УДК 629.1:658.567

Проект по утилизации в Греции вышедших из эксплуатации транспортных средств

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Рассмотрены вопросы приема на утилизацию, перевозки, демонтажа и переработки в отношении вышедших из эксплуатации автотранспортных средств (ВЭТС). Для Греции смоделирована замкнутая цепь по утилизации ВЭТС. Моделирование основано на использовании алгоритма многокритериального принятия решения, который позволяет решить задачу по обеспечению системы без ограничений пропускной способности (UFLP). На основе предложенного метода оцениваются различные конфигурации сетей по утилизации ВЭТС в пределах Греции.

Ключевые слова: вышедшие из эксплуатации транспортные средства (ВЭТС), сеть приема на утилизацию, демонтаж, переработка (ВЭТС), алгоритм многокритериального решения.

A Proposal for End of Life Vehicles Recycling in Greece

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End-of-Life Vehicles (ELVs) regarding collection, transportation, dismantling and the recycling process is examined. A closed-loop supply chain for the collection, dismantling and recycling of ELVs in Greece is modeled. The problem is modeled through a multi-criteria decision algorithm solving an Uncapacitated Facility Location Problem. Various configurations of ELVs systems networks within Greece are evaluated with the proposed method.

Keywords: End-of-Life Vehicles (ELVs), collection network, dismantling, recycling, multi-criteria decision algorithm.

Introduction. A vehicle's life cycle covers three discrete parts: production; use; and end-of-life [1]. End-of-Life Vehicles (ELVs) have been an environmental concern for a long time in a number of countries. An end-of-life vehicle (ELV) is dismantled to recover and recycle any re-usable parts, then shipped to the shredding facility for further recovery of steel with any remaining Automobile Shredder Residue (ASR) to be considered as wastes and to be disposed of by either thermal treatment or landfill [2—4]. End-of-life vehicles (ELVs) recovery and recycling is determined by standard practices of metal recycling. The process steps include the pre-treatment or de-pollution (e.g. removal of tires, the battery, lubricants and fuel), and shredding and sorting the vehicle to recover valuable metals. Legislative initiatives in Europe, the USA, China, Korea, and Japan have inspired automakers to continue improving recyclability rates of their end-of-life vehicles [5—13].

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A description of ELVs treatment in Europe is presented by Lundqvist et al [14]. This report provides scenarios of future recycling systems for the years 2015 and 2030 based on certain assumptions concerning technology development of the recycling processes, design for recycling from manufacturers, and investment in new processing techniques. Directive 2000/53/EC [15] aims at the prevention of waste from vehicles, the improvement of vehicle dismantling and recycling to make them more environmentally friendly, besides to set take-back obligations, quantified targets for reuse, recycling and recovery rates of vehicles and their components, and the promotion of improvements in the environmental performance of all operators involved in the chain. The EU End of Life Vehicles Directive compels all car manufacturers to 'take back' and dismantle vehicles at the end of their useful lives and to remove the hazardous substances from the production process. Each component will then be either reused or recycled. The legislation forces designers to introduce 'clean design' and 'design for disassembly' practices. Directive 2000/53/EC promotes additional coordination in the automotive closed-loop economy, towards the maximization of value recovery from ELVs. Concerning the amount of ELV material that they will be required to reuse and/or recover, and they will be required to provide evidence to the Government that they have met their individual targets. Data on end-of -life vehicles are neither accurate comparable across EU member states. Member States report statistics on the number of recycled cars in relation to the total de-registered and exported cars [16—18].

In China, there are currently some 356 certified disassembly and recycling companies. Some 900 000 cars are being disassembled and recycled each year — equivalent to around 80% of all obsolete cars. The industry provides over 2 million tonnes of steel scrap as well as significant quantities of rubber and plastics [19]. The ELVs recycling law in Japan came into effect in January 2005 prompted by the by the problem of insufficient landfill space, causing changes in the vehicle recycling business and creating a market for shredder dust recycling [20]. Fuse et al [21] examine the risk to resource security in Japan, this paper quantifies the outflow of base metals (iron, aluminum, copper, lead, and zinc) through export of end-of-life vehicles from Japan. The present ELVs recycle rate and management status at the dismantling stage were investigated in [22—23] to aid in the establishment of policies for the management of ELVs in Korea.

The Code of Statutes of the Swedish Environmental Protection Agency adopted on 17 December 2001 and published in February 2002 the Swedish EPA Regulations and General Guidelines on vehicle dismantling operations [24] concerning the storage, removal, dismantling and other commercial treatment of end-of-life vehicles.

In the early 1990s the automobile industry decided to address the problem of end-of-life vehicles in the Netherlands by establishing the Auto & Recycling Foundation [25]. The aim of the Foundation is to promote all recycling measures that will reduce the damage to the environment, including the recycling of end-of-life vehicles in the broad sense but also the recycling of other residual waste products in the automobile industry. The key to these measures is that they are efficient and environmentally sound.

