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ENERGY CONSERVATION AND CO_2-EMISSION ABATEMENT POTENTIAL IN THE GREEK RESIDENTIAL SERVICES SECTOR

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Abstract—A policy for CO_2-emission abatement will have to allow for the sectoral energy-conservation potential. The present paper outlines the energy-analysis method applied to the Greek residential and services sectors. The trends in energy requirements for 1990–2000 are forecast and energy-conservation and CO_2-abatement measures are proposed. A Maximum Action Scenario (MAS) and a Realistic Scenario (RS) are compared with a No-Action Scenario (NAS). Copyright © 1996 Elsevier Science Ltd.

INTRODUCTION

Despite the persisting degree of uncertainty as to the actual trend and level of the greenhouse effect, scientists agree that anthropogenic emissions of greenhouse gases including CO_2, NO_x, methane and other volatile compounds may upset the ecological balance.[1] At the summit held in Rio in June 1992, 154 countries signed the Framework-Convention on Climate Change (FCCC) in an effort to reduce emissions of CO_2 and other greenhouse gases drastically. The target set by the European Union to stabilize CO_2 emissions at 1990 levels by the year 2000 is to be achieved through stabilization in each of the member states, thereby obliging each state to adopt conservation measures to reduce emissions.[2]

Greece's energy demand was marked by a sharp increase during the 1970–1990 period, rising from 6.62 MTOE in 1970 to 15.10 MTOE in 1990 (or close to 5% per year).[2] Transport was shown to be the most energy-consuming sector, accounting in 1990 for 39% of total national energy consumption, with the industrial sector responsible for 26% and the residential services sector for the remaining 31%. It is estimated that 98% of Greek CO_2 emissions, which increased to 82 Mt in 1990 from 22 Mt in 1970, are attributable to energy production and consumption. In 1990, the residential and services sector accounted for 39% of the total.[2]

Planning for energy savings and CO_2-emission abatement calls for a detailed energy analysis of dominant activities in each sector and an analytic description of energy-saving measures. Increases in the energy-consumption forecast for the 1990–2000 period have been disaggregated to allow examination of the residential, commercial, and public services subsectors. These forecasts allow for population changes and life-style modifications. A number of useful measures for the year 2000 are proposed.

ANALYSIS OF ENERGY CONSUMPTION

Basic assumptions

For the purpose of this analysis, the residential services sector was divided into residential, commercial and public (services) sectors. These sectors have both similarities and differences in energy-consumption patterns. We established major energy requirements for *space heating, cooking, water heating,* the *use of various electrical appliances* and *street lighting.*

Energy requirements vary from region to region, depending on climate, dwelling types, and level of development. The geographical analysis depended on availability of data on number of households and shops and their rates of increase. For *residential sector* calculations, the country was divided into five

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regions: the Greek Islands (i.e. the Aegean and Ionian Islands plus Crete), Central Greece (the Peloponnese, Mainland and Thessaly), Northern Greece (Macedonia, Thrace and Epirus), Thessaloniki, and Athens. For *commercial sector* calculations, the same geographical divisions were maintained, except that Thessaloniki was merged with the rest of Northern Greece. Finally, for the *public services* sector, the entire country was treated as a single entity.

For residential sector, an additional dissociation was made, reflecting possible intraregional differences (depending on such factors as the buildings' energy balance, the energy resources used, or even the fraction of households with a particular type of electrical appliance). The regions of the Greek Islands, Central and Northern Greece were thus divided into *rural* and *semi-urban areas*, while the wider Athens and Thessaloniki areas were considered *entirely urban*. The parameter values used in calculation models are based on figures established by the National Statistical Service of Greece (NSSG) and by survey studies conducted by the Ministry of Industry, Energy and Technology.

