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PREFACE

The present Special Issue of Fresenius Environmental Bulletin contains selected and revised manuscripts that have been presented at the 5th International Conference on Environmental Management, Engineering, Planning and Economics (CEMEPE) which was held together with the Conference of the Society of Ecotoxicology and Environmental Safety (SECOTOX) and took place in Mykonos Island, Greece, from 14-18 June 2015. The conference was organized by the Society of Ecotoxicology and Environmental Safety (SECOTOX) as well as the Department of Planning and Regional Development, University of Thessaly, the German Research Center for Environmental Health, Germany, the Sector of Industrial Management and Operations Research, School of Mechanical Engineering, National Technical University of Athens, the Division of Hydraulics and Environmental Engineering, Department of Civil Engineering, Aristotle University of Thessaloniki, and the Food Technology Department, Technological Educational Institute of Thessaloniki. An international board of environmental scientists comprised its scientific community.

CEMEPE congresses have grown to be keystone congregations for environmental scientists. They are held on a biennial basis in selected places around Greece, characterized by both natural splendor and cultural significance. The aim of these congresses is to bring together experts from a variety of disciplines from the scientific community, to present and share their research related to environmental issues.

The papers that are selected to be published in this Special Issue relate to the most important aspects discussed at the Conference in the thematic areas of Wastewater Monitoring and Management, Water Pollution, Energy and Environment, as well as Transport and Environment.

Water and wastewater pollution and management are of utmost importance in the viability of urban environments and planet earth as a whole. Moreover, all human activities consume great amounts of energy, which unreservedly affects the environment. The relationship between economic growth and the protection of the environment remains controversial. The economy relies on planet’s ability to provide resources to cover the population’s demands, whereas at the same time, a healthy environment is a prerequisite for a healthy economy. A viable environment, on the other hand, requires less energy consumption, less transportation, and implicitly less economic growth. Sustainability attempts to bridge today’s needs with tomorrow’s security. By sustainability we infer to renewable energy sources, reducing of carbon emissions, protecting environment and keeping the delicate ecosystems of our planet in balance. In short, sustainability aims to protect our natural environment, human and ecological health, while driving innovation and not compromising quality of life.

We believe that the subjects contained in this Issue will help researchers, students and practitioners to thrive in environmental science, sustainable engineering management and planning. We hope that the ideas and perspectives will encourage researchers to create more efficient and environmentally friendly systems.

We would like to express our heartiest appreciation to all the authors of the papers submitted to the Special Issue, as well as to the Editor of the Journal, Professor H. Parlar, for his help throughout the handling of the manuscripts. Special thanks to the reviewers, for the time and effort they devoted in order to ensure high standards for the submitted manuscripts.

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ANALYTICAL SOLUTION OF THE SATURATED FLOW PROBLEM IN 7-SPOT, 2D GEOMETRIES

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ABSTRACT

The problem of saturated flow within a homogeneous and isotropic pore formation, confined between two horizontal impermeable planes, under 7-spot injection-extraction well pattern is considered. Such well patterns are typically implemented in soil remediation or enhanced oil recovery processes. Extraction wells (rectilinear sinks) are uniformly distributed over the reservoir domain, creating a honeycomb pattern of identical hexagons. An injection well (rectilinear source) is located at the centre of each hexagon. Uniform strength is considered for all sources. In that context, the flow within every hexagon can be partitioned into identical flows in each of the six equilateral triangles. To furnish the analytical expressions for the pressure and velocity fields, we have to solve an interior Neumann problem for the Laplace equation, considering that the normal derivative of the pressure is known on the boundary of the equilateral triangle. To deal with this unconventional geometry (the method of separation of variables is not applicable) we implement the new method provided by Dassios and Fokas in [1], whereby the authors study boundary value problems for the Laplace, the Helmholtz and the modified Helmholtz equations in the interior of an equilateral triangle.

KEYWORDS:
saturated flow, porous media, 7-spot

INTRODUCTION

Saturated flow in porous media is a core physical process with many engineering applications, mainly related to groundwater management (capture zones in pumping wells, salt-water intrusion in coastal aquifers, replenishment), seepage analysis of dams, discharge of wells near rivers, etc. The basic phenomenology of saturated flow is described by Darcy’s law, explicitly providing a linear relation between the superficial velocity (volumetric flowrate intensity) and the field pressure gradient, whereby the linearity constant is the ratio of the porous medium absolute permeability to fluid (water) viscosity. A variety of problems can be treated, either analytically or semi-analytically as long as these can be described in typical geometries. The solution of problems in more sophisticated or atypical geometries requires the implementation of appropriate numerical schemes. A collection of problems treated with various methodological approaches can be found in [2, 3].

An equally important physical process, in terms of engineering applications, is the unsaturated flow, or immiscible two-phase flow, in porous media. Indicative applications can be found in irrigation and drainage, i.e. the simultaneous flow of water and air, and in pollution of aquifers and the associated remediation interventions, water flooding of oil reservoirs, enhanced oil recovery, CO2 sequestration etc. i.e. the simultaneous flow of a wetting and a non-wetting phase. The governing equation for unsaturated (or two-phase) flow in porous media is produced by extending the conventional Darcy law to the fractional Darcy law, by introducing the concept of the effective permeability of each phase to account for the hydrodynamic and capillary coupling observed during the simultaneous flow of both phases. Conventionally, effective permeabilities are treated as functions of the saturation. Nevertheless, there are many inadequacies in correctly describing the flow with this approach. The recently developed mechanistic model DeProF and corresponding theory for steady-state two-phase flow in porous media [4] has derived a universal scaling law for the reduced pressure gradient in terms of the actual independent variables of the process, i.e. the local values of the superficial velocity of oil and water [5, 6].

Now, with the availability of an explicit scaling law describing the process, the associated twophase (unsaturated) flow problem can be transformed into an equivalent one-phase (saturated) flow problem. To this end any development of analytical solutions for the saturated flow problem in difficult, non-trivial or atypical geometries, would enhance our capability of understanding the flow response to various configurations and to design more efficient processes. One such atypical geometrical configuration is the 7-spot injection-extraction pattern [2, 7].

The 7-spot pattern flow equivalence analysis. The case of the 7-spot pattern flow arrangement
FIGURE 1
Modular break-down of a 7-spot pattern well pattern formation (a) Layout of the 7-spot formation of injection wells ("sources", ⊙) and water production wells ("sinks", ⊙). The honeycomb pattern extends infinitely in both directions. (b) The 7-spot pattern hexagonal building block (c) the modular unit cell (equilateral triangle).

within a homogeneous and isotropic porous medium will be considered. A schematic representation of the 7-spot pattern is provided in Figure 1, whereby production wells (rectilinear sinks) are uniformly distributed over a reservoir field and create a honeycomb pattern of identical right hexagonal prisms, with lattice constant, \( \ell \). An injection well (rectilinear source) is located at the axis of each hexagonal prism. If the whole space is filled with these identical prisms (7-spot modules), then it can be shown (by inductive reasoning) that in the asymptotic limit, the ratio of sources to sinks is \( \frac{1}{2} \), i.e. the number of sinks is twice the number of sources. In the present work, ⊙ indicates a point source and ⊙ indicates a point sink. Because of the porous medium homogeneity and isotropy and the geometrical symmetry, we can postulate that solving the problem in the infinitely extending 7-spot layout (depicted in Figure 1) is equivalent to solving the problem within an equilateral triangle with impervious sides. Suppose the strength of any source (specific flowrate or volume flowrate per unit source length) is \( q_s \) and, similarly, the strength of any sink is \( q_p \). The dimensions of both strengths are \( L^2 T^{-1} \). Because of the 7-spot geometrical symmetry, to find the flowrate per source (or sink) unit length within the isolated equilateral triangle (with impervious sides), volume balance suggests that \( q_s / 6 = 2q_p / 6 \), therefore \( 2q_p = q_s \).

Analytical/mathematical implications in triangular geometries. It is well understood that solving analytically the Laplace equation inside a triangle (given any type of Dirichlet, Neumann, Robin or mixed type boundary conditions) is not possible because there is no coordinate system matching the triangular geometry configuration upon which, when expressed, the Laplace partial differential equation can be separated into two (for 2D problems) independent ordinary differential equations.

Nevertheless, the particular case of the Dirichlet (or Neumann) problem for the solution of the Laplace equation within an equilateral triangle can be handled in an analytical manner, using the novel method introduced by Dassios and Fokas [1]. In their paper Dassios and Fokas manage the so called, "global relation" and present a procedure for the solution of boundary value problems for the Laplace, the Helmholtz and the modified Helmholtz equations in the interior of an equilateral triangle. So far there have been two applications of the Dassios & Fokas method. In [8], the Laplace equation was solved in an exterior non-convex domain which is the Kelvin image of an equilateral triangle- subject to Neumann boundary condition, while in [9] Baganis and Hadjinicolaou derive an analytic solution of the corresponding Dirichlet problem.

Here we present a methodological roadmap one has to follow in order to derive an explicit analytical solution for the sought problem, i.e. interior Neumann problem for the Laplace equation.

STATEMENT OF THE PROBLEM

Consider a point source with strength \( Q \) at \( r_1 = (-\ell/\sqrt{3}, 0) \) and a pair of sinks with equal strength \(-Q/2\), at positions \( r_2 = (\sqrt{3}/6, \ell/2) \) and \( r_3 = (\sqrt{3}/6, -\ell/2) \). The vectors \( r_1, r_2, r_3 \) correspond to the complex numbers \( z_1, z_2, z_3 \) as introduced in [1] and define the vertices of the equilateral triangle (the length of each side is \( \ell \)), see Figure 2. Following [1], we denote, also, the sides \((z_2, z_1), (z_3, z_2)\)
and \((z_1, z_2, z_3)\), as sides \((1), (2)\) and \((3)\) respectively.

In the interior of the triangle \(D\), the pressure field assumes the following form [In fact, the pressure field incorporates the constant factor, \((-k/\mu)\), with \(k\) the absolute permeability of the porous medium and \(\mu\) the dynamic viscosity of the fluid]

\[
p(r) = \frac{Q}{2\pi} \ln |r - r_*| - \frac{Q}{4\pi} \ln |r - r_*| + q(r) \quad r \in D
\]

where \(q(r)\) is a harmonic function in \(D\), while on the boundary \(\partial D\), as the sides of the triangle are impervious, the normal component of the velocity field must be zero and the following Neumann condition must be imposed

\[
\frac{\partial p(r)}{\partial n} = 0, \quad r \in \partial D
\]

(Eqn 1) express the contribution of the fundamental solution of two-dimensional Laplace equation while eqn (2) yields the Neumann data on each side of the triangle.

FIGURE 2

The fundamental domain \(D\).

Therefore, we have to solve an interior Neumann problem for the Laplace equation and the well-known compatibility condition (representing the mass balance within \(D\))

\[
\int_{\partial D} \frac{\partial p(r)}{\partial n} dl(r) = 0
\]

must be valid for a solution to exist.

With respect to the same parameter \(s \in [-\ell/2, \ell/2]\), the following set of vector parametric representations, \(r(s)\), and unit normals, \(\hat{N}\), are considered on the 3 sides of the equilateral triangle, see Figure 2:

Side (1)

\[
r(s) = \left( \frac{\ell}{2\sqrt{3}}, s \right), \quad \hat{N} = (1,0)
\]

Side (2)

\[
r(s) = \left( -\frac{\ell}{4\sqrt{3}} + \frac{s\sqrt{3}}{2}, -\frac{\ell}{2} - \frac{s}{2} \right), \quad \hat{N} = \left( -\frac{1}{2}, \frac{\sqrt{3}}{2} \right)
\]

Side (3)

\[
r(s) = \left( -\frac{\ell}{4\sqrt{3}} + \frac{s\sqrt{3}}{2}, -\frac{\ell}{2} - \frac{s}{2} \right), \quad \hat{N} = \left( -\frac{1}{2}, \frac{\sqrt{3}}{2} \right)
\]

The first step in implementing the method is the evaluation of the Neumann data \(q_j^{(i)}(s)\), \(j = 1, 2, 3\), with respect to \(s\), that define the new functions

\[
F_j(k) = \frac{1}{2\sqrt{2}} \int_{-\ell/2}^{\ell/2} e^{i\pi s} q_j^{(i)}(s) ds, \quad j = 1, 2, 3
\]

Next, one has to recover the unknown Dirichlet data \(q_j^{(i)}(s)\), \(j = 1, 2, 3\), on the boundary \(\partial D\). In [1, Proposition 3.3] the authors establish the so-called Neumann-to-Dirichlet map for the generalized Helmholtz equation. In the specific case of Laplace equation we can simplify the result by straightforward calculations as follows.

**Proposition 2.1.** Let the real valued function \(q(x, y)\) satisfy the Laplace equation in \(D\), with Neumann boundary conditions

\[
q_j^{(i)}(s) = f_j(s), \quad j = 1, 2, 3
\]

whereby the known functions \(f_j\) satisfy the compatibility condition

\[
\int_{-\ell/2}^{\ell/2} [f_1(s) + f_2(s) + f_3(s)] ds = 0
\]

Then, the Dirichlet data \(q_j^{(i)}(s)\), \(j = 1, 2, 3\) can be expressed in terms of the known Neumann data by the Fourier series

\[
q_j^{(i)}(s) = \sum_{n=-\infty}^{\infty} \left[ N(k_{3n}) + c_1^{(i)} e^{2i\pi n/3} N(k_{3n-1}) + c_2^{(i)} e^{4i\pi n/3} N(k_{3n-2}) \right] e^{-2i\pi n s/\ell}
\]

where

\[
c_1^{(1)} = c_2^{(1)} = 1, \quad c_1^{(2)} = c_2^{(2)} = a, \quad c_1^{(3)} = c_2^{(3)} = a, \quad a = e^{i2\pi/3}, \quad a = e^{-i2\pi/3}
\]

and

\[
N(k) = \begin{cases} \sqrt{1 + k^2} \sin \theta & \text{if } k > 0 \\ k \sin \theta & \text{if } k < 0 \end{cases}
\]
\[ N(k_m) = \frac{2}{m \pi e^{\pi/m} + (-1)^m} A \]  

where

\[
\begin{align*}
A &= \left\{ \begin{array}{l}
\left( \frac{3 + i \sqrt{3}}{6} \pi \right) e^{i \frac{\pi}{6}} F(k_m) \\
+ e^{i \frac{\pi}{6}} \left( \frac{3 - i \sqrt{3}}{6} \pi \right) F_i(k_m) \\
\left( \frac{3 + i \sqrt{3}}{6} \pi \right) e^{i \frac{pi}{6}} F_i(k_m)
\end{array} \right. \\
+ e^{-1} \left( \frac{3 + i \sqrt{3}}{6} \pi \right) F_i(k_m) + e^{i \frac{\pi}{6}} \left( \frac{3 - i \sqrt{3}}{6} \pi \right) F_i(\overline{k_m}) \\
+ \left( -1 \right)^m \left( \frac{3 + i \sqrt{3}}{6} \pi \right) F_3(k_m) + e^{i \frac{\pi}{6}} \left( \frac{3 - i \sqrt{3}}{6} \pi \right) F_3(\overline{k_m})
\end{align*}
\]

\[ k_m = \frac{2 m \pi}{3 \ell}, \quad m \in \mathbb{Z} \]  

and

\[ F_i(k), \quad j = 1, 2, 3 \]  

are given in [5].