In the US, relatively little in the way of laws and regulations apply to ELV management activities. There exist however, waste management regulations dealing with vehicle fluids and, to a lesser extent, disposal of scrap, tires and ASR. Instead, market forces have for the most part dictated operations and outcomes [26—28].

In Greece, AMVH (Alternative Management Vehicles Hellas) a non-profitable organization established in January 2004 by the 33 official importers of vehicles in Greece, deals with ELVs. The system consists of a network of independent enterprises in the business field of collection and treatment of old metals and used car spare-parts with a capacity estimated to 70 000 ELVs per year [3].

Design and implementation of ELVs treatment facilities is a matter of intensive research in the last decade [29—30]. Process design requires the simultaneous satisfaction of environmental, economic and social goals. This invariably requires some trade-off between these objectives. The challenge for process design engineers is to develop synthesis and analysis tools, which support this requirement. Often the ecologic prospects conflict with the economic return on investment, and appropriate regulations have to be enacted, to balance the backward flow incumbents, by mandatory supply chain prescriptions. The number of ELVs generated in a given year depends on a multitude of potential factors including: general economic conditions (e.g., expected lower generation rates during economic downturns, higher generation during economic boom periods), overall vehicle accident rates, general reliability of prevalent older-model vehicles. ELV generation rates can be conservatively estimated on an annual basis based on vehicle retirement data, which, in turn, is based on state-reported vehicle registration data [6, 31—32].

Appropriate collection systems should be set up in order to ensure that end of life vehicles (ELVs) are discarded without endangering the environment, Alberto et al. [33] provide a modelling framework that integrates different Operations Research methodologies: queuing networks, optimization with simulation, evolutionary computation and multiobjective methods to optimize the design and operation of an ELV decontaminating plant. Different plant management policies, queuing networks, optimization with simulation, evolutionary computation and multiobjective methods are defined and compared. Reuter et al. [34] compare fundamental models for the optimisation of the recycling rate of the car by determining the optimal system architecture of the recycling system.

De Figueiredo et al. [35] discuss the problem of designing minimum-cost recycling networks with required throughput is a subset of the broader class of facility location problems in which the recycler wishes to determine the optimal number and location of receiving centers as well as the correct financial incentive to be offered in order to stimulate collection of used or unrecoverable products to a degree required for regulatory reasons or otherwise.

In this paper the evolution of private cars sales in Greece from 1980 up today are investigated in an attempt to forecast the future trends in ELVs generation rates for the design of an efficient minimum cost ELVs collection and dismantling network. The existing ELVs management status in Greece, including collection, dismantling and recycling, was evaluated to provide some feasible data for future ELVs treatment. Then, the rate of ELVs generation is determined based on model a proposed by the European Environment Agency [36]. The proposed method estimates the amount of the expected ELVs rate up to 2030, for the determination of the required number of the receiving treatment centers and locate each one in such a way that the total costs incurred are minimized. Then, the ELVs transportation system from each collection station to the receiving treatment center is evaluated.

The car market and elvs evolution in Greece. Numerous analyses of the density of vehicle ownership are reported in the literature, mainly focusing on effects related to congestion of traffic or energy consumption. In these analyses, the development in the density of vehicle ownership is modeled by an S-curve approaching some maximum density. Holtmann et al. [37] use a simple time-dependent Gompertz function. Dargey and Gately [38—40] incorporate a GDP—dependent Gompertz function where the vehicle density depends on the GDP per capita. A common saturation level for all countries estimated to 62% of the population having a passenger car is assumed. A functional form for the long-run relationship between car ownership and independent variables concerning total household expenditures (used as proxy for income) is specified Linear and logarithmic models along with two specifications of the generation effect are used, which allow for the estimation of the saturation level of car ownership.

Fig. 1 shows the variation of the car density among countries in EU and Greece. Fig. 2 shows car density in terms of the development over time and related to GDP per capita for EU25, EU15, EU 10 and Greece [36]. Fig. 3 shows the population growth scenario for Greece ranging from 2005 up to 2050 according to the National Statistics Service [41].

The expected evolution of new car registrations has to be estimated in relation to population growth, car purchase and running costs, public transport fares and fuel costs. Fig. 3 shows the population growth projection in Greece for the years 2005—2050, based on the population as of January 1st 2004 [41].