Space heating

Residential sector — Heating needs were estimated on the basis of energy requirements [Eqn. (1)]. Factors such as height, external shell area, type of dwelling, year of construction, heating-degree days,[3] and space-heating means were used. Thus,

$$E_u = 24 \times DD \times \sum_i (UA)_{b-i} \times B_i, \tag{1}$$

where E_u = energy needs, DD = heating-degree days, $(UA)_{b-i}$ = overall heat-transfer coefficient for an i-type building, and B_i = number of i-type buildings. The building classification (B_i) reflects existence or absence of insulation, type of dwelling (attached, detached) and number of stores in each building. The energy types used to meet the space heating needs are primarily heating oil (diesel), electricity (storage heaters, radiators), wood (especially in the rural areas) and, to a lesser extent, LPG.[4] The energy consumption is given by

$$E_{f_i} = k_i \times E_u \times \varphi_i / f_i, \tag{2}$$

where E_{fi} = energy consumption of the ith energy type, k_i = percentage of the ith energy type usage, φ_i = an estimated correction factor applied to heating times and the percentage of heated surface-areas, and f_i = estimated efficiency of the ith energy type. $\varphi_i = 0.2$ for all fuels, with the exception of diesel where $\varphi = 0.7$ (on the assumption that 70–80% of the space is heated for 6–8 hours). The efficiency rates used were $f_i = 1$ for electricity, 0.7 for diesel (as an average of diesel use in central heating systems and oil stoves) and 0.96 for LPG.

Commercial and public sectors combined — The heating requirements of commercial shops and public buidings can be estimated in relation to their heat losses by

$$E_u = h \times S \times \theta \times DD \times t, \tag{3}$$

where h = average height of shops or public buildings (3.5 m and 3.3 m, respectively), S = total surface area heated, θ = specific heat loss coefficient equal to 1.6 kcal/(m^3h^0C),[5] and t = daily heating time (8 hours). The total surface area (S) was estimated assuming an average surface for shops equal to 50 m^2, and an average area per individual civil servant employed nationwide. The entire needs are covered by heating oil ($f_i = 0.7$).

Cooking

Energy needs for cooking are estimated by

$$E_u = P \times t \times N, \tag{4}$$

where P = average power of the appliances used (1.5 kW), t = 1.5 h/day,[5] and N = number of households. The principal energy types used for cooking are electricity, LPG and — in the rural areas — wood.[4] The energy consumption is given by

$$E_{f_i} = k_i \times E_u/f_i, \tag{5}$$

The efficiency rates used were $f_i = 0.9$ for electricity, 0.75 for LPG and 0.6 for wood.

Water heating

The energy requirements for water heating purposes are basically generated by the residential sector, although limited quantities are absorbed by the commercial and public sectors. Electricity, wood (in the rural areas) and to a large extent solar energy (especially in certain regions with ample sunshine, such as the Greek islands) are the principal energy types used to meet the energy needs.[4] They are calculated by

$$E_u = m \times c_p \times \sum_{i=1}^{12} (T_i - T_0) \times u \times C, \tag{6}$$

where m = amount of hot water consumed per use, c_p = specific heat-loss coefficient, T_i = the final temperature of the heated water, T_0 = the initial water temperature levels depending on the geographical position, u = monthly frequency of hot-water use per user, and C = the total number of hot-water users. We assume that T_i = 45°C and the average daily hot water needs per individual amount to 30 lt, while the commercial shops account for a mean hot water consumption of 20 lt/day. Energy consumption for water heating was calculated with a function similar to Eqn. (5), where the efficiency rates used were f_i = 1 for electricity, 0.7 for diesel, 0.3 for wood and 0.4 for solar energy.

Other electrical uses

Residential sector — Energy requirements for various electrical uses include the energy consumed for lighting and for the operation of elevators, washing machines, dish washers, television sets, refrigerators, irons and air conditioners. These energy needs are estimated by

$$E_f = P \times t \times N, \tag{7}$$

where P = average power of the appliances used, t = time of operation, and N = number of households equipped with the particular appliances. The basic modeling parameters adopted are presented in Table 1.

Commercial and public sectors combined — The energy requirements of the commercial and public sectors for various electrical uses involve the consumption of electricity for lighting and air-conditioning needs. These energy consumption levels are estimated by

$$E_f = P \times t \times S, \tag{8}$$

Table 1. Operational parameters for household-electrical uses.

Electrical uses	Capacity (W)	Operational time	Penetration in rural areas	Penetration in urban areas
Lighting	300	2.7 h/day	100%	100%
Elevators	1000	0.075 h/day	2–6%	22–26%
Washing machines	2000	2.5 h/week	40%	75%
Television sets	83	3 h/day	86%	100%
Refrigerators	200	9 h/day	95%	95%
Vacuum cleaners	1000	1.5 h/week	12%	45%
Ironing	1000	2 h/week	85%	90%
Total air-conditioners	67500	5 h/day for a 5 month period	0%	0.13%
Partial conditioners	1000	5 h/day for a 5 month period	0%	0.48%

where S = the total surface area under lighting or air-conditioning. We assume that $P = 15\ W/m^2$ for lighting installations and $0.75\ kW/m^2$ for air-conditioning systems.