We are ready now to apply the above proposition to the problem at hand.

**DETERMINATION OF THE UNKNOWN DIRICHLET DATA**

In view of (2), straightforward differentiation of (1) yields the Neumann data

\[ q^{(1)}(s) = -\frac{\sqrt{3}Q}{4 \pi s^2} \frac{1}{s^2 + 3 \ell^2/4} \]  

\[ q^{(2)}(s) = q^{(3)}(s) = -\frac{\sqrt{3}Q}{8 \pi s} \frac{1}{s^2 + 3 \ell^2/4} \]  

and the compatibility condition (7) is satisfied.

We define the functions

\[ F_i(k) = -\frac{\sqrt{3}Q}{8 \pi} G(k) \]  

\[ F_i(k) = F_i(k) = \frac{\sqrt{3}Q}{16 \pi} G(k) \]  

where

\[ G(k) = \int_{-1/2}^{1/2} e^{i \alpha s} \frac{3 \ell^2}{4} ds \]  

Then, the Dirichlet data on each side of the triangle can be expressed by the series

\[ q^{(i)}(s) = \sum_{n=1}^{\infty} \left[ c_1^{(i)} N(k_n) e^{-2 \pi n s} \right] \]  

where

\[ c_1^{(1)} = c_2^{(1)} = 1, \quad c_1^{(2)} = c_2^{(2)} = \pi, \quad c_1^{(3)} = c_2^{(3)} = \pi \]  

and

\[ N(k_n) = \frac{\sqrt{3}Q}{8 \pi} \left[ e^{i \frac{\pi}{6}} + e^{i \frac{\pi}{6}} \right] \]  

where

\[ B = \left\{ \begin{array}{l}
-2 e^{i \frac{\pi}{6}} \cos \left( \frac{3 + i \sqrt{3}}{6} \pi \right) \\
+ e^{i \frac{\pi}{6}} \cos \left( \frac{3 - i \sqrt{3}}{6} \pi \right) G(k_n) \\
\left( \frac{3 + i \sqrt{3}}{6} \pi \right) e^{i \frac{\pi}{6}} G(k_n)
\end{array} \right. \\
+ \left( -1 \right)^m \left( \frac{3 + i \sqrt{3}}{6} \pi \right) G(\overline{k_n}) + e^{i \frac{\pi}{6}} \left( \frac{3 - i \sqrt{3}}{6} \pi \right) G(\overline{k_n})
\]

The harmonic function \( q(r) \) enjoys the classical integral representation in \( D \)

\[ q(r) = \frac{1}{2 \pi} \ln |r| - r \int_{\partial D} \left( \frac{\partial q(r)}{\partial n} \right) dl(r), \quad r \in D \]  

where the integration is taken in the positive direction, \( \partial D/\partial n \) denotes the outward normal derivative on \( \partial D \) and \( dl(r') \) is the line element along each side.

In view of (14) and (17), the above integral representation provides the analytical expression for the harmonic function \( q(r) \) or \( q(x, y) \)

\[ q(x, y) = \frac{\sqrt{3}Q}{8 \pi} \times \int_{-1/2}^{1/2} \left[ \begin{array}{l}
2 K_1(x, y) - K_1(x, y) - K_1(x, y) \\
2 K_1(x, y)
\end{array} \right] \frac{\partial E_1(x, y)}{\partial n} ds \\
+ \sum_{n=1}^{\infty} N(k_n) \int_{-1/2}^{1/2} \left[ \begin{array}{l}
E_1(x, y) \\
E_1(x, y)
\end{array} \right] e^{-2 \pi n s} ds \\
+ \sum_{n=1}^{\infty} N(k_n) \int_{-1/2}^{1/2} \left[ \begin{array}{l}
E_1(x, y) \\
E_1(x, y)
\end{array} \right] e^{-2 \pi n s} ds \]  

where the functions,
of the Laplace equation, while the functions corresponding to the value of the fundamental solution on the boundary of the fundamental domain is involved into its integral representation. Then, the corresponding integral representation provides an analytical expression of the solution in terms of Neumann and Dirichlet data.

In a future work, we need to evaluate the integrals in (22), using complex analysis and simplify this expression as much as possible.

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EVALUATION OF RENEWABLE ENERGY SOURCES (SOLAR, WIND, AND BIOGAS) ESTABLISHED IN CYPRUS IN THE FRAMEWORK OF SUSTAINABLE DEVELOPMENT

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ABSTRACT

Cyprus is an island whose energy production is almost completely dependent on imported hydrocarbon fuels. Its electricity production sector is more than 80% depended on oil products while the remaining 20% are covered by imports of coal (5%) and by renewable energy sources (15%). However, renewable energy sources and more specific solar, wind, and biogas are not always without any negative impacts to the environment and the society. Environmental impact assessment is necessary to be done before a RES established in order to estimate, control and minimized any impact to the environment before the construction of those parks. There is absence of data regarding the impact of the renewable energy sources project that had been established and operated since now although there are several data before the installation. This paper focuses on the evaluation of three RES projects that had been established and operated the last years, covering the full range of exploited renewable energy sources in Cyprus. Thirty-two parameters in the holistic approach of the Sustainable Development framework had been used; and using the multi-criteria analyses method TOPSIS those parks were evaluated. The final results indicated that, the photovoltaic park is more efficient in the holistic approach of Sustainable Development than wind park and the biogas unit and is consider to be more acceptable from the citizens.

KEYWORDS:
Renewable Energy Sources, Environmental Impacts, Multi-Criteria Analysis, Sustainable Energy, Analytical Herocray Process

INTRODUCTION

RES (renewable energy sources) are sustainable (due to decarbonisation of the economic growth produced by them), secure (refrain from geopolitical risks), safe (no accident risk, e.g. an oil spill) and they can be mainly supplied even in rural remote areas [1]. Their development will satisfy all parameters of the sustainable energy having on mind future trends, financial, environmental and social aspects [2]. It is well known that RES contributes to the reduction on fossil fuel’s and mitigating climate change and are used as a sustainable energy production tool.

Until now, there is a gap of data regarding the impact of the RES project that had been established and operated in the holistic approach of Sustainable development (SD). Sustainable development is “development that meets the needs of the present without compromising the needs of future generations to meet their own needs.” The definition of Sustainable Development given by Brundtland in 1987 is the most common used by authors, researchers and other related to concept of sustainability [3]. The idea of «sustainable development» was born in 1713 when Carlowitz edited the first book on forest sciences [3]. He argued that timber would be “as important as our daily bread” and that it should be “used with caution in a way, that there is a balance between timber growth and lumbering”. This would allow forever a continuous, perpetual use “For this reason, we should organise our economy in a way that we won’t suffer scarcity [of timber], and where it is lumbered we should strive for young growth at its place” [4].

This paper focuses on the evaluation of three RES projects that had been established and operated the last years, covering the full range of exploited RES in Cyprus. Furthermore, the paper answers in one main research question; which one (of the RES: solar, wind, biogas) runs more effectively in the framework of sustainability in Cyprus under warm climate conditions.

RES IMPACTS

RES are directly connected to a numeral of positive impacts (in society, environment and
economy). However, as indicated by Abbasi and Abbasi [5], RES may present some negatives, including social and environmental aspects [6]. Wind turbines for example are noisy and can become dangerous for wild birds [7]. Kansas developed a comprehensive guidance document to help wind power project stakeholders as they consider potential project sites in the state. Among the impacts that Kansas guidance document suggests should be considered: land use, noise management, natural and biological resources, visual impacts, soil erosion and water quality, safety, cultural, archaeological, and paleontological impacts, socio-economic, public service, and infrastructure impacts, as well as public interaction considerations [8]. On the other hand, wind turbines present significant positive impacts as they do not need water and they do not produce any carbon dioxide emission according to Saidur et al. [7]. Technological developments according to Tampakis et al., [9] have allowed wind energy to become a major energy source, which can question the use of fossil fuel and be considered as the main solution for achieving the goals set. More over according to the same report indicated a positive attitude from the majority of the population in Europe and the US regarding wind energy, and the expansion of wind power.

Negative impacts of photovoltaic (PV) power generation include mainly impacts to land use (large areas are required for central systems and reduction of cultivable land), visual intrusion, impact to aesthetics, impact on ecosystems (applicable to large PV schemes), use of toxic and flammable materials (during construction of the modules) and slight health risks from manufacture, use and disposal [10]. Moreover Chiabrando et al. [11] mentioned that the most significant negatives impact are the loses of land as they cannot be used for production of energy and agricultural at the same time, countryside destruction, landscape optical and or visual pollution (which is consider to be very subjective indicator), the interference with fauna and flora, the microclimate change, the presents of the electromagnetic fields as well as the impacts (noise, dust mostly) during the construction phase. Furthermore, according to Holdren et al. [12] PVs, unusually includes toxic substances as manufacturing while wind power presents more often accident hazard from blade failures and topping towers, bird and insect kills, fall hazard during maintenance, interference with electromagnetic communications, aircraft navigation hazard, chemical, electrical and explosive hazards from storage batteries and noise. Additionally, biomass includes dust emissions from agricultural and human activities, high quantities of water use (where irrigation is required), pollution from pesticides, herbicides, solid/sludge residuals from conversion processes, ecosystem effects of mono culture etc. Poeschl et al. [13] indicated that the main negative impacts includes: toxicity to humans, photochemical oxidant formation, formation and exploitation of particulate matters (PM 2.5, PM10), radiation, terrestrial acidification, eutrophication, fresh, ecotoxicity, agricultural and urban land occupation, natural land transformation but also water, fossil and metal depletion and impact to climate change and ozone depletion. Moreover, Buratti et al. [14] indicated that emissions from biogas unit may include carcinogens and non-carcinogens and respiratory organics and non-organics.

The social aspects of RES are also very important as it is not easy to convince local population due to many suspicions and negative expectations about this type of applications in their neighbourhood [15, 16].

**RENEWABLE ENERGY IN CYPRUS STATE OF THE ART**

Cyprus which became member of the European Union in 2004 has equal population of up to 862000 [17]. Cyprus power system operates in isolation and for electricity production used to rely totally on imported fuels such as, heavy fuel oil and diesel [18, 19]. Although from 2011-2013, a reduction of power production was noted, a demand growth is also predicted for the next years expecting to reach more than 1165 MW in 2022 [20]. The yearly CO₂ emissions are equal to 10397 Kg/capita, higher than the EU 27 average which is 8180 Kg/capita. Some researches indicated that in the exclusive economic zone of the island may exist significant hydrocarbons reserves (although those were not yet been verified are estimated to be approximately 6-8 billion barrels or higher) [21].

Cyprus has a remarkable RES as it is one of the leading countries in the world utilizing solar water heaters with estimated area of flat plate solar collectors covering a total area of 560000 m², which corresponds to approximately 0.86 m²/habitant [18]. The last 5 years RES exploitation has been imported in Cyprus energy production system. The target is up to 13% of the total island energy production to be derived from RES by the end of 2020 [22].

Solar, wind and biomass energy seem to be a solution for the island energy system isolation and imported fossil fuel dependency. Different statistical analyses [17, 19] have indicated that all parts of the island enjoy sunny climate. The island is exposed to sunlight radiation on average 9.8 h in December and 14.5 h in June, and the annual solar potential can reach up to 2500 KWh/m² for two-axis tracking systems [19]. Moreover, the wind potential is between 150 and 250 MW [23]. Although high wind potential is not typical in Cyprus, several areas are identified as having annual mean values of wind...
speeds more than 5 m/s at 10 m height. Those locations are situated in the southern coastal zone of the island and in some locations in the mountains [18]. Biodegradable wastes, consists of the biodegradable fraction of municipal solid waste, sewage sludge, solid and liquid agricultural residues as well as solid and liquid wastes from food industries [24]. The potential energy that could be produced by those wastes is estimated to be 114-700 million m³, depending on the method used [25].

185031 KW of total renewable energy power were established on the island and connected to the grid by the end of 2013. More specific (Figure 1 and 2) 13 biomass / biogas units of 9714 KW total power, 1563 PV systems of 27859 KW total power, 57 PV systems on public buildings, of 758 KW total power and five (5) wind parks of 146700 KW total power were established and operated [26]. The total production by the end of 2013 was 25949741 KWh electric powers.

EIA IN CYPRUS REGARDING RES PARKS

EIA requirements in Cyprus are regulated by the Law 140(I)/2005 [27]. The law requires EIA for a number of project types, in order to be licensed. This obligation also applies for biogas unit, wind park and PV parks but only if the capacity is higher than 100 KW. EIA estimate all the negative and positive impacts of a project including the impacts to the environment, public health, quality of life and work conditions during the: (a) construction, (b) operation, (c) maintenance and (d) demolition of the projects. It is also required to assess the compatibility of the project with the government policies and the project area land use. Furthermore, it must also assess and examine the project impacts on several other parameters including the impact on the: public infrastructures, road traffic, daily life and convenience of the area residents, rural land and sea activities, monuments and architecture heritage, existent buildings and infrastructure stability, natural and structured environment including aesthetic and optical pollution, landscape and natural sources, flora and fauna, water (surface and underground), rivers, soil, navigation, microclimate and climate change, coasts, sea environment, etc.

MATERIAL AND METHODS

Renewable Energy Sources Evaluation. The most relevant methods used for the evaluation of RES include different multi-criteria analyses methodologies [28, 29, 30, 31] using a range of criteria, usually covering the technical, economic and environmental aspects [28]. Since the economic feasibility of RES projects is also significant, evaluation using only economic methods is another approach [19].

Sustainability indicators [32] like cost of electricity generation, greenhouse gas emissions and energy pay-back time have been used in order renewable based electricity generation technologies to be assessed by using data obtained from the literature [33]. Other sustainability indicators used for renewable energy sources evaluation are the price of generated electricity, greenhouse gas emissions during full life cycle of the technology, the availability of renewable sources, the efficiency of energy conversion, land requirements, water consumption and social impacts [32].

Assessment Method. Multiple criteria in the framework of sustainability that affect the success implementation of a RES project must be analysed and taking into account [31]. The three RES projects used in this research have been licensed, constructed and already run for at least 5 to 6 years. During their licensing procedure EIA studies was prepared and evaluated and each one was licensed with specific environmental terms and conditions in order to minimize their impacts to the environment especially during the construction process but also during the operation and demolition phase. Regarding this, the main research question that arised was which one of the RES projects is more effectively in the framework of sustainability in Cyprus. Moreover the paper aim to examined (a) if the EIA study was effectively prepared covering all the environmental
aspects, (b) if the environmental terms/conditions set were sufficient to prevent impacts and (c) what are their impacts in the framework of sustainability during the operation and until the end of their life.