The lower curve A scenario forecasts further fertility decrease of the lower reproductive ages, a low life expectancy increase, and lower net migration flow. In contrast, the higher curve C scenario, forecasts fertility increase (higher in women older than

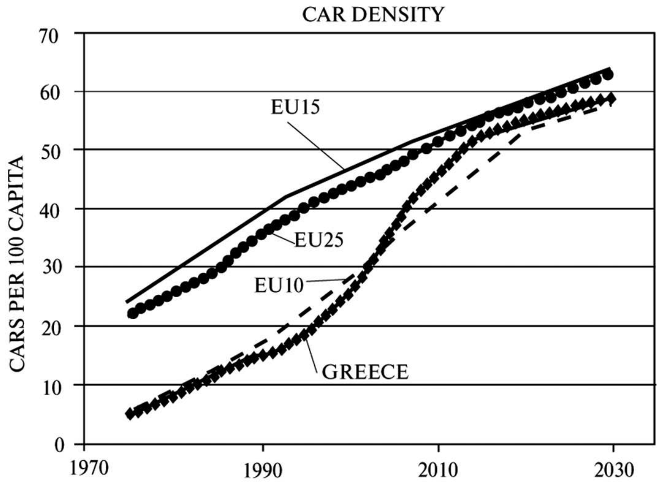

Fig. 1. Variation of car density in EU25, EU15, EU10— and Greece [36]

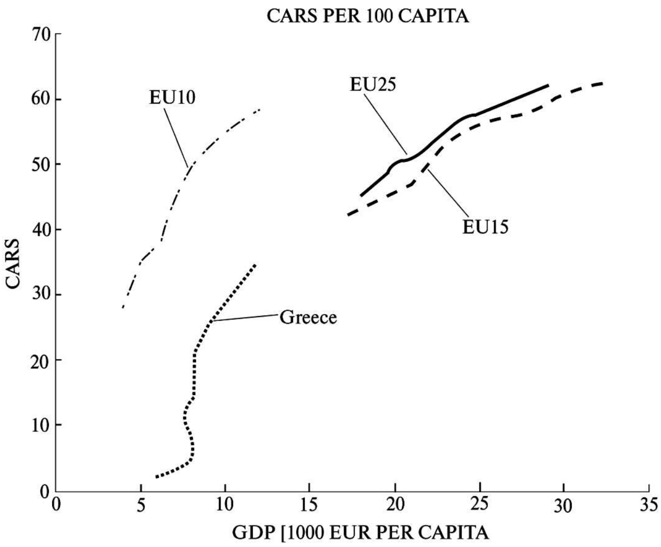

Fig. 2. Variation of car density in EU25, EU15, EU10— and Greece vs GDP per capita [36]

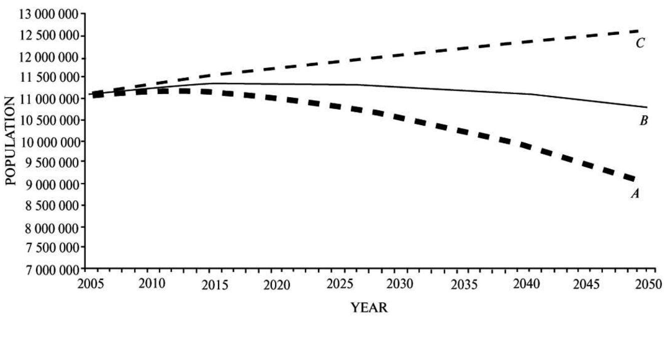

Fig. 3. Population growth scenarios in Greece 2005—2050 [41]

29 years), a higher life expectancy increase, and a high net migration flow. The intermediate forecast curve B represents a restricted fertility increase, life expectancy increase and maintenance of net migration flow in the current levels. In addition to population growth, other factors influencing the use of cars depend on GDP growth, interest rates, unemployment, the consumers' prices variation, and the fact that the evolution of the car ownership in Greece has a tendency to become similar with other Mediteranian countries (Italy, France, Spain) [38—40].

The evolution of the car market and ELVs in Greece from 1965 to 2010 is shown in Fig. 4. Fig. 4 shows PC registrations and ELVs generation in Greece from 1965 up to 2009 [41].

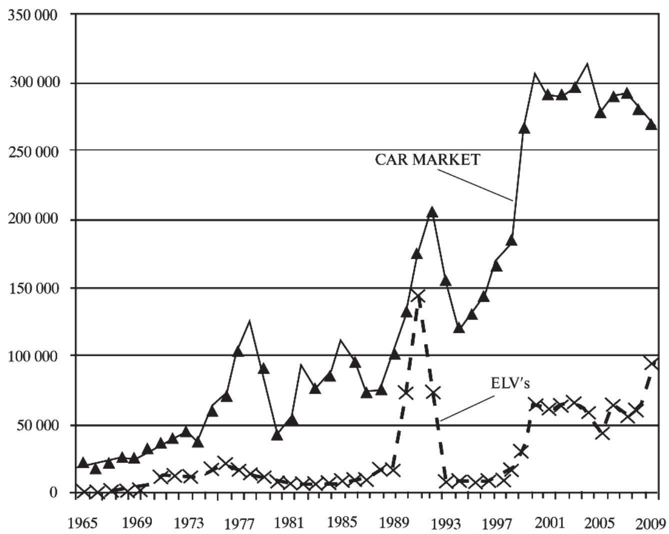

Fig. 4. PC registrations and ELVs generation in Greece (1965—2009) [41]

For the estimation of the future needs concerning the required capacity of an appropriate ELVs management system in Greece and simulation modeling, the factors determining car ownership for households living in different regions of the country have to be examined. Data for car density (C_t), in 9 main Regions in Greece (Attica, Sterea Hellas, Macedonia, Thessaly, Peloponese, Thrace, Ionian Islands, Aegean Islands, and Epirus, from 1990 up to 2009 are shown in Fig. 5 [41].