Street lighting

As indicated by the Public Power Corporation (PPC), the energy consumed for street lighting purposes amounted in 1990 to 40 ktoe. Street lighting is not achieved in a uniform manner nationwide, as lamps of different power and types (sodium, high pressure mercury, incandescent, etc.) are still used. In order to evaluate the energy conservation interventions proposed in the following section, it was necessary to estimate the energy consumed per lamp type and the number of each lamp type in use. The total number of installed lamps was estimated at 760,000 for 1990. Based on the models presented before, the estimations for the various energy demands are given in Table 2.

THE ENERGY CONSERVATION POTENTIAL BY THE YEAR 2000

Energy consumption trends

Forecast of the residential services sector's energy demand is achieved by estimating the variation in the number of households and shops, and — as far as public buildings are concerned — by projecting the average rates at which the sector's energy requirements increased during recent years, as recorded by the PPC.

As a result of the rise in the population's standards of living, the most significant variations anticipated in the energy balance of households for the 1990–2000 period are: (i) increase in the percentage of households equipped with central heating systems, (ii) increase in the energy requirements for cooking needs, estimated on average to reach an annual 8.8% per household, (iii) increase in the daily hot water requirements per person, estimated to increase by 16.7%, (iv) increased rates of electrical appliance penetration in households and (v) 6.9% increase in the annual household consumption of electricity for lighting.

Energy conservation interventions

The series of measures presented in this section — if not already in force — are either planned for immediate implementation or strongly advocated for achieving energy conservation and CO_2-emission abatement in the residential services sector. Depending on the methods and means resorted to for their promotion, the interventions are classified either as "hard measures" (where implementation is pursued through the enactment of regulations and laws), "soft measures" (consisting of advisory and educational programs) or "uncertain measures" (which depend on subsidies and incentives for their promotion and on the general socio-economic situation for their overall effectiveness). A classification of the advocated measures with regard to their present degree of implementation, their administrative planning and the

Table 2. Estimated energy consumption in 1990 per activity and energy form (ktoe).

	Space Heating	Cooking	Water Heating	Other Electrical Uses	Street Lighting
Residential sector					
Diesel	1352	0	8	0	0
Electricity	105	147	170	366	0
LPG	33	117	0	0	0
Wood	431	26	25	0	0
Solar energy	0	0	109	0	0
Total	1921	290	312	366	0
Commercial—Public Services sector					
Diesel	223	0	2	0	0
Electricity	0	0	4	455	40
Solar energy	0	0	4	0	0
Total	223	0	10	455	40

means according to which their implementation is to be pursued is attempted in Table 3. While some of these measures involve the substitution of conventional fossil fuels (supply-side measures), others are based on the use of more efficient appliances (consumption-side interventions):

Space heating: (i) switching fuel to natural gas, (ii) the installation of double-glazed windows (heat loss reduced by as much as 36%), (iii) the insulation of attics (heat loss reduced by as much as 56%), (iv) the gradual but compulsory replacement of all old boiler systems (expected energy conservation of 8%), (v) general information campaigns on the adjustment and maintenance of central boiler systems (expected energy conservation of 7%), (vi) the replacement of storage heaters.

Cooking: switching fuel to natural gas.

Water heating: (i) increase in the use of solar systems, (ii) fuel switching to natural gas, (iii) cogeneration (in large consumer units, such as hotels, athletic centers and hospitals).

Various electrical appliances: (i) substitution of fluorescent for incandescent lamps (75% reduced electricity consumption), (ii) introduction of automated lighting systems (20% energy consumption reduction), (iii) co-generation of heat and power, (iv) installation of automated air-conditioning systems (20% energy consumption reduction), (v) use of natural gas in air-conditioning.