The evaluation criteria can be summarized in four categories, i.e. technical, environmental, social and economic [34]. Those categories cover the pillars of sustainability but it is crucial to add the institutional dimension also [35]. Institutional dimension covers the details regarding the satisfaction of the established policies and legislation including also the interactions between the governmental and non-governmental organizations involved in the decision making as expressed by the terms set from the EIA committee which evaluate the EIA study for each project and in which participate representatives of both governmental and non-governmental organizations.

**Technique for Order Preference by Similarity to Idea Solution (TOPSIS) Method.**

The principle behind TOPSIS method is quite simple. An ideal solution is formed as a composite of the best performance value exhibited by any alternative for each attribute and the negative-ideal solution is the composite of the worst performance values. The chosen alternatives should be as close to the ideal solution as possible and as far from the negative-ideal solution as possible [31]. TOPSIS method has been developed by Hwang and Yoon [31] during 1981 and includes an ideal solution determination [31, 36]. According to San Cristóbal Mateo [31] TOPSIS method consists of six basic steps which includes: (i) normalized decision matrix calculation; (ii) weighted normalized decision matrix calculation; (iii) the ideal and negative-ideal solutions determination; (iv) separation measures calculation; (v) relative closeness to the ideal solution calculation and (vi) preference order ranking.

The alternatives are ranked by sorting the relative closeness value \( C'_{ij} \) calculated for each one in decreasing order and according to the method the solution is the alternative which is the best ranked (maximum) by the measure.

**Assessment Criteria.** The criteria to be used in Analytical Hierarchy Process (AHP) analysis for the evaluation of the three RES projects arising from the components of sustainable development are classified into four main categories (Table 1). Each basic category consists of a number of environmental, economic, social and institutional sub criteria (Table 1). For the comparative evaluation a pair wise evaluation were used.

The criteria (Table 1) represent the projects performance and since different projects with a variation of characteristics and values referring to different time periods have to be compared, they have been formed either as indicators to show the

<table>
<thead>
<tr>
<th>Code</th>
<th>Economic Criteria</th>
<th>Code</th>
<th>Environmental Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>KT1</td>
<td>Project implementation</td>
<td>KE1</td>
<td>Water consumption</td>
</tr>
<tr>
<td>KT2</td>
<td>Energy yield</td>
<td>KE2</td>
<td>CO₂ emissions conservation</td>
</tr>
<tr>
<td>KT3</td>
<td>Subsidy yield</td>
<td>KE3</td>
<td>Air pollution</td>
</tr>
<tr>
<td>KT4</td>
<td>Investment yield</td>
<td>KE4</td>
<td>Sewage</td>
</tr>
<tr>
<td>KT5</td>
<td>Electrical grid burden</td>
<td>KE5</td>
<td>Solid waste</td>
</tr>
<tr>
<td>KT6</td>
<td>Maintenance cost</td>
<td>KE6</td>
<td>Land impacts (roads) prevention</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Social Criteria</th>
<th>KE7</th>
<th>Land use impacts prevention</th>
</tr>
</thead>
<tbody>
<tr>
<td>KS1</td>
<td>New job places</td>
<td>KE8</td>
<td>Noise impact prevention</td>
</tr>
<tr>
<td>KS2</td>
<td>Accidents and incidents</td>
<td>KE9</td>
<td>Flora and fauna impacts prevention</td>
</tr>
<tr>
<td>KS3</td>
<td>Neighbour complaints</td>
<td>KE10</td>
<td>Cultural heritage and monuments impacts prevention</td>
</tr>
<tr>
<td>KS4</td>
<td>Compensational payments</td>
<td>KE11</td>
<td>Visual field impacts prevention</td>
</tr>
<tr>
<td>KS5</td>
<td>Social economic compensation</td>
<td>KE12</td>
<td>Electromagnetic impacts prevention</td>
</tr>
<tr>
<td>KS6</td>
<td>Social positive impact</td>
<td>KE13</td>
<td>Microclimate impact prevention</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Institutional Criteria</th>
<th>KE14</th>
<th>Fuel saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>KJ1</td>
<td>Licensed deviations</td>
<td>KE15</td>
<td>Ground impact prevention</td>
</tr>
<tr>
<td>K2</td>
<td>Deviations to authorities requirements and licenses</td>
<td>KE16</td>
<td>Smell, dust etc prevention</td>
</tr>
<tr>
<td></td>
<td></td>
<td>KE17</td>
<td>Traffic impact prevention</td>
</tr>
<tr>
<td></td>
<td></td>
<td>KE18</td>
<td>Material recycle</td>
</tr>
</tbody>
</table>

**Criteria weighting.** There are a number of methods for determining the weights varying on the way they process decision makers’ views [2, 28, 37]. For this research the proposed method by by Saaty [28, 37] was used. According to San Cristóbal Mateo [31] when AHP is applied, all the criteria are compared pair-wise with respect to specific criteria in the direct level.

**Projects under study.** The three different RES (Figure 3) projects under study were: (i) wind energy was represented by a wind park of 31.5 MW installation power, operating since January 2012, (ii) solar energy which was represented by a PV park, with installation power 150 KW, operating since October 2011 and (iii) biomass by a biogas electricity production unit, with installation power 2100 KW, operating since September 2010.
RESULTS AND DISCUSSIONS

The initial EIA studies (for all the examined RES project) were totally prepared according to the requirements of the National Law (175(I)/2005) [27] and after their evaluation from the Department of Environment a number of environmental terms and conditions were set to minimize their impacts during the contraction and operation as presented in Table 2.

TABLE 2
Environmental Terms regarding the construction and operation phase of the examined parks as given by the examination of the EIA law

<table>
<thead>
<tr>
<th>PV Park</th>
<th>Wind Park</th>
<th>Biogas Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual field and glare impacts prevention terms</td>
<td>Ground impact prevention terms</td>
<td>Sewage handling terms</td>
</tr>
<tr>
<td>Accidents and incidents prevention terms</td>
<td>Accidents and incidents prevention terms</td>
<td>Solid waste handling terms</td>
</tr>
<tr>
<td>Ground impact prevention terms</td>
<td>Noise impact prevention terms</td>
<td>Accidents and incidents prevention terms</td>
</tr>
<tr>
<td>Flora impacts prevention terms</td>
<td>Flora and fauna impacts prevention terms</td>
<td>Smell, dust etc. prevention terms</td>
</tr>
<tr>
<td>Smell, dust etc prevention terms</td>
<td>Land use impacts prevention terms</td>
<td>Ground (and ground water) impact prevention terms</td>
</tr>
<tr>
<td>Noise impact prevention terms</td>
<td>Visual field impacts prevention terms</td>
<td>Solid waste handling terms</td>
</tr>
<tr>
<td>Solid waste handling terms</td>
<td>Traffic impact prevention terms</td>
<td>Traffic impact prevention terms</td>
</tr>
<tr>
<td>Sewage handling terms</td>
<td>Air pollution prevention terms</td>
<td>Air pollution prevention terms</td>
</tr>
</tbody>
</table>

Those terms and conditions covered the construction, operation and demolition phase of each project but since the demolition phase cannot be evaluated at the moment, in the table are included only those regarding the construction and operation.

The terms and conditions include the necessary measures for most of the environmental impacts of RES projects as have been mentioned in the literature [8, 10, 11, 12, 13, 14].

Based on the AHP methodology the pairwise comparison matrix for the determination of the criteria weights was specified by accepting that social and environmental criteria are obviously more important than the economic followed by the institutional criteria which are more important than the economic. Social and environmental criteria are equal and the institutional criteria are less important than the social and environmental. Table 3 indicated the rate pf each criterion.

TABLE 3
Criteria Weights

<table>
<thead>
<tr>
<th>Criteria Code</th>
<th>Weight</th>
<th>Criteria Code</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>0.039</td>
<td>KE1</td>
<td>0.017</td>
</tr>
<tr>
<td>K11</td>
<td>0.003</td>
<td>KE2</td>
<td>0.043</td>
</tr>
<tr>
<td>K12</td>
<td>0.002</td>
<td>KE3</td>
<td>0.020</td>
</tr>
<tr>
<td>K13</td>
<td>0.019</td>
<td>KE4</td>
<td>0.004</td>
</tr>
<tr>
<td>K14</td>
<td>0.009</td>
<td>KE5</td>
<td>0.004</td>
</tr>
<tr>
<td>K15</td>
<td>0.001</td>
<td>KE6</td>
<td>0.005</td>
</tr>
<tr>
<td>K16</td>
<td>0.008</td>
<td>KE7</td>
<td>0.011</td>
</tr>
<tr>
<td>K17</td>
<td>0.133</td>
<td>KE8</td>
<td>0.015</td>
</tr>
<tr>
<td>K18</td>
<td>0.398</td>
<td>KE9</td>
<td>0.009</td>
</tr>
<tr>
<td>K19</td>
<td>0.028</td>
<td>KE10</td>
<td>0.006</td>
</tr>
<tr>
<td>K20</td>
<td>0.010</td>
<td>KE11</td>
<td>0.005</td>
</tr>
<tr>
<td>K21</td>
<td>0.008</td>
<td>KE12</td>
<td>0.006</td>
</tr>
<tr>
<td>K22</td>
<td>0.052</td>
<td>KE13</td>
<td>0.005</td>
</tr>
<tr>
<td>K23</td>
<td>0.021</td>
<td>KE14</td>
<td>0.017</td>
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<td>K24</td>
<td>0.028</td>
<td>KE15</td>
<td>0.003</td>
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<tr>
<td>K25</td>
<td>0.010</td>
<td>KE16</td>
<td>0.005</td>
</tr>
<tr>
<td>K26</td>
<td>0.008</td>
<td>KE17</td>
<td>0.008</td>
</tr>
<tr>
<td>K27</td>
<td>0.398</td>
<td>KE18</td>
<td>0.032</td>
</tr>
</tbody>
</table>

The collected data developed three quantitative groups, each one for each project, including the values of the criteria. The calculations following the six steps of TOPSIS method for the three alternatives data groups, applying the determined criteria weights, were made and the relative closeness value ($C^*$) which for the PV park was 0.693, for the wind park was 0.402 while for biogas unit was 0.274 (Figure 4). The TOPSIS indicated that the most efficient RES (according to what criteria were set) was the PV park followed by wind park and biogas unit.

The examined RES projects indeed have negative environmental impacts, just as it is widely stated in the literature for RES and their exploitation projects [5, 8, 10]. At the same time the examined RES projects presented with positive impact on the development of new job positions. This is consider to be an important finding, especially if this is compared with other research which indicated that there is no clear result about whether RES has positively or negatively effects on employment [38].

The projects ranking is fairly interesting. The nomination of the PV park as the nearest to the ideal solution is also supported and from other researchs
[39, 40]. However, Varum, et al., [33] rank wind parks as the most suitable and applicable solution comparing with other RES.

FIGURE 4
TOPSIS ranking results

The energy production from waste has been noted that it is interesting for Cyprus [25]. Besides a unit using biogas from waste, as the project was accessed, has a notable environmental benefit by contributing to the solid waste and wastewater environmentally friendly management. Cyprus has a quite high solid waste per capita index (almost 740 Kg/capita according to Zorpas et al., [41]) and this parameter is quite important and has to be noted, especially since this characteristic was not included in the multi-criteria analysis. Moreover in order to develop a complete RES project in insular communities’ education plays significant role. According to Ntona et al. [42], education on energy issues should be the means for helping citizens cope with present and future energy needs, which have social, economic and environmental dimensions.

CONCLUSIONS

The solar energy exploitation seems that should be in priority promoted in Cyprus. The island has a strong solar energy potential and although other renewable sources can also be further developed, solar energy projects are an efficient choice, although Cyprus has a quite high solid waste per capita index and maybe a waste to energy strategy concept could be also very promises solution due to the limited space of land. Since the obligation of Renewable Energy Projects for compensation payments to local communities, today is effective to wind parks only, it is suggested that, these could be implemented to all kinds of RES.

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ABSTRACT

The electromagnetic (EM) pollution can lead to performance degradation in electronic devices or systems. EM pollution has been categorized as a new form of environmental pollution. In this preliminary study, so as to detect EM pollution emitted from some important base stations in Nigde province, measurements carried out with mobile equipment -Spectran RF&EMF Hand Held Spectrum Analyser Set (Pro 3) with a frequency range of 1 Hz to 9.4 GHz- were made in three main categories including changes of electrical field, magnetic field and EM power. Measurements were performed near the base stations that are located in three certain areas including the Nigde Castle, Yukarı Kayabaşı and the Fire Department areas. It was found that (a) magnetic field (A/m) differed, being high in outdoor areas and low in indoor areas, with a difference of 10 to 100 times, (b) lower electromagnetic field values were detected in coordinates at higher points from two coordinates located in the same distance from the base station but in a different height, (c) electromagnetic field was reduced by increasing the distance. The results fall into the limit of international “Uncontrolled Response in Public Living Space to GSM900 and DCS1800 Systems” and Turkish “Uncontrolled Response” standards.

KEYWORDS: environment, electric field, electromagnetic pollution, electromagnetic power, magnetic field

INTRODUCTION

Electromagnetic (EM) fields increasingly became a common constituent of the general and workplace environments in the early 20th century [1]. Power and communication systems have drastically altered the frequencies and the strength of the nonionizing EM radiation in the environment. All electronic power devices generate and emit unwanted electrical signals, a form of EM noise or pollution [2].

Current technologies have become a source of omnipresent EM pollution from generated EM fields, resulting EM radiation. In many cases, this pollution is much stronger than any natural sources of EM fields or radiation. Wireless and radio communications, power transmissions, or devices in daily use such as smartphones, tablets, and portable computers expose people to EM pollution every day. EM fields and/or EM radiation, as EM pollution, affect various elements of the environment, among which all living organisms should be considered in the first place. Therefore, it becomes very important to appropriately determine the nature and related side effects of EM pollution. Every day, living organisms are exposed to different types of EM pollution. However, all of them can be well characterized by their physical parameters such as type (electric, magnetic, EM), frequency, and intensity/power [3].

EM pollution that consists of electric field and magnetic field components can be grouped into two general classes when sources are considered. These classes are:

a) low frequency EM pollution emitted from electrical devices in daily use,

b) high-frequency EM pollution emitted from radio and TV transmitters, and base stations [4].

The use of mobile phones has increased rapidly in many countries since the early 1990s, which has increased concern about possible adverse health effects of mobile phone use, particularly risks of brain tumors [5-11]. Cell phone technology incorporates base stations, namely, transmission tower antennae, and cell phone handheld units. Cell phone base stations or masts emit EM radiation continuously and with far greater power than cell phones which emit EM radiation continuously only during calls [12]. EM pollution is responsible for interference between electrical devices, but it also affects the human body.