From Fig. 5 a considerable variation in car density between Attica and the rest 8 geographical Regions is observed. This variation is explained by the demographic structure of each Region and the unbalanced economic development in the country.

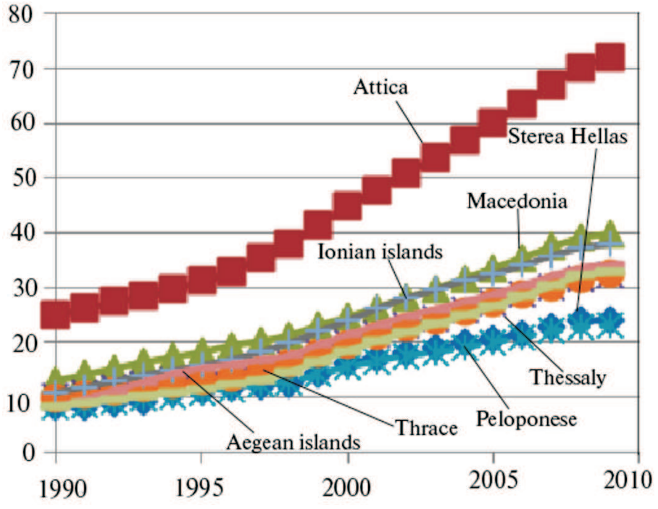

Fig. 5. Car density (Cars/100 capita), years 1990—2009 for 9 geographic Regions [41]

For the regions of Macedonia, the Ionian Islands and Peloponnese, a slight indication of a saturation level is observed. However, a common saturation level for all Regions is not achieved yet. Over time the density of cars has been almost steadily increasing in all Regions. Car density is larger in Attica that includes the city of Athens with 4.6 mil citizens. In 2009 the highest car density with 72 vehicles per 100 inhabitants is observed in Attica, followed by the Ionian Islands and Macedonia. The Region of Macedonia, including Salonika with 1 mil inhabitants, reached car density of 40%. Thessaly with the major cities of Larissa (150 th) and Volos (160 th) shows car density figures of 38%. Thrace and Epirus 33% followed by Peloponnese and Sterea Hellas with car densities of 22% and 24%, respectively.

Car density evolution in Greece. To model an ELVs management system, the problem of the simultaneous design of a distribution network with central treatment facilities, transfer stations and landfills, and the coordination of waste flows within this network for a long—term planning horizon has to be defined [42—43]. This problem is handled with Reverse Logistics, modeled through an Uncapacitated Facility Location Problem [29]. The cost for the collection centers, and the dismantling and recycling facilities required, will be investigated here for the expected ELVs capacity.

Car density values for the 9 Regions will be extrapolated up to year 2030 according to the model proposed in [36] combined with data from the rate observed during the years 2004—2010 shown in Fig. 4. This period is considered a time of maturity for the Greek PC market with 310,000 new car registrations in 2004, lowering down continuously to an expected 160,000 new car sales in 2010. Observation of the car density rates for the period 2004 to 2010 for each Region and comparison with other EU member states yields an extrapolation of the saturation level figures for each Region, up to 2030, shown in Table I.

The time-dependent Gompertz *S* function [36] will be adopted here for the estimation of the car ownership per capita, for each Region of the country up to 2030, as:

$$C_t = \gamma e^{\alpha e^{\beta(t-t_0)}}, \qquad (1)$$

where is saturation level adopted before, α, β are negative values, t is the year and t_0 a base year, assumed 1990.

For the determination of the Gompertz function coefficients α, β in Eq. (1), a curve-fitting technique will be implemented. This algorithm solves non-linear least squares problems acquiring data for car density values from 1990 up to 2009. By incorporating an unconstrained non-linear optimization method, the coefficients α and β are calculated conditioned on the respective as shown in Table 1 [44].

Table 1

a/a		γ	α	β
1	Attica	75	–2,5708	–0,0981
2	Ionian Islands	50	–2,7785	–0,0925
3	Epirus	50	–3,2176	–0,0815
4	Macedonia	50	–2,3537	–0,0876
5	Peloponese	50	–2,4533	–0,0492
6	Sterea Hellas	62	–2,7066	–0,1221
7	Thessaly	50	–2,5469	–0,0712
8	Thrace	50	–2,6726	–0,0730
9	Aegean Islands	50	–2,6959	–0,0798

Based on car density data from 1990—2009 and the coefficients α and β shown in Table I, an estimate of the saturation level in car density from the solution of Eq. (1) can be found for each Region. Fig. 6 shows an estimation of the car ownership per capita, for each Region of the country up to 2030.