Street lighting: (i) general substitution of fluorescent for the incandescent lamps still in use (75% expected energy consumption reduction), (ii) general substitution of high-pressure sodium lamps for the high-pressure mercury lamps still in use (12–40% energy consumption reduction), (iii) generalized use of high-pressure sodium lamps in all future projects (both within and outside city limits), (iv) introduction of lighting intensity adjustment systems in all of the new, but also in existing lighting installations (35% energy consumption reduction).

INTERVENTION SCENARIOS

The increases in energy consumption and CO_2-emission levels that will actually be registered by the residential services sector over the 1990–2000 period will depend on the combination of the above-mentioned interventions selected and their respective success rate. Three basic scenarios can nevertheless be envisaged: (i) the no-action scenairo (NAS), (ii) the maximum action scenario (MAS) and (iii) the realistic scenario (RS).

The no-action scenario (NAS)

This scenario is based on the assumption that none of the interventions proposed previously will be implemented. In such an event, the respective increases in energy consumption and CO_2-emission levels would depend on the changes in population figures and on the assumptions made for the rise in the population's standards. In the event of a NAS during the 10 year period from 1990 to 2000, it is estimated that the residential services sector would register increases of 35% in electricity consumption, of 31% in thermal energy consumption and 34% in CO_2-emissions.

Table 3. Overview and CO_2-abatement measures.

Measures	Degree of implementation†	Administrative planning‡	Types of measures¶
Fuel switching to natural gas	B	I, PD	U
Co-generation	C	D	U
Double glazing	C	P	H
Insulation of attics	C	P	H
Replacement of all old boiler systems	C	PD	H
Maintenance of central boiler systems	A	PD	S
Storage heater replacement	C	P	H
Solar systems	A	I	U
Fluorescent lamps	B	PD	H
Automated lighting systems	C	P	S
Automated air-conditioning systems	C	P	S
Street lighting	A, B, C	D, PD, P	H

†A, in progress; B, starting; C, in process of definition.
‡I, in the process of implementation; D, decided; PD, planned/pending design; P, proposed.
¶H, hard measures; S, soft measures; U, uncertain measures.

Table 4. CO_2-emission abatement measures included in the maximum-action and realistic scenarios.

Measures	MAS	RS
Public Gas Corporation program for natural gas penetration	100%	75%
Utilization of the estimated co-generation potential (75 MW_{el})	15%	15%
Double-glazed windows installation		
—in households	1%	—
—in commercial shops	5%	—
Insulation of attics	16%	—
Replacement of all old boiler systems	20%	—
Maintenance of central boiler systems	100%	100%
Storage heaters replacement	10%	—
Solar systems installation	1,500,000 m^2	1,125,000 m^2
Substitution of fluorescent lamps		
—in households	20%	14%
—in public sector	100%	70%
—in commercial shops	15%	10.5%
Automated lighting systems installation		
—in households	10%	—
—in public sector	100%	—
—in commercial shops	30%	—
Automated air-conditioning systems installation		
—in public sector	4%	—
—in commercial shops	5%	—
Street lighting measures implementation	100%	70%

The maximum action scenario (MAS)

The MAS is based on the assumption that all of the recommended measures are carried out by the year 2000, as specified in Table 4. Based on these, the residential services sector would, during the 1990–2000 period, register increases of 18% in electricity consumption, of 24% in thermal energy consumption and of 18% in CO_2-emissions. The abatement in CO_2-emissions achieved with each general category of measures is represented in Fig. 1. It is worth noting that, in comparison with the NAS, the increase in CO_2-emission levels is restricted by 47%.

The realistic scenario (RS)

The RS is based on the assumption that only the measures whose implementation is either in course, has been decided upon or has been scheduled for the immediate future will in fact be achieved (Table 4).