In this study, magnetic field, electric field and EM power measurements were made around 3 base stations situated in different places in Nigde province (Turkey). These preliminary measurements indicated where Nigde is in terms of national and international EM standards. The study will be continued in all base stations in Nigde to determine EM pollution of this city.

MATERIALS AND METHODS

Different methods are used for measuring high frequency EM pollution from base stations. In this study, measurements were performed in horizontal and vertical positions in three base stations. They are
located at three selected areas in central district of Nigde province (Turkey); Yukarı Kayabaşı (Latitude: 37°57′43,78″, Longitude: 34°40′56″), the Fire Department (Latitude: 37°58′22,41″, Longitude: 34°40′8,6″) and the Nigde Castle (Latitude: 37°58′6,9″, Longitude: 34°40′46,96″).

Spectran RF&EMF Hand Held Spectrum Analyser Set (Pro 3) (Spectran HF 60105 and Spectran NF 5035 HyperLog), which is mobile equipment (Photograph 1), was used to measure three main components of EM pollution, which are electric field (EF), magnetic field (MF) and EM power. This analyzer has the whole frequency band from 1 Hz to 9.4 GHz to detect and analyze. The measurements can be displayed both from its own screen and the mobile computer via USB connection. This analyzer provides the opportunity to watch EF, MF, and EM power in terms of EM components that can convert each other [13]. The mobile computer connection of this device is shown in Photograph 2. Reported by Kapucu et al. (2011) [14], this measuring method exemplifies the work done in this field.

RESULTS AND DISCUSSION

In this preliminary study, the measurements for MF, EF and EM power, given under three main headings, were carried out from specified locations (Yukarı Kayabaşı, the Fire Department and the Nigde Castle areas). The measurements were done both indoors and outdoors, in differing conditions, in certain distance from base station, depending on the altitude.

The results for these 3 areas were given in Figure 1, 2, and 3. "Starting time" and "time after 30 seconds" in these graphs showed the measurements done when the analyzer began and 30 seconds after reading. The base station located in Yukarı Kayabaşı (Figure 1) was chosen for comparison of MF in the indoor and outdoor areas. This graph shows that MF values were decreased from 10 to 100 times indoors in the ranges of 3.14x10^{-7}-2.71x10^{-6} (A/m) and 1.05x10^{-3}-2.22x10^{-4} (A/m).

As an example of EF measurement, base station located near the Fire Department of Nigde was chosen in the study. Measurements, ranging from 1.25x10^{-3}-6.27x10^{-2} and 2.07x10^{-4}-5.70x10^{-2} V/m, done at 0 m and 10 m from the base station were shown in Figure 2.

The Nigde Castle area was chosen for comparisons of height difference in MF, EF and EM power. It was determined that MF, EF and EM power showed decreasing trend when altitude is increasing (Figure 3), varied from 3.57x10^{-4} to 1.53x10^{-3} A/m, 4.74x10^{-1} to 4.99x10^{-2} V/m and -95.578 to -92.529 dBm.

In this study, the values for EF (2.07x10^{-4}-4.74x10^{-1} V/m) and MF (3.14x10^{-7}-1.53x10^{-4} A/m) from three base stations in Nigde province are found below the limits of international “Uncontrolled Response in Public Living Space to GSM900 and DCS1800 Systems” and Turkish “Uncontrolled Response” standards (Table 1, 2). These results are also considerably lower than those obtained from other studies in the literature (Table 3).
FIGURE 2
EF measurements made near the base station located in the Fire Department area in 0 m (a) and 10 m (b) distances

TABLE 1
Uncontrolled Response in Public Living Space to GSM900 and DCS1800 Systems [15]

<table>
<thead>
<tr>
<th>Component</th>
<th>Base Station Frequency</th>
<th>ICNIRP*</th>
<th>IEEE/FCC**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>900 MHz</td>
<td>EF</td>
<td>MF</td>
</tr>
<tr>
<td>EF</td>
<td>41.25 V/m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MF</td>
<td>0.111 A/m</td>
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<td>-</td>
</tr>
<tr>
<td></td>
<td>1800 MHz</td>
<td>EF</td>
<td>MF</td>
</tr>
<tr>
<td>EF</td>
<td>58.33 V/m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MF</td>
<td>0.157 A/m</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(*ICNIRP: The International Commission on Non-Ionizing Radiation Protection (ICNIRP) **IEEE: Institute of Electrical and Electronic Engineers, FCC: Federal Communications Commission (USA)

TABLE 2
Turkish uncontrolled response standards (limits) for EM pollution [15, 16]

<table>
<thead>
<tr>
<th>Component of EM Pollution</th>
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<th>1800 MHz</th>
</tr>
</thead>
<tbody>
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<td>14.47 V/m</td>
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<tr>
<td>MF</td>
<td>7 A/m</td>
<td>0.111 A/m</td>
<td>0.038 A/m</td>
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TABLE 3
Comparison of EM pollution results obtained from this study and other studies in the literature

<table>
<thead>
<tr>
<th>Studies in the literature</th>
<th>EF (V/m)</th>
<th>MF (A/m)</th>
<th>EM power (dBm)</th>
<th>Power density (W/m²)</th>
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<tbody>
<tr>
<td>Örgünmaz et al. (2010)</td>
<td>&lt;4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Çerence and Seker</td>
<td>&lt;1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kurucu et al. (2011)</td>
<td>-</td>
<td>-</td>
<td>-60 dBm</td>
<td>-</td>
</tr>
<tr>
<td>Cansev and Kurt (2012)</td>
<td>4.68</td>
<td>0.0124</td>
<td>0.058032 W/m²</td>
<td>-</td>
</tr>
<tr>
<td>This study</td>
<td>2.07x10⁻¹⁰</td>
<td>3.14x10⁻⁹</td>
<td>95.578</td>
<td>-92.529 dBm</td>
</tr>
</tbody>
</table>

CONCLUSION

This preliminary study focuses on changes in height, distance and indoor and outdoor conditions for EM pollution. EM pollution components that are MF, EF and EM power were determined to decrease when height and distance (in indoor areas) increased, respectively. ICNIRP applies a safety factor of 10 to derive occupational exposure limits, and a factor of
50 to obtain the guideline value for the general public. Therefore, in the electromagnetic frequency ranges, the maximum levels we might experience in the environment or in our home are at least 50 times lower than the threshold level at which first behavioural changes in animals become apparent [19]. In this study, EF and MF values have been found below the national and international standards (more than 100 times lower) which suggest that no harm should be caused by EM pollution on living organisms around these base stations in Nigde (Turkey). The study will be continued in all base stations to determine EM pollution of this city.

ACKNOWLEDGEMENTS

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EFFECT OF FLY ASH CONTRIBUTION TO THE PHYSICAL AND MECHANICAL PROPERTIES OF CEMENTED PUMICE-BASED LIGHTWEIGHT WALL MATERIAL

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ABSTRACT

In this study, using CEM I and CEM II type cements in different mixing ratios, pumice-based lightweight wall material with the contribution of fly ash (FA) was produced so as to evaluate the likely use of this waste material in the construction sector. Physical and mechanical properties were determined in the samples. This study consists of two stages. In the first stage, pumice in 0-4 mm size was used as coarse aggregate. The average axial compressive strength (ACS) values of samples obtained by using only pumice were 9.2 and 11.7 MPa for Bims Concrete 40 (BC40) and BC80 in CEM I, 5.05 and 10.6 MPa for BC40 and BC80 in CEM II, respectively. In the second stage, FAs were added (25, 50, 75 and 100% in weight) as fine aggregates. The ACS values of samples obtained by using FA additive in different ratios ranged from 4.15 to 5.2 MPa for BC40 in CEM I, 3.0 to 3.45 MPa for BC40 in CEM II, respectively, on the other hand, they ranged from 7.4 to 8.7 MPa for BC80 in CEM I, and 4.9 to 6.8 MPa for BC80 in CEM II, respectively. Turkish and European (TS-EN) standards were used to do experiments and interpret the results.

KEYWORDS: environment, construction, fly ash, lightweight wall material, pumice, reuse, waste

INTRODUCTION

In the literature, there are a number of studies on pumice, lightweight concretes, heat insulation on building material and optimization of bricks [1-6]. In Turkey, due to catastrophic earthquakes and energy saving policy, producing building materials with lightweight, high strength and heat insulation and noise retention properties has been an important issue for the last two decades [7-10].

Lightweight concrete manufactured either from natural or artificial aggregate is classified into three categories according to its strength and density [11]. Pumice concrete blocks, which are used in Interior Anatolian Region of Turkey, can be classified in the second category. Volcanic pumice that is a natural lightweight aggregate with vesicular structure and found in granulated form have been used in the production of lightweight concrete, in particular they can be found in the Mediterranean area (Italy, Turkey, Greece, and Spain) [7, 12-14]. Pumice aggregate concrete mixture design has special characteristics from the viewpoint of mixing water content. Due to high water absorption capacity of pumice aggregates, the total mixing water requirement of pumice concrete mixture can be extremely high, causing an increase in water/cement (W/C) ratio [16].

Fly ash (FA) is the major solid waste and coal-combustion by-product having inherent heterogeneous property, porous particle structure and higher amorphous content [17-19]. Besides the environmental benefits of waste disposal and CO2 sequestration [20, 21], FA improves workability, reduces heat of hydration and thermal cracking in concrete at early ages and improves mechanical and durability characteristics of concrete especially at later ages [22, 23]. It has been used as replacement for cement [14, 24-27] in lightweight concrete. Volcanic pumice and FA are pozzolanic materials because of their reaction with lime liberated during the hydration of cement [28]. Referring to buildings, lightweight concrete can be used in structural frames and marine structures [29], but it proves to be more suitable for wall system structures, where the local ductility demand (in seismic zones) and the required strength of the materials are reduced. It has been found that, by using volcanic pumice, satisfactory concrete, from 30 to 40% lighter than normal concrete can be manufactured [30, 31].

Since pumice is abundantly found in Turkey, this material might be used as an additive in lightweight wall material applications or as a precaution against magnesium sulphate attack [32]. This study was carried out in Turkey and many experiments on the effects of FA to physical and mechanical properties of cemented pumice-based lightweight wall material were done.
TABLE 1

Chemical analysis of the pumice and the FA

<table>
<thead>
<tr>
<th>Chemical</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>TiO₂</th>
<th>K₂O</th>
<th>MgO</th>
<th>P₂O₅</th>
<th>SO₃</th>
<th>Na₂O</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumice %</td>
<td>72.02</td>
<td>14.58</td>
<td>1.72</td>
<td>0.84</td>
<td>--</td>
<td>3.45</td>
<td>--</td>
<td>--</td>
<td>5.68</td>
<td>1.06</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Fly ash %</td>
<td>58.05</td>
<td>21.23</td>
<td>6.73</td>
<td>5.76</td>
<td>1.80</td>
<td>1.71</td>
<td>0.70</td>
<td>0.20</td>
<td>0.15</td>
<td>--</td>
<td>3.15</td>
<td></td>
</tr>
</tbody>
</table>

MATERIALS AND METHODS

Pumice. In this study, FA and pumice are used as filling materials. Pumice from Nevşehir province is the source of material we use in our experiments. Pumice deposits in this region spread from Avanos to Derinkuyu. The thickness of the pumice in the region varies from 1 to 20 m. Basalt, diabase and obsidian pieces in pumice range from 1% to 3%. Pumice beds existing in Nevşehir and nearby are in good quality and preferred to use. Grain sizes of pumice in the neighborhood generally range from 1 to 70 mm. Pumice is normally found white, gray and cream in color, but in the upper levels and altered zones they are white and yellowish beige in color. The studies in the field showed that pumice in the area was found good enough in quality to be used in the production of lightweight materials [33].

Pumice is obtained from Okçu Concrete and Engineering Inc. Co. that operate in Niğde Bor Mixed Organized Industrial Site. Pumice brought to the laboratory was sieved with 4 mm square mesh. After sieving, granulometric distributions of the pumice were complianted with the rules of Bims concrete construction and production stated in Turkish Standards (TS) 3234 [34]. Obtained granulometric distributions are given in Figure 1. Compacted dry unit weight (UW) of the pumice used in this study is $\gamma_p=0.62$ g/cm$^3$. Its chemical analysis is given in Table 1.

Fly ash (FA). FA used in this study as raw material was obtained from international firm, İSKEN Inc. Co. Sugözü Termal Power Plant (located in İskenderun, Turkey). The amount of waste ash in this plant is 300000 tons/year. This ash was sieved with 500 μm sieve. Therefore, in this study, FAs whose grain sizes are less than 500 μm were added to granulometric distribution. Granulometric distribution of sieved FA was complianted with the rules of Bims concrete construction and production stated in TS 3234 [34]; but, considering pumice granulometry, the amount of percentage that passed through 500 μm sieve was displaced by the FA. Obtained granulometric distributions of the FA are given in Figure 2. Oven dried compacted UW of the FA that was used in this study was found to be $\gamma_{FA}=1.10$ g/cm$^3$. Chemical analysis of the FA is given in Table 1.
### TABLE 2
Sample ratios of the first phase

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Pumice by weight (g)</th>
<th>Pumice moisture content ratio (%)</th>
<th>Cement by weight (g)</th>
<th>Water (g)</th>
<th>W/C ratio</th>
<th>Sample number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-0.5 mm</td>
<td>0.5-4 mm</td>
<td>0-0.5 mm</td>
<td>0.5-4 mm</td>
<td>CEM I</td>
<td>CEM II</td>
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<td>129.8</td>
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<td>-</td>
</tr>
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<td>129.8</td>
<td>4.5</td>
<td>1.6</td>
<td>65</td>
<td>-</td>
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<tr>
<td>NC-BC40</td>
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<td>129.8</td>
<td>4.5</td>
<td>1.6</td>
<td>-</td>
<td>37.5</td>
</tr>
<tr>
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<td>129.8</td>
<td>4.5</td>
<td>1.6</td>
<td>-</td>
<td>62.5</td>
</tr>
</tbody>
</table>

In sub-indexes, P and C indicate CEM I (Portland) and CEM II type cements, respectively. Other indexes represent the percentage of FA ratio.

---

**Cement.** Two types of cement were used in this study. One of them is CEM I 42.5 R type Portland Cement. This cement having the strength class of 42.5 is produced by CIMSA Inc. Co. Portland cement is the most commonly used cement for a wide range of applications that cover dry-lean mixes, general-purpose ready-mixes, and even high strength pre-cast and pre-stressed concretes. Another one is CEM II/A-L 42.5 (CIUMSA Super Bims) type Portland Calcareous Cement. This cement type is designed and produced also by CIUMSA Inc. Co. for especially Bims manufacturer. It is a building material with high heat and noise isolation performance, fire and earthquake resistant, light, economic, healthy and environment friendly properties and it is used in the building interior and exterior walls as an alternative to brick and gas concrete [35]. These cements are manufactured to comply with the requirements TS EN 197-1 standard [36] and CE marked under the European Union system of conformity evaluation which provides independent third party certification of product conformity. The initial and the final setting time were determined as 210 and 265 minutes for CEM I and 510 and 550 minutes for CEM II cements. Compacted dry UWs of these cements were found to be $\gamma_C = 1.35$ and $\gamma_{CI} = 1.40$ g/cm$^3$, respectively.

