoral analysis is imposed by scarcity of disaggregated data by specific industrial units. A reliable reference for potential energy savings and required investment costs is the recent study by *Hellenic Bank of Industrial Development* (ETBA).[19] In the following industrial sectors: *cement plants, fertilisers, metallurgy, non-ferrous metals, sugar, bricks & refractories, pulp & paper, glass, yarns & fabrics, dyeings and preserved foods*, energy cost constitutes more than 10% of the operating cost giving a serious economic incentive for implementation of housekeeping procedures and the adoption of EE position.

The first five sectors—cement plants, fertilisers, metallurgy, non-ferrous metals and sugar—are not examined since they involve large industrial units. As Table 1 depicts, the other six sectors consume 16% of total industrial energy consumption and represent 50% of all the establishments of this middle category. The other 50% of industrial units form "Other sector" and energy consumption of these units is estimated by the total number of middle voltage consumers and their specific consumption.

Table 1. Industrial sectors examined and their energy consumption (1992).[19]

Sector	**Number of industrial units**	**Annual energy consumption (ktoe/year)**			**As a percentage of the total industrial demand**
		Thermal	**Electrical**	**Total**	**(%)**
Bricks & Refractories	224	180	10	190	(5.0)
Glass	7	50	4	54	(1.5)
Pulp & Paper	26	100	30	130	(3.5)
Yarns & Fabrics	640	74	32	106	(2.8)
Dyeings	400	32	3	35	(0.9)
Preserved Food	290	72	4	76	(2.0)
Others	1,000	402	257	659	(17.4)
Total	**2,587**			**1,250**	**(33.1)**

The basic scenario is established on the assumption of an overall energy saving of 3.3% annually. This figure conforms well with projections made by Hellenic Bank of Industrial Development. Table 2 presents potential energy savings and investment costs for all industrial sectors. The total potential energy saving is equal to 41,180 toe with a total initial cost reaching the level of 670 million GDRs or 260,000 GDRs per industrial unit (constant 1992 prices).

As an overall energy saving of 3.3% seems to be rather pessimistic, alternative scenarios are formed ranging from 5 to 10% annually. The energy conservation for each industrial sector is a linear extrapolation of the figure given by Hellenic Bank of Industrial Development for the base scenario. In Table 3 the scenarios and the corresponding potential energy savings for each industrial sector are presented. Other important assumptions are: (i) the time horizon is assumed to be *5 years* because housekeeping procedures have small payback periods. (ii) The exchange rate is equal to 200 GDR/$ and all prices are referred to constant 1992 market prices (including taxes). (iii) The price of heavy fuel oil is equal to 53,750 GDR/toe and of electricity 187,500 GDR/toe. (iv) The EE's annual remuneration is assumed to be equal to 5 million GDRs and is augmented in the first year by 50% for training. (v) The individual's discount rate is taken to be 10% (above the inflation rate) whereas the real social discount rate is equal to 5%. (vi) The shadow price ratio (to be defined as the ratio of shadow price to market price) for labour and investments is assumed to be equal to 0.8; for the import-energy bill, it equals 1.3; for

Table 2. Potential energy savings and investment costs for housekeeping procedures (constant 1992 prices).[19]

Sector	**Annual energy conservation (ktoe/year)**			**As a percentage of the sectoral consumption**	**Initial cost (million of GDRs)**
	Thermal	**Electrical**	**Total**	**(%)**	
Bricks & Refractories	4.20	0.10	4.30	(2.3)	50
Glass	1.25	0.05	1.30	(2.4)	60
Pulp & Paper	3.00	0.60	3.60	(2.8)	140
Yarns & Fabrics	2.00	0.87	2.87	(2.7)	55
Dyeings	2.55	0.25	2.80	(8.0)	55
Preserved Food	5.85	0.08	5.93	(7.8)	50
Others	14.47	5.91	20.38	(3.1)	260
Total	**32.00**	**7.88**	**41.18**	**(3.3)**	**670**

Table 3. Estimated energy conservation in different sectors.