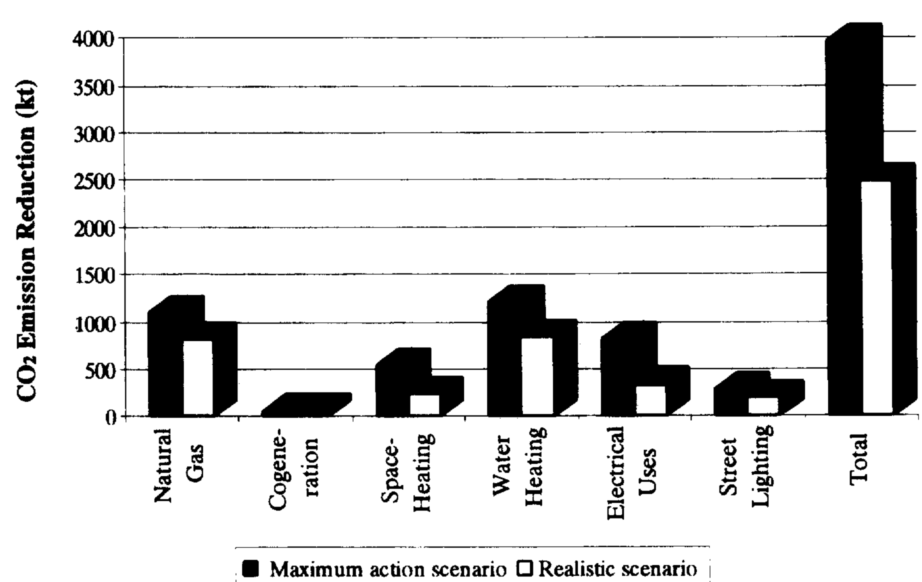

Fig. 1. CO_2-emission abatement reduction over the 1990–2000 period.

Table 5. Energy conservation potential by the year 2000 (ktoe).

Measures	MAS		RS	
	Electricity conservation	*Thermal energy conservation*	*Electricity conservation*	*Thermal energy conservation*
Fuel switching to natural gas	48.3	1.3	36.2	1
Co-generation	5.4	−8.4	5.4	−8.4
Double glazing	0.2	2.7	0	0
Insulation of attics	2.5	15.9	0	0
Replacement of all old boiler systems	0	110.6	0	77.4
Maintenance of central boiler systems	0	23.9	0	0
Storage heater replacement	7.6	−28.7	0	0
Solar systems	83.1	0	58.2	0
Fluorescent lamps	32.5	0	22.8	0
Automated lighting systems	20.4	0	0	0
Automated air-conditioning systems	3.6	0	0	0
Street lighting	18.9	0	13.2	0
Total	222.5	117.3	135.8	70

Based on these, it is estimated that the residential services sector during the 1900–2000 period would register respective increases of 25% in electricity consumption, of 27% in thermal energy consumption and of 24% in CO_2-emissions. The restriction in CO_2-emission increase achieved with each category of measures is represented in Fig. 1. In comparison with the NAS, the increase in CO_2-emissions is contained by 29%.

CONCLUSIONS

The results of the three scenarios presented above point to a substantial energy conservation and CO_2-emission abatement potential in the residential services sector. The MAS, though ambitious is not inconceivable, in the sense that all of the incorporated interventions — if not already at a first stage of implementation — have either been decided upon (e.g. natural gas) or would imply sufficiently mature technological solutions capable of being implemented by the year 2000. The RS, on the other hand, is made up exclusively of measures which are either already in the course of being implemented or have been decided upon, and by certain additional relatively low cost measures. In addition, more conservative targets (realization levels) for the year 2000 have been set in comparison with the MAS.

The successful implementation of these actions will depend on: (i) the resolution of a series of obstacles, including social inertia, (ii) the continuous monitoring of the selected program's implementation, (iii) the sound management of the allocated financial resources, (iv) the mobilization of State mechanisms and educational institutions in order to achieve the widest possible dissemination of information to the general public, (v) the bold, in many cases, application of financial incentives and the enactment of quality standards so as to encourage the penetration of more efficient technologies and (vi) the realization of pilot-energy saving projects in buildings and households, capable of serving as reference models.

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NOMENCLATURE

B_i = Number of i-type buildings
N = Number of households or shops
DD = Heating-degree days
$(UA)_{b-i}$ = Overall heat-transfer coefficient for an i-type building
θ = Specific heat-loss coefficient
E_u = Energy needs
E_{fi} = Energy consumption of the ith energy type
k_i = Percentage of the ith energy type used
f_i = Estimated efficiency of the ith energy type
φ_i = Estimated correction factor applied to heating times and the percentage of heated surface areas which depends on energy form and building type
h = Average height of residential dwellings, shops, etc.
S = Surface area
t = Duration of appliance operation
P = Power used for the appliance
m = Amount of hot water consumed per user
c_p = Specific heat-loss coefficient
T = Temperature
u = Monthly frequency of hot-water use per user
C = Total number of hot-water users