**Method.** This study consists of two experimental steps. In the first phase, according to mixing design, only pumice-based BC40 and BC80 (Abbreviations used in Turkey for Bims Concrete types. 28-day compressive strength values of these concrete types are 4 MPa (40 kgf/cm$^2$) and 8 MPa (80 kgf/cm$^2$), respectively) samples were obtained. These samples are the base samples of this study. Mixing calculations were used to obtain samples in accordance with TS 3234 Bims concrete standards [34] that were used in Bims block production. CEM I and CEM II types of cements were used as binders. Obtained parameters from these samples became the base for the second phase. Samples were produced in size of 40x40x160 mm. Sample ratios were summarized in Table 2.

Since the granulometric distribution of the pumice brought to the laboratory was not in conformity with TS 3234 [34], the granulometric distribution of the pumice to be used to produce samples was made to conform to the standard by sieve analysis and it was given in Figure 3. The mixture calculation was made with pumice as shown in Figure 3. Since the sample mixture calculation was made on the weight basis, it was taken into account in this study. In the mixture calculation, the amount of mixture required for 1 m$^3$ molded and compressed samples was calculated. By using linear proportion for mixing calculation of 1 m$^3$ sample, the sample weights were determined in 40x40x160 mm mold and the amount of material required for 1 sample production was given in Table 2.

As stated in the introduction part, pumice has high water absorption capacity. Therefore, for Bims block production in damped materials in 3% ratio, W/C ratio recommended in TS 3234 [34] is about 1.10 for BC40 and 1.15 for BC80. In this study, calculations were made within this ratio. However, since the sample contains too much fine material in its production, the wetted surface area increases. In the study, the W/C ratio was not sufficient due to the pumice’s inherent effect and the excess mixture.
When ratios were used to displace the used pumice. When way as in the first phase. In sample production, fine produced in the second phase was made in the same Bims block production. The mixture of the samples 3234 Bims concrete standards [34] that were used in obtained samples in accordance with TS properties, and 3 them were stored as proof samples. 3 of them were used to determine their physical properties, 3 them were used to determine their axial compressive strength (ACS), 3 of them were used to determine their mechanical and physical properties and 3 of them were stored as proof samples. In the second phase, the FA addeditves samples with pumice were produced. Pumice and FA were selected in 0.5-4 mm and 0-0.5 mm sieving ranges, respectively. In all BC40 and BC80 samples that were produced, pumice and FA are used as coarse and fine materials, respectively. Mixing calculations were used to obtain samples in accordance with TS EN 196-1 [37]. Samples produced in both phases were kept in molds and placed with the help of vibration. 9 items were produced from each sample. Samples were kept in molds for 24 h after they were placed. These samples were taken out from the molds and water cure in 23±2 °C temperature was applied. 7 and 28-day ACS, UW, porosity and WAP of them were summarized in Table 4. UWs of the samples are in oven dried condition.

**RESULTS**

Experimental studies were done on the samples that were produced from both phases. Samples that were produced in the first phase processed in the same conditions and 7-day and 28-day ACS, UW, porosity and WAP of them were summarized in Table 4. UWs of the samples are in oven dried condition.

![Table 3: Sample ratios of the second phase](image)

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>FA by weight (g)</th>
<th>Pumice by weight (g)</th>
<th>Cement by weight (g)</th>
<th>Water (g)</th>
<th>W/C Ratio</th>
<th>Sample number</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>82</td>
<td>2.19</td>
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<td>37.5</td>
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<td>--</td>
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<td>1.31</td>
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<tr>
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<td>129.8</td>
<td>--</td>
<td>62.5</td>
<td>1.38</td>
</tr>
</tbody>
</table>

---

* In sub-indexes, P and C indicate CEM I (Portland) and CEM II cements, 4 and 8 indicate BC40 and BC80, respectively. Other indexes represent the percentage of FA ratio.

** The values in this table are for only one sample.
TABLE 4  
ACS, UW, porosity and WAP values of the samples considering FA mixing ratios

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>ACS for CEM I (MPa)</th>
<th>ACS for CEM II (MPa)</th>
<th>UW (g/cm³)</th>
<th>Porosity (%)</th>
<th>WAP (%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>7-day</td>
<td>28-day</td>
<td>7-day</td>
<td>28-day</td>
<td></td>
</tr>
<tr>
<td>NP-BC40</td>
<td>3.1</td>
<td>9.2</td>
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</tr>
<tr>
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<td>-</td>
<td>2.1</td>
<td>5.05</td>
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<td>-</td>
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<td>10.6</td>
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FIGURE 4  
According to FA mixing ratio, the changes of ACS values of the samples with CEM I for BC40 (4 MPa) and BC80 (8 MPa)

FIGURE 5  
According to FA mixing ratio, the changes of ACS values of the samples with CEM II for BC40 (4 MPa) and BC80 (8 MPa)

For strength tests, samples were first tested by loading at the required load speed limits in accordance with the procedures specified in TS EN 772-1 [38], and the ACS of the relevant group was found by taking the arithmetic mean of the obtained values. The ACS values obtained from this study were given in Table 4 and plotted in Figure 4 and 5 according to the type of cement used.

According to TS 3234 standard [34], for BC40, ACS tests were conducted on the samples with which mixing designs were made with CEM I cement with the addition of FA as fine material. Although significant pressure losses were observed in the samples of FA additive, 100% FA additive samples provided the values of the target ACS values. According to TS 3234 standard [34], for BC80, although FA additive leads to significant pressure losses in the samples with which mixing designs were made with CEM I cement, target ACS value was provided.
According to the same standard [34], for BC40, the ACS tests which were applied to FA additive were carried out on the samples obtained by CEM II cement mixing design. Based on the obtained data, the values under the target ACS were observed in the FA additive samples. On the other hand, for BC80, ACS losses were seen in FA additive samples obtained by CEM II cement mixing design.

The UWs of the samples in Table 4 that were changed according to the ratio of FA additive was shown in Figure 6. In this figure, the effects of different mixing ratios on samples were shown. The UWs of the samples were determined according to TS EN 772-13 [39]. For this, dry UWs of the samples were determined first. UWs were calculated by taking the arithmetic mean of these 9 samples. As can be seen in Figure 6, samples with 100% pumice additives that were produced by CEM I and CEM II cements in BC40 and BC80 lightweight concrete classes had the lowest UWs. In the samples produced by Isken FA additive in displacement with pumice, as the proportion of fine material increased in mixing samples UWs increased. The reason for this was that the UW of the FA was more than the pumice. The
proportion of FA fine material was increased linearly in samples produced with each different FA mixture. The increase in UWs of the obtained samples was also considered to be close to the linear. Each sample was in the lightweight building class, although the UWs varied.

The calculated value of WAP ratio of the produced sample was also evaluated as the apparent porosity of the material and the percentages of the porosities were determined according to TS EN 772-4 [40]. The porosity of the samples in Table 4 plotted into graphics and given in Figure 7. In this figure, the porosities of the samples produced with CEM I, CEM II and fine material (İskên FA) according to the BC40 and BC80 lightweight concrete class did not change very much and the results were close to each other. However, it can be said that the poarity of the samples produced with pumice is higher. This is due to the fact that mixed samples containing FA are very fine and that the pumice fills the pores. However, the porosity of the samples produced with CEM II according to BC40, and the samples with 25% and 50% FA additives are different from the other samples.

The WAPs of the samples were found to be in accordance with TS 771-1 [41]. They are given in Table 4 and plotted in Figure 8. They were the lowest in samples produced with CEM I and CEM II cement in 100% pumice addition according to BC40 and BC80 lightweight concrete classes. Despite the fact that the pumice had higher water absorption capacity than the FA, the result was reverse. A complex relationship was formed in the WAP of FA-additive samples. It is difficult to interpret these results according to cement quantities and FA ratios.

Depending on the FA ratio, measurements made on the samples indicated a shrinkage tendency at negligible level (ranging from 0.01% to 0.3%). Since there is a very high value (0.23 W/mK) in TS, no study could be done to improve the thermal conductivity value. In this study, no calculation was done for cohesion.

DISCUSSION AND CONCLUSION

In this study, possibility of using FA that is solid waste obtained from İSKEN Inc. Co. in cemented pumice-based lightweight material production was investigated. Following results were reached from experimental findings:

1. Materials passed from 4 mm sieves were used in the production of pumice based lightweight wall material complied with BC40 and BC80. CEM I and CEM II cements were used as binder in both mixing. Durable construction material complied with the TS were produced from each mixing ratios.

2. No deformation and cracks in the obtained samples were observed.

3. 28-day maximum ACS values are obtained as 9.2 MPa and 5.05 MPa for CEM I and CEM II (to BC40), respectively, 11.7 and 10.6 MPa for CEM I and CEM II (to BC80), respectively.

4. 28-day maximum ACS values were obtained as 5.2, 4.8, 4.6, 4.15 MPa and 3.45, 3.3, 3.05, 3.0 MPa for the samples of CEM I+25-50-75-100%FA+pumice for BC40 and CEM II+25-50-75-100%FA+pumice for BC40, respectively. It was seen that the samples complied with BC40 could be obtained if FA additive samples were produced with CEM I cement. This leads to the conclusion that FA is suitable in construction technology when it is used with CEM I. In this study, CEM II cement was not thought to give the same conclusion, but it could be used for constructive lightweight material.

5. 28-day maximum ACS values were obtained as 8.7, 8.4, 8.1, 7.4 MPa and 6.8, 5.7, 5.5, 4.9 MPa for CEM I+25-50-75-100%FA+pumice samples (to BC80) and CEM II+25-50-75-100%FA+pumice samples (to BC80), respectively. It was seen that the samples complied with BC80 could be obtained if FA additive samples were produced with CEM I cement, but the samples complied with BC80 could not be obtained with CEM II cement. It was concluded that FA is suitable in construction technology and lightweight material when it is used with CEM I cement.

6. UWs of the samples were 0.65 g/cm³ for pumice+CEM I (to BC40), 0.64 g/cm³ for pumice+CEM II (to BC40), 0.85 g/cm³ for pumice+CEM I (to BC80) and 0.84 g/cm³ for pumice+CEM II (to BC80), respectively.

7. UWs of additive samples were 0.90, 0.92, 0.95 and 0.97 g/cm³ for CEM I+25-50-75-100%FA+pumice (to BC40) and 0.91, 0.94, 1.07 and 1.16 for CEM II+25-50-75-100%FA+pumice (to BC40). According to the results, samples can be assessed in lightweight building material status.

8. UWs of additive samples were 0.98, 1.00, 1.05 and 1.18 g/cm³ for CEM I+25-50-75-100%FA+pumice (to BC80) and 0.94, 0.96, 1.02 and 1.09 g/cm³ for CEM II+25-50-75-100%FA+pumice (to BC80). They were complied with BC80; compare to BC40, a negligible increase was seen. According to the results, samples can be assessed in lightweight building material status.

9. In the study, no obvious differences were seen between porosity and WAP for each mixture obtained by each sample. However, necessary attention and measures should be taken when they use in wet places in the occurrence of frost.

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ABSTRACT

CA models are systems consisting of blisters-tesserae which interact in a simple manner even though they exhibit a complicated behavior. These models can produce very complex structures and can be used for exploration of an expanded spectrum of fundamental dynamics and development issues. It is an approach for modeling of open, complex and self-organized systems and emphasizes the ways in which local decisions can lead to the creation of global standards. A CA model is a discrete dynamic system in which space is divided into regular territorial cells and time progresses in discrete steps. Each cell in this system receives a state. The state of each cell is updated in accordance with local rules, for example, the state of a cell of a given moment depends on its situation and the situation of adjacent cells in the previous time step. In this paper, we used the thematic maps of 1996 and 2007 for the island of Skiathos for making the forecast for 2020. From the prediction, it was concluded that in 2020 in the island of Skiathos there would be an increase of urban areas and a reduction of the crop areas, the grasslands and the forest areas. These results would be useful for the spatial and environmental Planning of the island.

KEYWORDS:
Cellular Automata Model, Skiathos, thematic maps, forecast.

INTRODUCTION

The science of CA is not new, it was first proposed by the physicist Stanislaw Marcin Ulam in the 1940s and used by John Von Neumann to investigate the self-reproduced systems.

The application of CA in geographic modeling was first proposed by Tobler, and first-applied in a residential structure by Batty and Yeh & Li [1, 9, 15]. But the Pioneers in CA urban expansion were Clarke et al., Couclelis and Clarke & Gaydos [3, 4, 5].

The cellular automata are systems consisting of cells which interact with each other in a simple manner and exhibit a total of complex behavior. These models can lay complicated structures and are used to explore a wide range of fundamental theoretical dynamics and development issues [12]. The CA is a modeling approach of open, complex, self-organized systems that emphasize the ways in which local decisions are an incentive for the development of global standards [14].

A CA is a self-operated mechanism that processes the information, so with logic functions and carries out the next step after applying the data, which is received from the outside surroundings, under the guidance of the orders under which planned [6]. In a CA model, the space is divided into normal cells. The state of the cell is determined from the cell itself and the state of the neighboring cells is determined by temporally previous steps through a series of local and defined transformation rules. The state of all cells is updated simultaneously. The overall behavior of the system is determined by the combined effects of all local transformation rules [10, 7].

A CA model is composed of five essential characteristics. These are:

i. The grid is the area where a CA is evolving with time. In the first CA grid was dimensional, so it served mainly linear phenomena, such as the modeling of congestion [2]. In the modeling of urban expansion and land use grids CA is usually two-dimensional. However, there are grids and omega-dimensional but they mainly serve other applications.

ii. The state, which determines the characteristics of the system. Each cell can take only one state at any time through a series of statements. In CA-based urban models, the state of the cells may represent the types of land use, whether the use is urban or rural, or something else. Still can represent other features of an urban area such as social population groups (immigrants or natives) [8].

iii. The concept of the neighborhood, which has to do with a set of cells that interact with each other after a question. In a two-dimensional space, there are two basic types of proximity. The first is the proximity of four cells which has made the von Neuman Neighborhood and is from north, south, east and west neighbors of a cell in a question and the second is the neighborhood MOORE eight cells consisting of neighbors specified by von Neuman with the additional North-West, North-east and South-west direction.
iv. The transformation rules determine the behavior of their evolution in time and decide on the future conditions of the cells based on a set of defined rules. In a strict CA, these transformation rules formulated proposals IF, THEN, ELSE, in a neighborhood standard to easily enable them to assess their results. In this sense the transformation rules can replace traditional mathematical functions models operated by procedures based on rules [1].

v. The time, which determines the temporal dimension of a CA. The state of all cells is updated simultaneously in all repetitions over time. However, this limitation can be eliminated if the CA model functioned in different time speed for different cells [11].