Total	Energy conservation in sectors, (%)						
Energy conservation (%)	Bricks & Refractories	Glass	Pulp & Paper	Yarns & Fabrics	Dyeings	Preserved Food	Others
3.3	2.3	2.4	2.8	2.7	8.0	7.8	3.1
5.0	3.4	3.7	4.2	4.1	12.1	11.8	4.7
6.0	4.1	4.4	5.0	4.9	14.5	14.2	5.6
7.0	4.8	5.1	5.9	5.8	17.0	16.5	6.5
8.0	5.5	5.8	6.7	6.6	19.4	18.9	7.4
9.0	6.2	6.5	7.5	7.4	21.8	21.3	8.3
10.0	6.9	7.2	8.3	8.2	24.2	23.7	9.2

pollution cost, it is 1.15. (vii) Economic data for pollution control technologies can be found in OECD/IEA (Table 4). (viii) The financial incentive examined in this analysis is the tax credit for the engineer's remuneration in the first year and the initial investment for equipment.

Micro-economic analysis results

The basic information obtained from the micro-economic analysis refers to adoption rate of the measure (the employment of EEs at each industrial sector) according to the potential energy savings achieved by housekeeping procedures. Using the conservative scenario of 3.3% overall energy conservation, the adoption rate is equal to 17.5% of total establishments examined or one EE per seven establishments. This proportion is quite favourable in view of the small size of a Greek industrial unit.

Table 4. Economic data of pollution abatement technologies (1987 mills/kWh).[20]

	Heavy Fuel	Diesel	Coal	Lignite
SO_2				
Investment	1.620	1.620	1.810	1.810
Operating Cost	2.380	2.380	2.400	2.400
NO_x				
Investment	0.425	0.425	0.750	0.750
Operating Cost	1.750	1.750	4.125	4.125

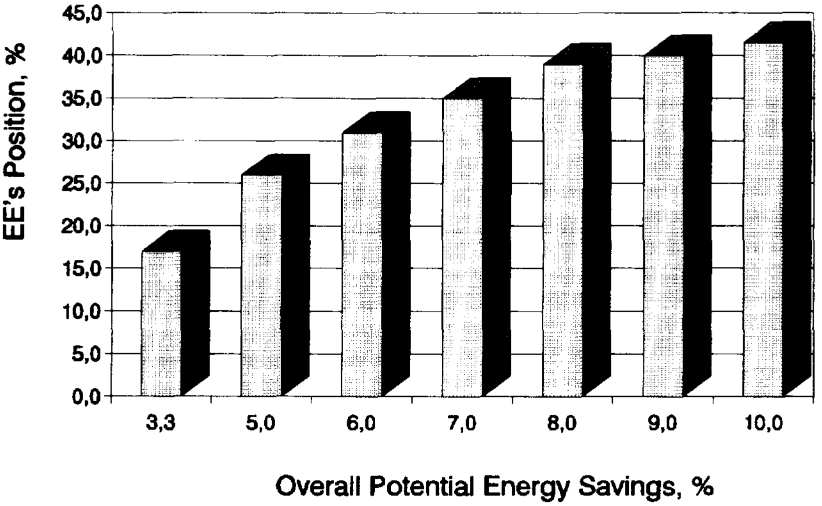

Fig. 2. Adoption of the EE position by Greek industry for various scenarios of overall potential energy savings.

As Fig. 2 depicts, the magnitude of the new labour market could reach the level of 1040 EEs for an overall potential energy saving of 10%. This is a quite reasonable goal.

The impact of potential energy savings on the NPV of an individual consumer is further examined in Fig. 3. The proportion of one EE per seven industrial units gives a positive value of the NPV which in the case of a 10% overall energy reduction reaches the level of 13 billion GDRs.

Should one EE position be allocated to five industrial units an overall energy conservation of 5% annually is realised. The NPV for this scenario is obviously lower than that for the case of one EE per seven units although it steadily increases reaching the level of 10 billion GDRs. Finally, for one EE to four industrial units and an overall energy reduction of 10% the overall NPV for individual consumer reaches the level of 8 billion GDRs or 310,000 per industrial unit.