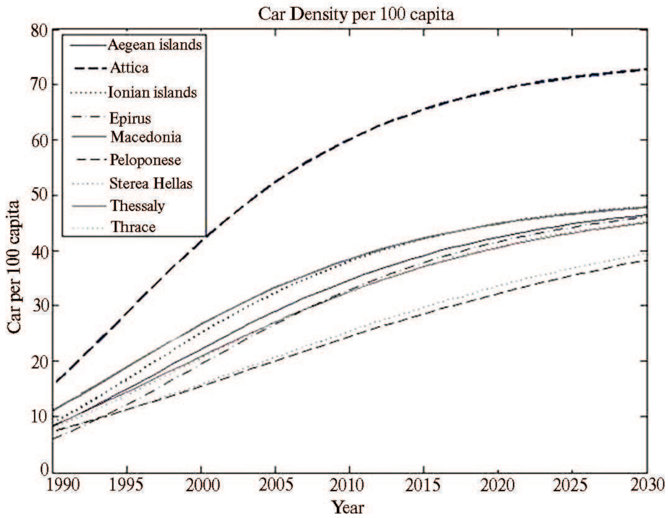

Fig. 6. Cars/100 capita for the years 1990—2030 and the 9 geographical Regions (Attica, Sterea Hellas, Macedonia, Thessaly, Peloponnese, Thrace, Ionian Islands, Aegean Islands, and Epirus)

Multiplying car density by population yields the stock of cars:

$$S_t = C_t\, P_t, \tag{2}$$

where P_t is the population on year *t*.

Figure 7 shows the estimated growth of the number of cars in Greece based on the assumptions for the population growth [41] and the solution of Eq. (2).

The rate of ELVs generation in Greece. In order to model ELVs generation, historical data on population, the number of cars per capita (car density), GDP per capita and the vintage distribution of cars have to be combined. An approach incorporating energy and transport scenarios and the projections of the population and economic development [36] will be adopted for the estimation of the number of ELVs expected up to 2030 for each Region of the country. Then, the issues affecting a closed—loop supply chain for the collection, dismantling and recycling of ELVs in Greece are examined.

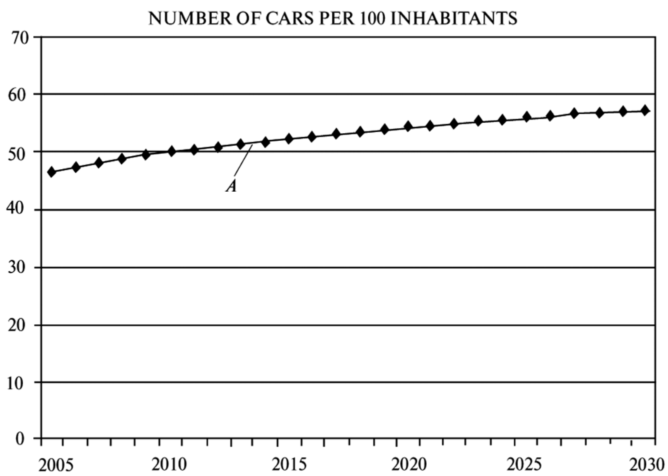

Fig. 7. Cars per 100 capita in Greece, 2005—2030 (Eq. 2)

The determination of the ELVs expected generation up to 2030 was based on the model proposed by the European Environment Agency [36]. For a specific vintage of cars, the lifetime of those cars is described by a Weibull distribution given by:

$$F(t) = e^{-[(T-\theta)/\lambda]^k}, \text{ and } F(T) = 1 \text{ for } T \le \theta, \tag{3}$$

where *T* is the age of the cars, *F*(*T*) is the lifetime function giving the fraction of cars of vintage *v* still in operation in year *t*, ($T = t - v$). $\lambda > 0$ (scale along the *y*—axis), $k > 0$ (shape) and θ (location along the x—axis) are parameters describing the Weibull distribution. Assuming that the lifetime function is identical for all vintages, then in year *t* the remaining stock of a given vintage of cars is given by:

$$S_{v,t} = S_{v,v}\, \mathrm{F}(t - v), \tag{4}$$

where $S_{v,v}$ is the initial stock of vintage *v* cars. In year *t* the end—of—life vehicles of vintage *v* cars will be

$$ELV_{v,t} = S_{v,t-1} - S_{v,t}, \tag{5}$$

Thus, the total number of ELVs in year *t* is calculated as:

$$ELV_t = \sum_v ELV_t. \tag{6}$$

The number of new cars in year *t* is calculated as:

$$S_{t,t} = S_t - \mathrm{S}_{t-1} + ELV_t. \tag{7}$$

The number of new cars in year *t* Eq. (7) is equal to the change in stock of cars from year to year calculated from Eq. (5) plus replacement of scrapped cars in year *t* Eq. (7) with the assumption of zero import and export of old cars. This model is rather insensitive to short—term variations [38—40].