**METHODOLOGY**

**Study area.** The island of Skiathos belongs to the territorial unity of the northern Sporades and the capital is the city of Skiathos. It is 2.4 miles from the coast of southern Pelion and 4 miles from Skopelos. The area is about 49.89 Km² while the length is 12 Km and the width is 9 Km. Within the administrative boundaries of Skiathos island the smaller islands of Tsougria, Small Tsougrias, Repio, Aspronisi, Maragos and Arcos are included. The population of the island, in 2011, was 6,088 and the density was 122 people/km².

A large part of the island is covered by woodland and the rest of the island is dominated by olive trees. Around the island there are about seventy (70) beaches. The town of Skiathos is connected with the islands of Skopelos and Alonissos, Volos, Ag. Konstantinos and Evia, via the trade - Passenger port. It also has air connection through the National Airport which is located in the northeastern part of the island. Administratively the Municipality of Skiathos is part of the Magnesia Region of Thessaly.

**Method.** For the implementation of the model the following steps have been made:

i. Data input
ii. Analysis of land use change
iii. Model Development
iv. Simulation
v. Provision

(1) **Data input.** The data entered was: land use of 1945 and 1996, the distance from roads, the distance from the coastline and the distance from the main road. Due to the high correlation between distance from the main road and the distance from the coastline, the distance from the main road was not involved in the model.

(2) **Analysis of land use change.** The land use changes were determined by comparing the two thematic maps of 1945 and 1996.

(3) **Model Development.** We used artificial neural networks to create the dynamic transition maps which would be introduced in the model of cellular automata.

Five parameters were used in neural networks:

- **Neighborhood:** size 2 (ie. 5x5 = 25 cells)
- **Learning rate, momentum and max iterations number (0.1, 0.05, 1000).** These parameters define the neural network training process. Large learning-rate and momentum leads to rapid learning. Small learning-rate and momentum provides slow but more stable learning. The stability has to do with the large variations in the graph.
- **Hidden levels:** we defined one hidden layer with 10 nodes - neurons.

(4) **Simulation.** The simulation was achieved by cellular automata. The cellular automata take account of the original map, the factors affecting land use changes and the model developed in the previous paragraph. The cellular automata operate as follows:

- The simulator takes the transition probabilities and calculates the number of cells that have changed.
- The simulator calls the cellular automata model and adds the original map land use and variables.
- The simulator scans the cells and calculates the transition probabilities in each class.
- The simulator creates a mesh level "certainty": each cell defines the difference between the two largest probabilities of lattice transition levels.
- The simulator creates a mesh with the most probable transitions: the cells are transition classes with the highest probability of transition. This mesh level auxiliary level to the next step.
- For each class of transition, the simulator is looking to mesh with the most potential transitions the number of cells with the greatest change.

Following the above procedure the cellular automata give the result of the simulation for a repetition (iteration). Applying and second iteration, the result of the simulation will be used as initial land use map. In each iteration, therefore, the previous simulation is used as initial state land use.

(5) **Provision.** Using the model developed above, we created a forecast for 2020. The prediction was performed using the structure of the above model in which to investigate land use change maps were used in 1945 and 2007.

**RESULTS**

The changes of land uses are very important and can be observed in the Figure 1, 2, 3 and 4. In the next chart we are comparing land uses from the last year that there were data (2007) with the land uses that result from the model.
FIGURE 1
Land uses area

FIGURE 2
Land uses in Skiathos Island for the year 2007

FIGURE 3
Land uses in Skiathos Island – Simulation of the model
FIGURE 4
Land uses in Skiathos Island – Prediction 2020

From the Figure 1, an important increase in urban areas and a reduction in forests can be observed. As it can be concluded, the burned area was not taken into account. These results are presented more analytically in the next thematic maps.

The result of the simulation (2 replications) was compared with the actual map of 2007 and gave 93.88\% accuracy rate with Kappa 0.901.

Finally, in the thematic map below, we can see the land uses prediction for the year 2020.

Differences in land uses between the thematic maps of simulation and the prediction were very small. This means that we achieved great precession.

CONCLUSIONS

In the application of the model there are some limitations. For example, in the model we could not insert economic or demographic data but only spatial data. So in the prediction for 2020, we could not calculate the effect of the economic crisis.

The CA model is a very useful tool in order to make predictions. Using the simulation we can see the model procession. As we can see from our results, the application in our model is very good. The procession of the model is improving with the use of indicators. In our case study, we can note the increase of urban areas due to the increase of population and the number of tourists. On the other hand, crop areas, grassland and forest areas were reduced. As we noticed and before the human factor like burn, doesn’t take into consideration in the prediction. The results of the paper can be used for the spatial planning of the island of Skiathos.

The results of the research can be used in the development of a suitable master and spatial plan. More specifically, restrictions could be recommended to avoid environmental damages and to protect the less developed areas from a rapid and uncontrolled development.

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INVESTIGATION OF ENGINE PERFORMANCE AND EMISSIONS OF AN SI ENGINE USING BIOGAS-HYDROGEN MIXTURES

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ABSTRACT

Currently, fossil fuels such as petroleum, natural gas and coal meet most of the world's energy demand. However, combustion products of these fossil fuels, such as carbon monoxide (CO), carbon dioxide (CO2), oxides of sulfur (SOx), and oxides of nitrogen (NOx), hydrocarbon (HC), toxic metals and ashes cause many environmental problems and posing hazardous effect for the world. The limited fossil fuel resources and toxic emissions exhausted from internal combustion (IC) engines have pushed research to focus on alternative fuels. In this study, combustion and emission performance characteristics of an IC engine were experimentally investigated for different mixtures comprising of 70-80-100% biogas (65% CH4 and 35% CO2) and 30-20-0% H2 by volumetric. The fuel mixtures consisted of 15% H2 and 85% biogas content of 65% CH4+35% CO2, 60% CH4+40% CO2 and 55% CH4+45% CO2, were also investigated to determine its effect on performance and emissions. Experimental studies were carried out in Ford 1.8 L, four strokes, four cylinders, water cooled SI engine. Experimental studies were performed at different engine speeds (1500, 2000, 2500 and 3000 rpm) for different excess air ratios in the range of 1.0 to 1.4 with 0.1 increments. For all mixtures, it has been found that CO and CO2 emissions and maximum pressure decrease with the increase of excess air ratios. The highest torque and power values were obtained at 15% H2-85% biogas content of 65% CH4+35% CO2 mixtures. It can be concluded that the addition of biogas could result in an improvement in the combustion parameters.

KEYWORDS:

INTRODUCTION

Fossil fuels supply nearly 80% of world energy demand [1]. Burning of fossil fuels has been always associated with nitrogen oxides (NOx), sulfur oxides (SOx), carbon monoxide (CO) and unburned hydrocarbons (UHC). These emissions have some negative environmental impacts that are both local and global. Moreover, in the recent years, air quality has become a severe problem in many countries, and the interest to replace fossil fuels with renewable and sustainable energy fuels has increased for reducing CO2 and other harmful emissions. This has also forced researcher studying on internal combustion engines to reduce emissions. In this regard, a way for improvement in emission emitted from internal combustion engines is alternative fuels use such as biogas and hydrogen. Biogas is a good renewable gaseous fuel, and is produced by the anaerobic digestion of cow dung, non-edible seed cakes, animal waste, food waste, agricultural waste, municipal waste, sewage sludge, etc. [2,3]. Biogas consists primarily of methane (CH4) and carbon dioxide (CO2) and may have small amounts of hydrogen sulfide (H2S), moisture and siloxanes. Although biogas is an alternative fuel to fossil based fuels for IC engines, it has a drawback in flame stability due to a high level of CO2 in its content. This means that a part of the combustion heat is absorbed by CO2 which has a high heating value, which causes to reduce flame speed propagation in a cylinder. Huang et al. [4] conducted experiments in a single cylinder SI engine using simulated biogas. They found that the presence of CO2 in biogas can reduce NOx emissions; nevertheless, this results in lower cylinder pressures. Engine power and brake thermal efficiency were reduced as compared to other gaseous fuels and the level of unburned HC emission also increased. They have reported that increasing the compression ratio is an effective way to improve the performance of biogas fueled engine when CO2 is present. Ceper et al. [5] numerically investigation on biogas fueled spark ignition engine. They studied at 8.5, 10.0, 11.5 compression ratio and constant nominal speed of 1500 rpm. They concluded that at biogas combustion, higher compression ratio should be preferred. Jung and et al. [6] experimentally studied on performance and NOx emissions of a biogas-fueled turbocharged internal combustion engine. They clarified that the brake power, brake thermal efficiency, and NOx emissions increased as the
The experiments were performed on a Ford 105 hp, 1796cc, four cylinders, four-stroke, and spark-ignition (SI) gasoline engine. The engine specification is given in Table 1. The engine was linked to a Cussons-P8601 brand hydrokinetic dynamometer to measure brake power and torque (Fig. 1). The in-cylinder pressure values were recorded using AVL type 8QP500C water cooled piezoelectric pressure transducer. A Sun MGA 1500 type exhaust gas analyzer was used to measure CO, NO, CO₂, HC, and λ values. During the tests, the temperature of cooling water was maintained at 80 °C. The ignition timing is also 19°BTDC for all cases.

The experiments were carried out at different excess air ratios. Significant reductions in hydrocarbon levels were seen. There was no increase in nitric oxide emissions due to the use of retarded ignition timing and the presence of carbon dioxide. On the whole 10% hydrogen addition was found to be the most suitable. Rakopoulos and Michos [14] have experimentally studied closed cycle simulation code of an SI engine operating on biogas–hydrogen mixtures of variable composition is used for application of second-law analysis. The main focus is on the demonstration of the spatial distribution of combustion irreversibility’s inside the burned gas during the combustion process for the various hydrogen fractions examined. This is revealed by the use of a multi-zone thermodynamic model, in combination with a quasi-dimensional combustion model. Ceper et al. [15] experimentally analyzed on cylinder pressure for H₂/CH₄ mixtures at different loads. They studied on a four-stroke spark-ignition engine operating on natural gas-hydrogen blends of 0, 10, 20 and 30% at full load and 65% load for different excess air ratios. They stated that while the excess air ratio increases, CO and CO₂ emission values decrease. Park et al. [16] investigated the effect of EGR on the combustion and emissions characteristics of the biogas and hydrogen mixture. They concluded that repositioning the discharge location improved the thermal efficiency, and the maximum tolerable EGR rate increased because of spatial advantages such as relatively short flame propagation lengths and high electrode temperatures.

This paper focuses on determining the effect of the change in the content of biogas and hydrogen addition rate on the engine’s performance and emissions at different excess air ratio. Tests were conducted on a four cylinder spark ignition engine at wide open throttle (WOT). During the test, in cylinder pressure traces, emissions, the output power of the engine were recorded for each mixture. The combustion characteristics were also analyzed with the heat release rates obtained from the first principle of thermodynamics.

### Experimental Setup and Test Procedure

The experiments were performed on a Ford 105 hp, 1796cc, four cylinders, four-stroke, and spark-ignition (SI) gasoline engine. The engine specification is given in Table 1. The engine was linked to a Cussons-P8601 brand hydrokinetic dynamometer to measure brake power and torque (Fig. 1). The in-cylinder pressure values were recorded using AVL type 8QP500C water cooled piezoelectric pressure transducer. A Sun MGA 1500 type exhaust gas analyzer was used to measure CO, NO, CO₂, HC, and λ values. During the tests, the temperature of cooling water was maintained at 80 °C. The ignition timing is also 19°BTDC for all cases.

The experiments were carried out at different excess air ratios.
engine speeds in the range of 1500 to 3000 rpm with 500 rpm increment for each excess air ratio and biogas hydrogen blend. The brake thermal efficiency value was calculated utilizing brake power measured from the dynamometer and the fuel consumption using the mass flow meter, as follows:

\[ \eta_{th} = \frac{P_b}{m_f H_u} \]  

where, \( P_b \) is brake power, \( H_u \) is low heating value of a fuel blend, and \( m_f \) is mass flow rate.

Heat release rate analyses for combustion characteristics were also calculated from the cylinder pressure values using the first law of thermodynamics as follows: The heat release rate was calculated using the first law of thermodynamics as given in [17], as follows:

\[ \frac{dQ}{db} = \gamma \frac{dV}{dt} + \frac{1}{\gamma-1} \frac{dP}{db} \]  

where, \( Q \) is heat release, \( \gamma \) is specific heat ratio \((cp/cv)\), \( \theta \) is the crank angle, \( P \) is cylinder pressure and \( V \) is cylinder volume.

![FIGURE 1](image)

**Experimental setup**

1-Engine Chassis, 2- Hydrokinetic Dynamometer, 3-Engine, 4- Engine Cooling Unit, 5- Air Tank, 6- Control Unit, 7-Main Fuel Tank, 8-Regulator, 9- Fuel Select Key, 10-Fuel Tank 11-Mass Flow Meter, 12- Exhaust Gas Analyzer

### TABLE 1

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### RESULTS AND DISCUSSION

**Performance and emission parameters.**

Fig. 2a shows the brake power values versus the EAR for different hydrogen ratio (0, 20, and 30%), constant biogas mixture (65% CH₄ + 35% CO₂) and 2000 rpm. The maximum values of brake power have been obtained at 1.15 EAR value and 20% H₂ and 80% biogas. When the hydrogen fuel is added into biogas, engine power values increase.

Fig. 2b shows the variation of brake power with different excess air ratios and CO₂ percentages in biogas (45% to 40% and 35%). It can be seen that there is an increase in the brake power output as expected with a reduction in the CO₂ concentration at 2500 and 3000 rpm. The maximum power values were obtained as approximately 15.2, 20.8, 26.4 and 27.3 kW at 65% CH₄+35% CO₂ mixture. Brake power peaks with slightly leaner mixtures than the stoichiometric mixtures.

![FIGURE 2A](image)

**FIGURE 2A**

Variation of power values versus EAR at 2000 rpm for different hydrogen ratio.

![FIGURE 3](image)

**FIGURE 3**

Variation of brake thermal efficiency versus EAR for different hydrogen ratio (0, 20 and 30%), constant biogas mixture (65% CH₄ + 35% CO₂) and 2000 rpm. Increasing EAR values, brake thermal efficiency values are almost constant. However, the maximum values were obtained at 20% H₂. Addition of small amount hydrogen improved the combustion. In the case of higher than 20% hydrogen, volumetric efficiency decreased. Therefore, brake thermal efficiency values decreased.

Fig. 3b shows the brake thermal efficiency (BTE) values versus the EAR for different hydrogen ratio (0, 20 and 30%), constant biogas mixture (65% CH₄ + 35% CO₂) and 2000 rpm. Increasing EAR values, brake thermal efficiency values are almost constant. However, the maximum values were obtained at 20% H₂. Addition of small amount hydrogen improved the combustion. In the case of higher than 20% hydrogen, volumetric efficiency decreased. Therefore, brake thermal efficiency values decreased.