The main conclusion of micro-economic analysis is that housekeeping procedures and the adoption of an EE position by the industrial units are economically justified. A 3.3% annual reduction of the overall energy consumption is a rather conservative estimate since in many European countries a 30% reduction was achieved during the last 10 years.[9]

Social cost-benefit analysis results

The social NPV depends on the criteria used by the government to evaluate such programs and the overall goals and priorities established. For this reason four scenarios are formed (see Table 5 for a

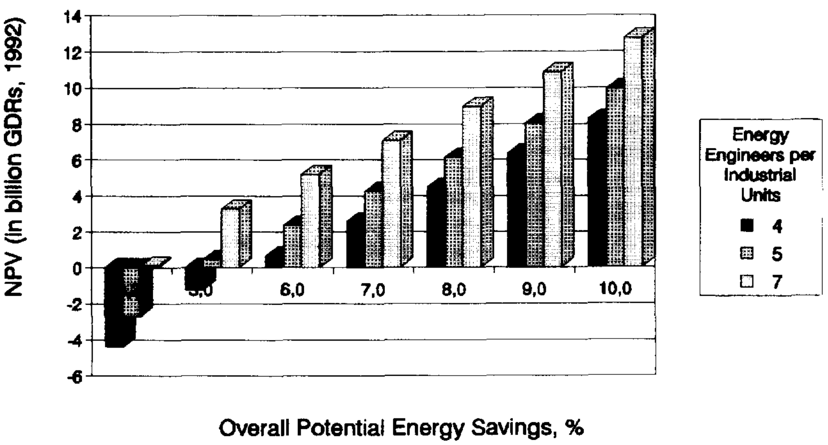

Fig. 3. The NPV for the private investor as a function of overall potential energy savings and the number of EEs per establishments.

Table 5. Formation of scenaria for the cost–benefit analysis.

Scenario Description	Environment	Taxation
Scenario A	NO	NO
Scenario B	YES	NO
Scenario C	NO	YES
Scenario D	YES	YES

description of the four scenarios used by the social cost-benefit analysis). The social parameter included in this analysis is the reduction of the air pollution from fuel burning as a consequence of a reduced final energy demand. The impact of taxation refers both to the income tax of the industrial units (affected by the expenses of the engineer's salary and the initial cost of the required equipment for housekeeping procedures) and the fuel consumption tax (on heavy fuel oil and electricity consumption).

Figure 4 depicts the social NPV for the four scenarios for an overall energy reduction of 3.3%. When environmental concern is taken into account, housekeeping procedures and adoption of the EE position are socially preferred. When taxation is considered the conservation measure becomes more attractive. However, decisions that offer multiple benefits both to society and to individual consumer must not soley depend on the distributive effects they cause.

Figure 5 shows further the impact of potential energy savings on the social NPV for Scenario A and B (without taking into account the influence of taxation). With an overall energy conservation of 6% or greater, NPV of scenario A is positive and adoption of the EE position by Greek industry is socially preferred. Environmental benefits are steadily increased with the rise of the overall energy reduction. At an energy conservation of 3.3% the benefit is 3 billion GDRs whereas at 10% energy savings it reaches the level of 16 billion GDRs.

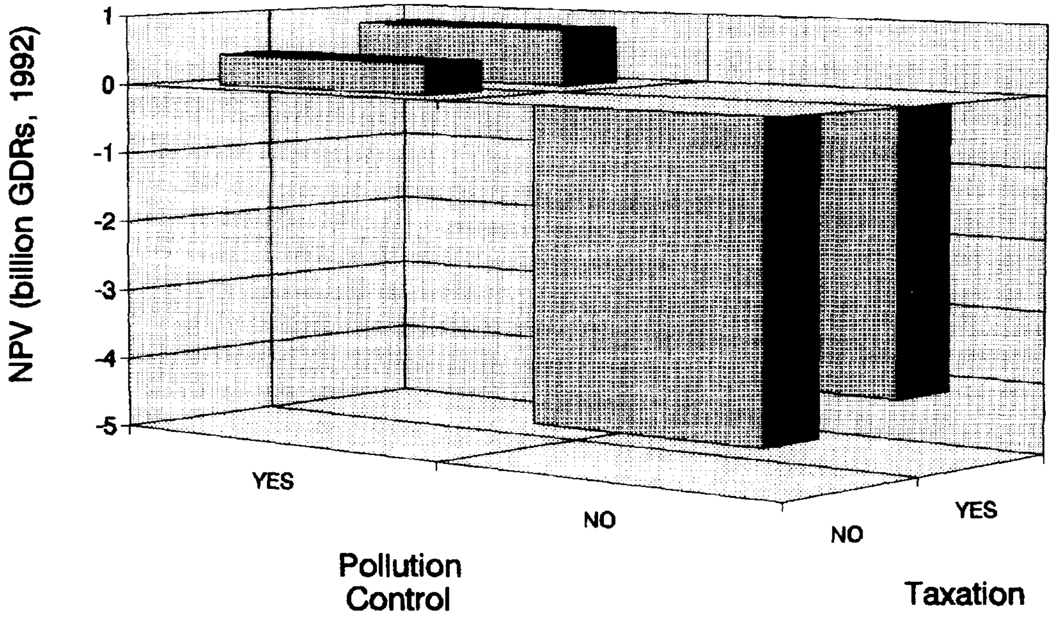

Fig. 4. The NPVs for various scenarios of environmental control and taxation impacts (overall potential energy savings of 3.3%).