Car density found from the solution of the time—dependent Gompertz function, Eq. (2), with values for γ, α, β listed in Table 1 and $t_0 = 1990$ the base year, is shown in Fig. 5, for each of the 9 Regions of the country. Fig. 6 shows the expected rate of cars per 100 capita in Greece for the years 2005—2030, Eq. (2) with $\gamma = 62$, $\alpha = -0{,}765$, $\beta = -0{,}050$, and $t_0 = 1980$ the base year.

ELVs collection and recycling network in Greece. Cruz-Rivera et al [29] provide an algorithm for the determination of the ELVs collection points in Mexico in terms of facility location theory. It was proved that a widespread network of almost 100 collecting points for ELVs covering 100% of the demand in Mexico operates with minimum cost. They were seeking a solution for the Uncapacitated Facility Location Problem, otherwise mentioned as Fixed Charge Facility Location Problem (FCFLP) implemented to an ELVs management system.

A different approach to the one suggested by Cruz-Rivera et al [29] was followed for the evaluation of the most appropriate ELVs collecting system in Greece. Collecting facilities were assumed allocated close to the 54 prefectures' capital cities. This arrangement ensures that each collection facility serves the ELVs demand locations in the same prefecture and might be capable to cover the demand from other prefectures in case of excess demand or putting other facilities out of operation for some reason.

The model adopted here is described as:

minimize

$$\alpha_i \sum_i \sum_j h_i d_{ij} Y_{ij} = 1 \forall i \quad (8)$$

subject to

$$\sum_i \alpha_i = 1 \forall i; \quad (9)$$

$$Y_{ij} \le X_{ij} \ \forall i, j; \quad (10)$$

$$X_j = 0,\ 1 \ \forall i; \quad (11)$$

$$Y_{ij} \ge 0 \ \forall i, j, \quad (12)$$

where I the set of ELV generators, indexed by i (locality), J the set of candidate facility locations, for collection centres, h_i the demand (ELV generation) at node $\in I$ (ELVs), d_{ij} the distance from demand node i to candidate location j (km), and a cost per unit distance per unit demand (€ELV—km) The decision variables are: $X_j = 1$ if located to candidate j and $X_j = 0$ if not. The objective function (8) minimizes total costs, which are the sum of fixed facility costs and total demand weighted distance multiplied by the cost per unit distance per unit demand. The constraint (9) forces each demand node i to be served. The constraint (10) assigns the demand from node i to node j, just in case a facility is located at node j. Constraints (11) and (12) are the integrality and non-negativity constraints, respectively. Since facilities are uncapacitated, all demand at node i will be assigned to the nearest open facility, thus the assignment variables Y_{ij} will naturally assume integer values [46].

The ELV process can be described as a four-step process: pre-treatment, dismantling, shredding, and shredder residue (ASR) treatment. Since dismantling is costly, the solutions sought today focus on evaluating the available ASR treatment technologies from economical, technical and environmental points of views. The conventional route for end-of-life vehicle recovery and recycling is determined by standard practices of metal recycling. The process steps include the pre-treatment or de-pollution (e.g. removal of tires, the battery, lubricants and fuel), and shredding and sorting the vehicle to recover valuable metals. These metals are recovered by using magnetic separation, and constituting about 75% of the total weight of ELV's they are recycled in iron and steelmaking processes [44—45].

Equations (4—7) provide figures for the generation of end-of-life vehicles, and the vintage distribution of cars. The solution of Eq. 6 provides an estimate of the number of ELVs for each Region as shown in Fig. 8 for Attica, Macedonia, Thessaly

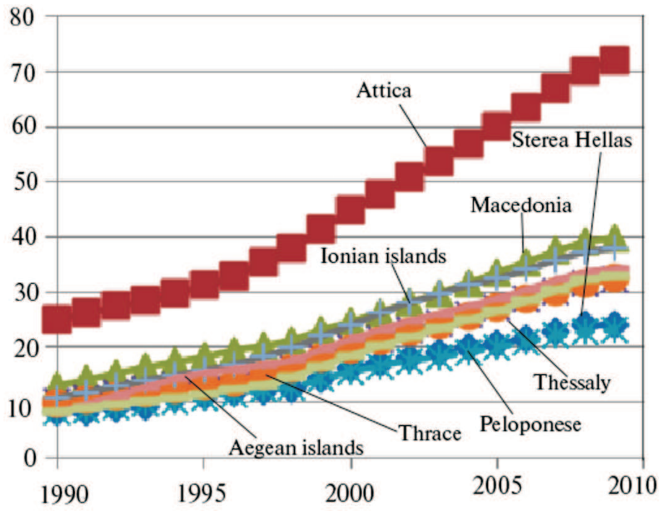

Fig. 8. ELVs expected rate up to 2030 (Eq. 6)