Fig. 3b shows the brake thermal efficiency (BTE) values versus the EAR for different engine speeds and biogas mixtures. When CO₂ fraction in biogas mixtures increased, brake thermal efficiency values decreased. This is due to the fact that more amounts of fuel are needed to generate same power output with the increase in a CO₂ fraction. The peak brake thermal efficiency values were obtained at 65% CH₄+35% CO₂ mixtures at all engine speed. The maximum brake thermal efficiency was obtained nearly as 13.5, 15, 18 and 15% at 1500, 2000, 2500 and 3000 rpm respectively. With the addition of hydrogen to biogas, the brake thermal efficiency values increased compared to pure biogas. For 2000 rpm, brake thermal efficiency was maximum as 15% and 12.5% between 1.0 and 1.1 EAR at 15% H₂+85% biogas and 65% CH₄+35% CO₂ mixtures respectively.
Variation of power values versus EAR at 1500, 2000, 2500 and 3000 rpm for different contents of biogas.

The BTE values versus the EAR for different hydrogen ratio (0, 20 and 30% H₂)

Fig. 4 shows the CO₂ emission values versus excess air ratio at different biogas and hydrogen mixtures and different engine speeds. It was noticed that with the increase of CO₂ values in the mixture, CO₂% emissions increase. While the methane content of biogas decreases the carbon-dioxide content increases. This indicates the necessity of adding hydrogen with high energy content. It can also be seen that CO₂ emission gets its peak value at the stoichiometric mixture. Thus, the increase in the excess air ratio decreases the CO₂ emissions due to proper mixture dilution. At the lean mixture combustion, the bulk quenching leads to a sharp decrease in CO₂. When the hydrogen fraction increases, CO₂ values increase. In this figure, it can be seen that the combustion characteristic was improved.
FIGURE 3B
BTE values versus EAR at 1500, 2000, 2500 and 3000 rpm for different biogas ratio

FIGURE 4
CO₂ emission values versus excess air ratio for different biogas and hydrogen compositions
**FIGURE 5**

Variation of CO emission versus EAR at 2000 and 3000 rpm for different biogas ratio

**FIGURE 6**

Cylinder pressure values versus crank angle for different biogas compositions and excess air ratios at 2000 rpm.
Fig. 5 illustrates the CO emission plotted against the excess air ratio at different engine speed and different biogas mixtures. CO emissions slightly decreased with the increase in EAR. At excess air ratios larger than 1.0, CO remains at a very low level regardless of the mixture concentration and engine speed. It was also observed that the CO concentration of 65% CH₄+35% CO₂ mixture is comparatively high near to stoichiometric excess air ratio level. The insufficient oxygen is responsible for this increasing trend. While excess air ratio values were increased, CO values have exponentially decreased. When EAR values have less than 1.2, CO values have high values. The minimum values of CO were obtained less than 1.2 of EAR.

Combustion parameters. Fig. 6 shows the pressure values versus crank angle at different biogas mixtures and different excess air ratios (1.0, 1.1, 1.2 and 1.3) at 15% H₂+85% Biogas and 2000 rpm. As seen in this figure, the peak pressure values decrease with increased EAR. The peak pressure values are obtained nearly between 10-15° ATDC and 36, 37 and 38 bar for 45, 40 and 35% CO₂ mixtures at EAR=1.0 respectively. Generally, the engine can reach the highest efficiency when maximum pressure occurs at 10-15° ATDC. The cylinder peak pressure values are gradually decreasing with the increasing of carbon dioxide into the mixture. Heat release rates with a lean mixture and also with nearly stoichiometric mixture are seen in Fig. 6. The heat released rises with reduced CO₂ concentrations in the biogas at 2000 rpm.

CONCLUSIONS

Experimental studies on the performance, combustion and emission characteristics of different H₂+ Biogas mixtures were investigated in an SI engine. The main results are summarized as follows.

- The maximum power value was obtained 65% CH₄+35% CO₂ mixtures at 3000 rpm.
- The brake thermal efficiency (BTE) increase with the addition of hydrogen. With the increase of CO₂ amount, BTE is decreased. Power and thermal efficiency reduced for leaner mixtures.
- The maximum power and BTE was obtained with 20% H₂ + 80% Biogas.
- The emissions of CO decreased with the increasing engine speed. Especially, when running with lean fuel mixtures, the CO emissions were low and did not change with the CO₂ fraction in the biogas.
- CO and CO₂ emissions values decrease with increasing H₂ percentage.
- With the increasing of EAR, cylinder pressure values decreased at all engine speed and biogas mixtures. The heat released rises with the reduction in CO₂ concentrations of biogas content at 2000 rpm.
- In the case of small amount hydrogen addition up to 20% into biogas, improvements in the combustion parameters were determined.

ABBREVIATIONS

- ATDC  after top dead center
- BTDC  before top dead center
- CAI  controlled auto ignition
- CH₄  methane
- CI  compressed ignition
- CO  carbon monoxide
- CO₂  carbon dioxide
- EGR  exhaust gas recirculation
- HRR  heat release rate
- Hₘ  low heating value of a fuel blend
- NOₓ  nitrogen oxide
- Pₚ  brake power
- SI  spark ignition
- SOₕ  sulfur oxides
- UHC  unburned hydrocarbons
- mᵢ  mass follow rate
- λ  excess air ratio
- θ  crank angle
- γ  specific heats ratio
- ηₜ  thermal efficiency

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engine, Fuel, 77 (15), 1793–01.
ABSTRACT

One of the most important linear features on the earth’s surface is coastline, thus the detection and monitoring of coastline is critical. The study of coastal system processes and coastal zone environmental management requires the information about coastlines and their changes. In this study, a methodology that extracts coastline efficiently by processing high-resolution orthophotos derived by UAV is presented. The photogrammetric UAV-based remote sensing approach reveals high-resolution digital surface models of coast. These models were derived from accurate and dense 3D point clouds, which are used for the 3D representation of the coast and can be used for calculating the erosion events of the study area. The methodology examines the capabilities of the integration of UAV data acquisition, GIS, remote sensing, and 3D visualization. Method applied in the Eressos beach, a very touristic sandy beach with large face, on Lesvos Island, Greece. Eressos beach is threatened by erosion which is clearly shown in the results. In addition, several features representing previous sea states were successfully determined in orthophoto map. The difference between the two acquisitions revealed specific areas with erosion and sand movement. Finally, the composition of 3D representation and the orthophoto map exposed vectors representing new beach characteristics e.g. erosion crests, berm zones and sand dunes. Vectors accuracy depends on the beach complexity. In conclusion, UAV’s data reveal such information in spatial resolution which permits the study of coast changes with extreme confident. Applications include coast management, port installations and coastal energy projects.

KEYWORDS:
UAV data acquisition; coastal management; aerial photo; Structure from Motion; image processing; 3D visualization.

INTRODUCTION

Coastal management requires knowledge on large amount of data on a certain buffer zone of coastline. In relative small scales, coastline detection is relative easy when satellite images with infrared band are used. However, once there is a need for a detailed coastline map the need on specific line describing the relative sea status is extremely important. In addition, when there is beach erosion or extreme waves/waves in an economically wealthy area the risk assessment on the beach erosion is getting more than important [1].

Coastal erosion requires rapid, correct and up-to-date information on small movements. Remote sensing is a key technology in such problems and up to now is one of the most effective tool to detect and monitor coastlines. Scope of the present paper is to find the differences in the coastline of a very touristic beach in Lesvos island, Greece during a certain period of 6 months. Coastline detection is based in very high resolution orthophoto maps coming from the use of UAV with a normal RGB camera.

Satellites have an increased role in such measurements due to improved spatial and spectral resolution. However, satellite images are not able to monitor movements in a small scale due to inherit limitations. On the contrary, unmanned aerial vehicles (UAVs), are able to provide extremely high resolution images at low cost but in a limited area [2]. The use of drones the last years have exploded because of their agility and quality to image an area with high end products. They deliver digital images with spatial (1-5cm) and temporal resolution superior of satellite imagery, on demand, and most important economically than the high resolution satellite images [3–5].

Coastline is defined as the line that forms the boundary between land and the sea and its detection in very high resolution includes several discontinuities. The exact definition of coastline (or the zone defining the coastline) should be clearly given. The four typical beach zones include the swash zone i.e. the area where the land which is alternately covered and is exposed by wave run-up and the sea waves crack into the beach (wet part in a sandy beach),
beach face i.e. the sloping section that is exposed to the swash of the waves, wrack line i.e. the highest reach of the daily tide and the wave run-up and berm i.e. the almost horizontal dry portion of the coast with usually sand dunes. In the present study, the coastline is detected as the upper limit of the swash zone (or the upper limit of the wet beach area).

MATERIALS AND METHODS

Study area. Lesvos is the third larger Greek island located in the Northeastern part of Hellenic territory (Figure 1). Eressos beach is a large sandy beach of approximately 4km length affected by large north waves. It has a typical profile with swash zone, beach face, and big berm with sand dunes. It is affected by erosion since the southern part is losing its width during the winter north storms. The last decade the southern part has been reduced of more than 10 meters.

UAV System Data Collection. The main surveying device was a UAV «quad-copter» Iris+ for the acquisition of very high-resolution aerial images of the study area and a Canon 130 camera.

The UAV system is a Vertical Take-off and Landing (VTOL) configuration with autonomous capability to take off to land and to do programmed mission using predefined ground control points with specific coordinates (Figure 2). The airborne system consists of the airframe the motors the actuators power system and the motors. Its configuration includes the Pixhawk autopilot system, a GPS and compass, a 3-axis gyroscope, an accelerometer / magnetometer, a barometer and a ground station telemetry radio. The take of payload capacity was 0.4 kg and each flight time was approximately 15 minutes. Also, UAV controlled from a remote control within a 2.4 GHz frequency band.

The Canon ELPH 130 compact camera used as survey camera. It was selected because of the lightweight, manual functions and programming capabilities through open source custom software. The open access Mission Planner v1.25 software used for monitoring the UAV and setup the flight missions [6].

Acquisitions acquired in two time frames, one in the end of spring on 06/05/2015 with very calm sea state and one during winter time on 19/11/2015 after a large storm with high coastal waves. The time to collect a single set of photos was 12 minutes (using one battery for each flight). Additionally, the flights were planned in such a way to cover all the beach face with the decided resolution.
TABLE 1
Workflow of the used methodology.

<table>
<thead>
<tr>
<th>Flight</th>
<th>Ortho GSD (cm/pix)</th>
<th>DSM Resolution (cm/pix)</th>
<th>X RMSE (m)</th>
<th>Y RMSE (m)</th>
<th>Z RMSE (m)</th>
<th>RMSE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eressos</td>
<td>2.34</td>
<td>4.68</td>
<td>0.0408</td>
<td>0.0389</td>
<td>0.00404</td>
<td>0.187</td>
</tr>
</tbody>
</table>

All the targets measured 29.7 cm 42 cm (A3 size) and were designed in a black and white pattern, having circles with a 3-cm radius in each target center. The GCPs error statistics for the Eressos survey mission are summarized in the following Table 1.

The use of 14 GCPs in the Eressos survey had as a result an RMSE of 0.187 (m). The achieved accuracy met the requirements of the authors for creating highly detailed 2D/3D visualizations and for defining coastal variations and dissimilarities in beach profile, which was the main focus of this study.

Methodology. The acquired images were the basis for the coastline detection measurements and 3D modelling of the coastal systems. The workflow of the used methodology is presented in Figure 4. Methodology allows a generation of a very detailed orthophoto, and 3D model of the case study area and coastline visualization in both time frames.

Structure from Motion (SfM) and multi-view stereopsis (MVS) techniques, where used as methods able to produce very detailed 3D geoinformation from UAV captured unstructured aerial images. SfM and MVS algorithms were used to detect image feature points in each image and match them through the total of images captured from the UAV system. These matches produce a sparse point cloud as a basis of the generation of the scene geometry represented as dense point cloud [10–13]. The SfM procedure derivatives consisting of a set of points, which are containing X, Y, Z information additionally with the color information derived from photographs. These SfM outputs lying on an internal arbitrary coordinate system, thus must be transformed to real-world coordinates [10]. Finally, the dense 3D point cloud and the total of images used could be meshed to create i) a 3D mesh of the geometry ii) high-resolution orthophotos, iii) Digital Surface Models (DSM) as well as iv) Digital Terrain Models (DTM).

FIGURE 3
UAV Survey auto mission lines (above) and overlap in-track and cross-track side-lap for image acquisition (bellow).

After the production of the orthophoto maps, coastline was manually digitized in the wet zone e.g. the upper limit of the area of the extreme wave run up of the beach for both cases. Also, a 3D comparison performed using DSM comparison of the created models. Images were analyzed through geographic object based image analysis [7–9] for breach zone identification.
RESULTS AND DISCUSSION

UAV-based remote sensing bridges the gap in scale and resolution between ground observations and imagery acquired from conventional manned aircrafts and satellite sensors. The computer vision SfM and MVS techniques supplement the need for accurate geodata for 2D and 3D analysis. The UAV-SfM derived products that enable change detection and landscape erosion analysis for coastal zones possible in various spatial and temporal scales.

An example of the generated orthophoto is shown in Figure 5. Eressos coast orthophoto with contour lines of 0.5m, DSM of swash zone, wrack lines, and berm zone are clearly shown. The quality of the orthophoto map releases the high degree of detail achieved with the use of UAV-SfM methodology. Not only coastline is very clearly detected but also very small height variations such as small rocks and small benches in the beach are visible over the whole extent of the mapped area. The derived data products enable detailed 2D and 3D analysis for larger areas is possible. The high resolution and precision of the derived orthophoto maps and 3D visualisations cannot be achieved from satellite datasets. Also, the LIDAR high resolution data products as are not yet available for areas such as our study areas. Thus the UAV-based data acquisition provides a valuable alternative for mapping and monitoring of coastal zones detection and erosion as well as other environmental applications [14]. In high resolution orthophoto maps several important beach characteristics are visible in contrary to high resolution satellite images.

Orthophoto maps cannot be processed with the classical remote sensing pixel based classification methodologies e.g. nearest neighbor, for coastline detection because spectral representatives are very similar for the different classes and no infrared band was available. On the contrary manually digitation of the coastline in such resolution considered the most appropriate method.

Coastline detection in orthophoto maps with spatial resolution of some centimeters is much dependent on the beach complexity. In cases with simple structure, i.e. sand beach with large face, the detection of swash zone and beach face can be achieved with high accuracy. However, in complicated cases where the beach is a mixture of composition like shingles with various sizes, dead algae, tree shadows and erosion gaps detection of coastline is becoming difficult. Digital surface models can help in the determination of vectors describing beach characteristics.