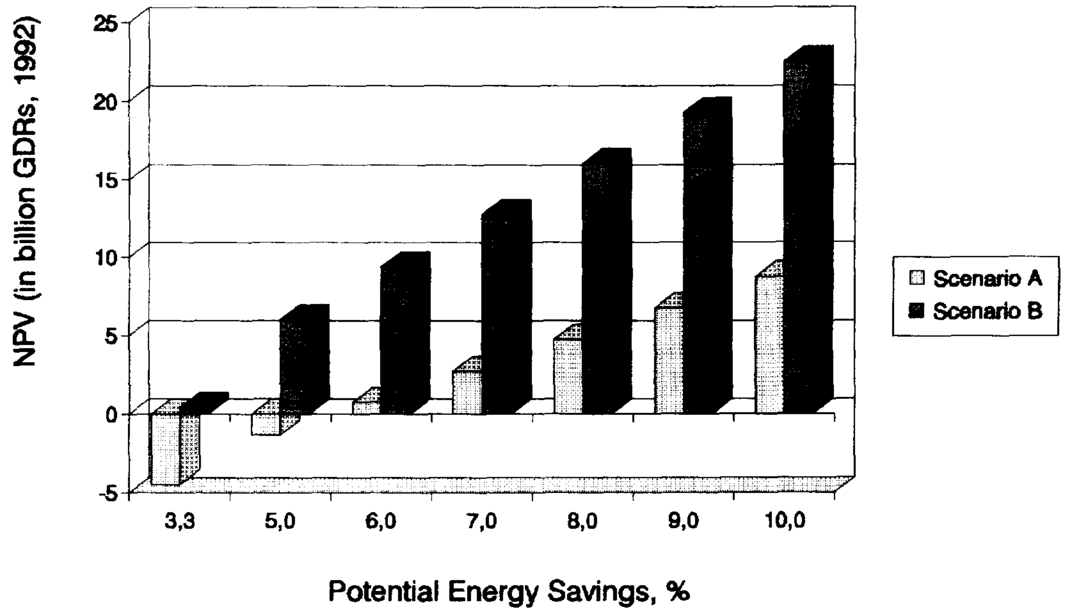

Fig. 5. The NPVs for various scenarios of environmental control as a function of the overall potential energy savings.

CONCLUSIONS

The energy-conservation measures of housekeeping procedures and the adoption of the EE position by the Greek industrial units are both socially preferred and profitable from the point of view of an individual consumer. The potential energy savings are so large they can offset the remuneration of the engineer and the required investments in equipment leaving a surplus to consumers even for large real discount rates (up to 10%). The measures are also socially preferred when the externalities associated with them are internalised leaving an even greater surplus to society. Evaluation of the pollution avoided is only one of the many social benefits of the program (others could be the impacts on health, reduction of unemployment, etc.).

Many conservation measures have rates of return significantly higher than alternative investments in stocks, bonds and real estate. However, many empirical studies in U.S.A. and European countries have shown that the level of conservation activity is still inconsistent with these high yields.[21,22] Several barriers exist which inhibit the necessary investments and conservation is perceived as a risky alternative. The cost of obtaining reliable information is high. Furthermore, energy conservation requires comprehensive policies to overcome the economic, institutional, political, social and cultural inhibitions.

In the case of the Greek energy market, state authorities possess many mechanisms that can be effective in promoting the adoption of EE position by Greek industries.[23–25] Among these are: (i) the regulation of prices for energy services. (ii) The raising of awareness of industrial consumers with respect to the problem and the potential benefits from implementing housekeeping procedures and adopting the position of EE using information campaigns. (iii) The formation of a public institution for EEs to analyse the production process of all the establishments, design a housekeeping programme, implement it, and periodically review the results achieved. The economic incentives such as tax credits and grants are obviously the most promising, especially for Greek industries facing the high cost of money in the last decade.

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