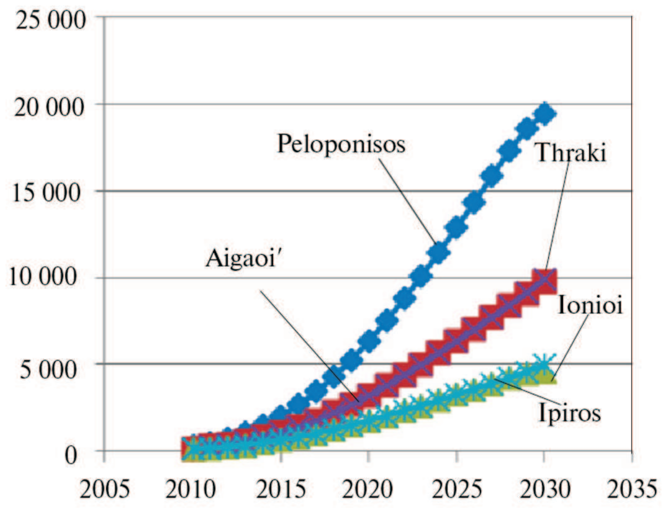

Fig. 9. ELVs expected rate up to 2030 (Eq. 6)

and Sterea Hellas, and Fig. 9 for the Peloponnese, Thrace, Ionian Islands, Aegean Islands and Epirus up to the year 2030.

Based on the expected figures for ELVs generation in Greece up to 2030, the issues affecting a closed-loop supply chain for the collection, dismantling and recycling of ELVs in Greece are examined. To address this task, it was assumed that the collection centers will be allocated close to the major cities, the capitals of the 54 prefectures in the country. As a first approach, the capacity of each dismantling and recycling facility was at least 5,000 ELVs/year. This figure guarantees a cost-effective small facility that is flexible enough to increase productivity by adding more shifts.

The solution of Eq. (6) provides the expected ELVs generation rates for each Region. The areas served by each of the 54 collection centers were tabulated in a data base containing: the geographical location of 1000 cities around the country and the in-between distances; road network evaluation data; population data from Fig. 3 for the three scenarios indicated [41]; and car density from the solution of Eq. (7). Road network evaluation data correspond to the criterion of safety in transportation by selecting principal road network, railroad and ferry lines. A maximum distance of 100 km from the ELVs generation point to the collection centers was allowed. In this view an algorithm was constructed [44] for the solution of Eqs (1—6) distributing the ELVs generated to each collection center.

For the location of the dismantling and recycling facilities the candidate locations would be the existing industrial areas in the country operating under strict environmental conditions. Thus, 11 industrial areas were also tabulated in the data base. The solution of Eqs (8—12) provides the means for the estimation of the optimum path for the ELVs collected to the 54 collection centers towards the dismantling and recycling facilities located in the 11 industrial areas was investigated. Then, the dismantling facilities were arranged under the following assumptions: 1) the longest transportation route from the ELVs collecting points to the dismantling and recycling facilities is less than 150 Km, and 2) the routes of massive ELVs transportation from the ELVs collecting points to the dismantling and recycling facilities are major highways offering appropriate conditions of road safety, or a railroad line. Those criteria were also incorporated in the algorithm.

Under those assumptions the solution of Eqs (8—12) provides the areas served by the selected dismantling and recycling facilities as shown in Fig. 10.

Thus, an integrated ELVs collection, dismantling and recycling facilities network based on 7 major areas, for which the solution of Eq. (8) provides a local minimum were selected as shown in Fig.10. Each of those major areas (numbered 1 to 7 in Fig.10) includes at least one dismantling and recycling facility with a minimum capacity of 5,000 ELVs/year. In this configuration the rectangular areas shown in Fig. 10 are arranged as: Area 1 covers the Creta island; Area 2 contains Peloponnese and part of Sterea Hellas; Area 3 covers Attica and Aegean islands; Area 4 covers Sterea Hellas and the island of Lesbos; Area 5 ranges to Corfu, Epirus, and western Macedonia; Area 6 for central Macedonia and Salonika; and Area 7 covering eastern Macedonia, Thrace and northern Aegean islands.

Conclusions

ELVs recycling can roughly be divided into logistic costs (collection, transport, etc.) and processing costs (liberation, separation, etc.). Processing costs heavily depend on the complexity of the recycled product. The recycling installation required becomes more sophisticated and,

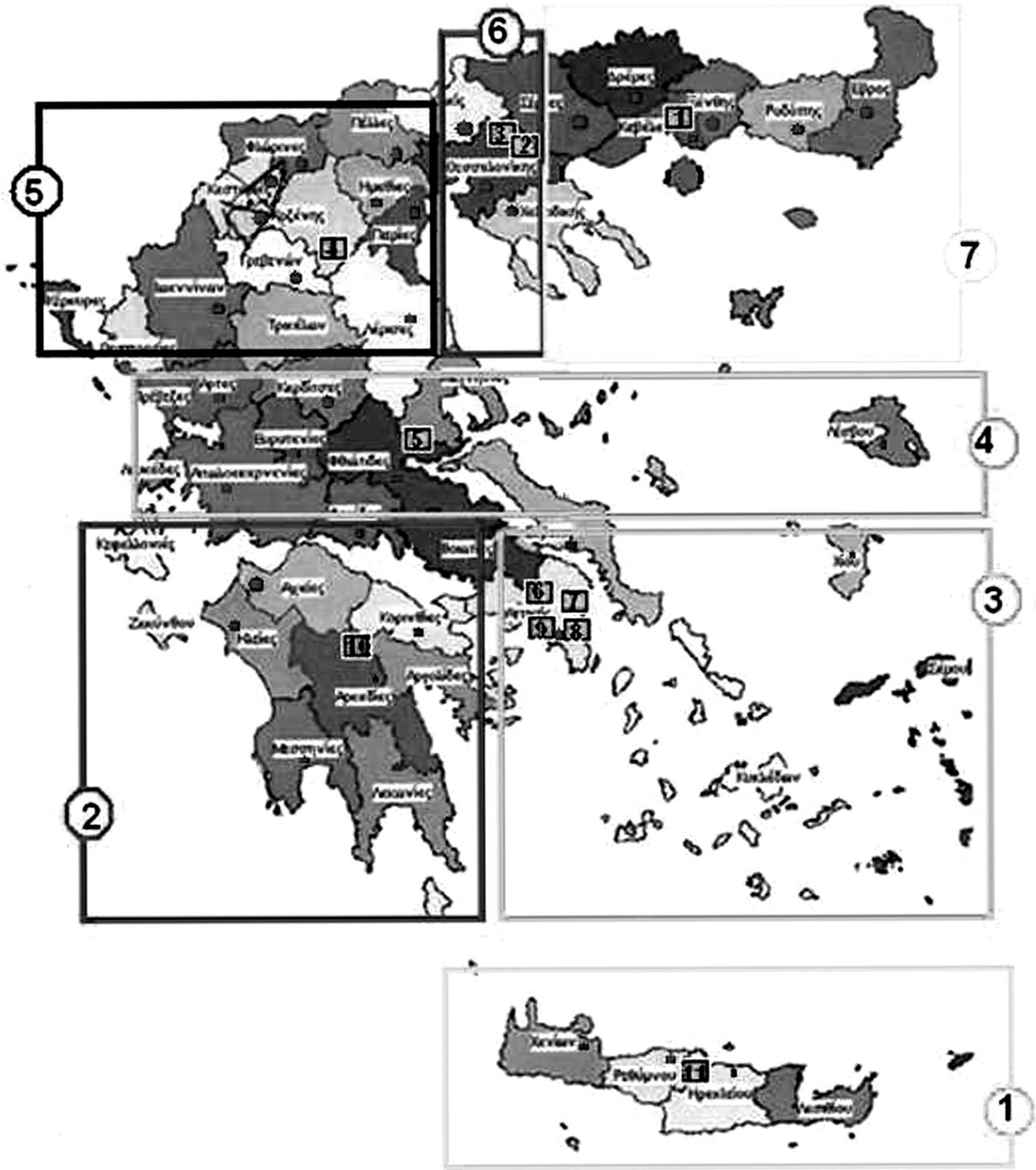

Fig. 10. Division of the major areas, numbered 1 to 7, with an integrated ELVs collection, dismantling and recycling facilities network. 11 dismantling and recycling facilities located in industrial areas numbered 1 to 11 in rectangles

henceforth, more expensive with increasing product complexity, whereas the recovery rate of the marketable materials decreases. Logistic costs, on the other hand, are primarily determined by the collectable amount of discarded products and transport distances. Processing costs in recycling progressively decrease with increasing throughput, which is known as the *economy of scale*. On the other hand, the existing regulations ask for an efficient policy that guarantees environmental awareness in the whole process and flexibility in adapting to varying recycled product generation rates. Proper design for recycling greatly improves the recyclability of products as well as the quality and recovery rate of materials attainable in recycling. Further improvements in material recycling can be expected from developing new, efficient size reduction and separation technology.

The expected population growth, the extrapolated figures for PC ownership and ELVs generation rates were investigated in an attempt to predict the requirements for an effective ELVs collection, dismantling and recycling network in Greece. A conceptual framework, an analytical model, and an algorithmic solution for the problem are presented. The problem is modeled through a multi-criteria decision algorithm solving the Uncapacitated Facility Location Problem. The design and operation of a collection and dismantling network within Greece is examined. 54 collection centers were distributed in the main cities and 11 dismantling and recycling facilities were located within existing industrial areas. The 54 collection and 11 dismantling and recycling facilities is adequate to cover the ELVs generation for the next 20—30 years based on multiple units with a capacity of 5,000 ELVs/year. Furthermore, the effectiveness of the ELVs recycling system has to be considered in the frame of an interrelated network with raw materials market fluctuation, and spare parts recycling systems.

It appears that an economic optimum in the recycling of end-of-life vehicles can be found in a proper combination of collection and dismantling and recycling facilities with an efficient interconnection algorithm for the proper distribution of the demand to available recycling points. However, it is a challenge to find the right proportion, partly because this optimum shifts in time as the demand fluctuates and furthermore, due to technology improvements.

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