From the two DSMs, we created profiles and topographic transects are extracted using the 3D Analyst® ArcGIS extension in the form of profile length/elevation (Figures 6-8). From the orthophotos the position of the coastline is derived, since it is clearly detectable as the line between the sea and the shore. The coastline was digitized manually in ArcGIS. In Figure 9 the subfigure A depicts the two coastlines and their differences along the study area.

The difference between the coastlines obtained on 6th May and 19th of November 2015 reveals significant change detection in the study area (Figures 6-11), where the largest difference of the cost line is close to 6 m. Most of the sand face was removed from the western part of the beach revealing a large rock beneath the sand (Figure 10).

From both surveys two orthophoto maps produced and with the use of a GIS system the maximum and minimum shoreline evolution are calculated. The shoreline evolution profile is depicted in the Figure 8 where the maximum distance between the two shorelines is 5.37 m and the minimum 0.42 m.

The difference between the coastlines obtained on the two surveys reveals the biggest erosions in the western and eastern parts of the study area when in the material deposition in the central part is close to 1 m.

Additionally, for the study of material allocation two transects of the coastline are selected (Figure 9, subfigures B and C). Between the two surveys the wet-dry line retreated, causing a lowering of the beach profile. In Figures 6 and 7 the beach profile for both surveys is depicted and is clear the significant change of the coastal morphology. However, the change of the costal morphology is not clear if it is due to seasonal variation or erosion phenomenon.
CONCLUSIONS

The study area of Eressos beach chosen since it is gradually eroding due to extreme winds and wave conditions. The erosion on these sections of coastlines may not be visible via traditional change detection techniques. In this paper, we used the UAV-SFM technique to generate accurate 3D geo-visualization of the study area to detect and visualize coastal changes over time. As UAVs provide a platform for close-range aerial photography using small sensors can become a useful tool for researchers to spatial and temporal coastal observation and environmental monitoring as well as monitoring erosion in coastal zones. This study applies SFM and MVS techniques, thus combining computer vision algorithms, to imagery acquired from a quad-rotor UAV for the 3D representations. The low UAV flying height and speed improves coastline definition and the used SFM technique can capture complex shapes allowing for the very detailed representation of coastal features such as hollows, small sand dunes as well as swash zone and beach face.

The results indicate that the coastline detection can be very effective using UAVs with extreme confidence. Specific coastline area changed after an extreme wind-wave event for almost 6m. This result is crucial for costal management and the methodology can be routinely used for risk assessment in such touristic places. The georeferenced 3D model and the point cloud derived with accuracy of 0.9-1.9 cm and the orthophoto with 3 cm spatial accuracy from the quadrotor flying at 100 m AGL.
FIGURE 9
Subfigure A depicts the difference between the two timestamps of coastlines. The base orthophoto produced from the 06-05-2015 UAV survey. Subfigures B & C presenting transects 1 & 2 for estimating morphology changes. Subfigure D coastline evolution in the East part of the study area.

FIGURE 10
From the coastline change the morphology of the sand face has changed revealing a large rock beneath the sand.
In conclusion, the UAV-based aerial image acquisition provides the required spatial resolution and temporal repetition to map and monitor natural coastal phenomena and changes. SIM and MVS techniques, combining photogrammetry and computer vision image processing techniques can be used to automate the detection procedures and to create in-situ measurements with very large spatial cover.

In addition, it can be concluded that the availability of Digital Surface Models (DSM) at high spatial resolution and vertical accuracy can have important role in scientists interested in the two or three-dimensional reconstruction of the environment. Specific vectors i.e. coastline, swash zone, wrack lines, berm crests, swash limits and berm areas can be detected. Most of those vectors are result of the wave run-up in different time frames. Coastal geomorphologists that require accurate topographic information of the coastal systems can perform reliable simulation of coastal erosion. Coastal management, port installations and coastal energy projects are areas of interests of such methodology.

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CONSTRUCTION, DEMOLITION AND EXCAVATION WASTE MANAGEMENT IN EU/GREECE AND ITS POTENTIAL USE IN CONCRETE

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ABSTRACT

Construction, demolition and excavation waste (CDEW) of private and public works comprises one of the largest waste streams in the European Union. It is maintained that, on average, 750 million tonnes of CDEW are produced every year. In Greece alone, almost 4 million tonnes of CDEW are generated per annum. In the present paper, the legislative background associated with the management of CDEW is initially presented, followed by the advancements achieved concerning its implementation in the EU and Greece in two periods before and after the construction boom linked to the 2004 Olympic games. Furthermore, attention is focused on current progress made in recycling CDEW during the construction of reinforced concrete structures. It is confirmed that recycled aggregates and recycled concrete aggregates can be effectively re-used in structural concrete applications, while pulverized concrete dust can potentially be introduced as a supplementary cementitious material into the concrete mix. Finally, the usage of nanoparticles in recycled aggregate concrete is expected to open new markets in the near future.

KEYWORDS:
CDEW; EU-legislation; recycled-aggregates; marble slurry; nanotechnology.

INTRODUCTION

The waste stream generated by the construction and demolition industry is classified as “construction and demolition waste” (C&DW), with an annual average production of 750 million tonnes [1]. Recently, this definition has expanded, incorporating also excavation waste. More specifically, construction demolition and excavation waste (CDEW) includes materials generated from construction, demolition and excavation activities emerging from transportation, building, and land clearing industries. CDEW are generated by building and packaging materials and rubble resulting from construction, remodelling, repair, and demolition of buildings and infrastructure (bridges, ports, pavements, etc.) as well as disaster debris, soil and turf [2]. Since 1991, C&DW has been recognised by the European commission as one of the six main waste streams, which were investigated under the “priority waste streams programme”. In the report produced seven years later by Symonds Group Ltd, definitions were clarified, economic and administrative obstacles to re-use and recycling were summarized and best practice guidance/recommendations for the demolition, renovation and recycling sites, as well as construction and road maintenance sites were presented [2]. Since then, a number of regulations have been developed and guidance published within the EU with which member states are required to conform. In Greece, the adaptation of national legislation to Community law started at a slow pace [3], but has recently started to gain momentum [4]. In this paper the progress observed during the last decade in adopting the legislative framework is reviewed and suggestions are proposed. Furthermore, with respect to concrete design, the technical barriers which have been overcome are discussed in both non-structural and structural applications. Present work reviews the potential benefits stemming from the use of crushed aggregates in concrete design. Reviewing the latest advances in recycled concrete science, it can be concluded that in spite of their shortcomings (e.g. associated with some of their material properties) recycled aggregates (RA) and recycled concrete aggregates (RCA) can be effectively incorporated in concrete design without compromising structural performance requirements set by the relevant standards. Finally, the advancements achieved in nanotechnology can also contribute to the industrial expansion of engineered recycled aggregate concretes.

LEGISLATIVE BACKGROUND UNTIL 2005

In the EU until 2005. After WWII significant quantities of rubble from the destroyed infrastructure
had to be dealt with. This lead to the evolution of the concept of recycling demolition wastes. The rubble was, then, first used for the production of RA [5]. Furthermore, the FRQWUXFWLRQERRPLQWKHU brought about an increase in the C&DW, which was mainly used for landfill. Indicatively, as shown in Figure 1 Spain and Luxembourg used over 90%, C&DW for back-filling, while Ireland and Italy used approximately 60%. Only a few of the then 15 member-states (Austria, Germany, Denmark, Italy, Ireland and the Netherlands) started adopting recycling by 1999, while Denmark and the Netherlands were also using incineration (Figure 1) [2]. Adding to the construction boom, the shortage of natural aggregates lead to an increase in recycling rates in this first reports. Nonetheless, this is the point in time when EU classified C&DW as one of the main waste streams. It has been estimated that by 2004 C&DW generated approximately 450 million tonnes per year [6] hence reaching 49% of the then total waste generation at that time [7]. The management of C&DW generation and disposal became, therefore, imperative and in-depth investigations started towards the formation of a legislative framework to address the issue.

![Figure 1](image)

**FIGURE 1**
C&DW management in the 1990’s [3] (data collected from [2]).

Fifty-seven EU directives and decisions related to CDEW and hazardous waste management were enforced by the EU Commission by 2005 and are analytically presented by Papatzani [3]. A number of best management practices were aimed to achieve broader acceptance of the use of recycled aggregates. Such measures included; (i) limiting or even abolishing the use of landfills, (ii) applying taxes on natural aggregates, (iii) sorting of CDEW at source or in the recycling stations and (iv) developing of codes and standards.

In Greece until 2005, Compliance with EU legislation on hazardous materials and solid waste management had started taking place with the Joint Ministerial Decision, 69728/824/96 signing the beginning of the consideration of C&DW management as a separate waste stream. However, until 1998, neither fiscal policies nor legislation on the management of the separate waste stream of C&DW were implemented. In fact, still in 1999, in the study by Symonds group [2], there were no data for C&DW generation and management in Greece.

The framework on the management of C&DW was set by the Law 2939/2001. This comprised a milestone, given that the construction boom before (and shortly after) the 2004 Athens Olympic Games was affecting C&DW generation in the entire country and not only in the capital. With the introduction of this law, the “national organization of alternative management of packaging and other waste” was also established. All laws and ministerial decisions on waste management and responsibilities of authorities by the year 2005 are discussed in [3].

**ADVANCES WITHIN A DECADE; 2005-2015**

In the EU between 2005 and 2015, Following the construction boom in the early 2006, the economic crisis caused a reduction in civil engineering works, after 2009 [8]. Still, according to Eurostat CDEW comprise one third of the total waste production in EU by 2010. When comparing percentages of recycling of CDEW amongst EU countries, it is interesting to also note who is producing the most. In fact, as shown in Figure 2, France and Germany produced in 2010 over 50% of the total CDEW quantities in the EU [8]. It is understandable, therefore, that in waste framework directive (WFD), priority was given to prevention, re-use and recycling of CDEW.

As stated in the Environmental Policy context of the European Commission: “Environment action programmes have helped shape EU environment policy since the early 1970s”. However, the most recent legislation relating to CDEW directly or indirectly is presented below:

Initially in June 2008, an EU Decision on the public procurement for a better environment was established. Moreover, new recycling targets for construction demolition and excavation waste CDEW were set in November 2008 with the waste framework directive (WFD) enforced in 2008.

Then, By March 2010 it was decided under “A resource-efficient Europe – Flagship initiative of the Europe 2020 Strategy”, that a minimum of 70% recycling by weight of CDEW by 2020, is explicitly required within the EU-28.

Lately, the strategic initiative of the Low Carbon Economy Roadmap of the 7th programme, adopted in late 2013, running to 2020 and entitled “Living well, within the limits of our planet” is related to the CDEW management, since low carbon
concretes can be delivered containing such materials, as discussed in the third part of this paper.

**In Greece between 2005 and 2015.** In May 2011 a working committee was commissioned by the Technical Chamber of Greece in order to report the current status of the CDEW legislation and management in Greece [4]. However, since then, several amendments have been signed by the Greek parliament as shown in Table 1 presented below.

**TABLE 1**

<table>
<thead>
<tr>
<th>Legislative action</th>
<th>Amendment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Ministerial Decision 21017/84/2009</td>
<td>By Joint Ministerial Decision 4229/395/2013: conditions on the establishment and operation of enterprises undertaking demolition works, asbestos or materials containing asbestos removal works</td>
</tr>
<tr>
<td>Joint Ministerial Decision 36259/1757/E103/2010 on the terms, conditions and schedules for alternative excavation and CDEW management</td>
<td>Law 3854/2010 (after 2006/72/EC) adding excavation wastes to the construction and demolition waste stream</td>
</tr>
</tbody>
</table>

It should be noted that Law 3854/2010 amended Law 2939/2001 on measures to improve energy efficiency in end-use energy services and other provisions, regulating the market of environmental services, creating a framework for energy savings in the public domain and setting the cornerstone for the development of the energy market.

In practice, though, significant quantities of CDEW generated by both public and private works are not being recycled, notwithstanding Law 4042/2012 (after Directive 2008/99/EC) on the protection of the environment through criminal law. For example, old paving slabs produced by road resurfacing works (Figure 3) or demolition waste emerging from re-design of flats and apartments. Given the economic crisis and the subsequent decline in the construction of new buildings, the rehabilitation, strengthening and redesign of existing buildings is expected to increase the quantities of CDEW produced.

**FIGURE 3**

Road resurfacing works with the collaboration of Governmental entities – pavement tiles and concrete substrate – photos by authors’ private collection

One of the major issues to be highlighted is the necessity to differentiate materials straight at the source, rather than mixing wood, bricks, tiles and glass in lumps. Such condition still comprises com-
mon practice, as shown in Figure 4, in most rehabilitation/redesign construction sites. Therefore, further education should be enforced and strict regulation and monitoring is necessary, until the recycling culture is implemented.

An interesting show case pertains to the waste produced by the processing of marble (cutting and shaping), which in Greece, dates back to the millenia (Figure 5). The yearly production of marble fragments and slurry waste ranges between 360 tonnes (low season) to 720 tonnes (high season) per factory/production plant [personal communication, February 11, 2016]. The fragmented pieces of marble can be crushed to produce aggregates or can be processed (mixed with additives, fillers, pigments and other materials) and used in mosaic type of paving or cladding surfaces, also known as engineered or agglomerated stones. The agglomerated stones are produced in accordance with definitions given in EN 14618 E2 - 2009. There are thirteen EN standards for the testing of physical and mechanical characteristics of the agglomerated stones (EN 14617.01, 14617.02E2, 14617.04 - 14617.13 and 14617.15). Furthermore, distinction should be made for engineered stones made with Portland cement as the binding agent. Their use and testing is governed by EN 13748-1 and EN 13748-2 standards. It is estimated that 130,000 square meters of agglomerated stone pavement was placed in Heathrow Terminal 5. Moreover, there are approximately 30 industrial units in EU producing such products (approximately 20 million square meters on a yearly basis), therefore, comprising markets for further recycling of marble and stone C&DW [9].

The marble slurry is typically reused in Greece for the production of marble-based plaster and other additives. One final use emerges by the mixing of marble slurry with soil to restore marble quarries.

![FIGURE 4](image1.png)

**FIGURE 4**

Private entities - Significant demolition waste generated from the rehabilitation of old houses—photos by authors’ private collection

![FIGURE 5](image2.png)

**FIGURE 5**

Private entities - Marble processing factories – broken remains and marble slurry—photos by authors’ private collection

Cement science and RA / RCA. Although the cost of separating concrete solids from clay bricks in recycling plants renders the process impossible, so far there has been only one publication, by Liu et al. [11], on cement pastes made of hybrid recycled dust of concrete solids and clay bricks, as a supplementary cementitious material (SCM). In this paper, the pozzolanic activity of recycled clay brick powder or demolished concrete solids dust produced by the recycling factories has been reviewed and justified the necessity for research on hybrid dust used as SCM. Indeed, Liu et al. examined the chemical and mineral composition of the hybrid powder, as well as the thermogravimetric performance and microstructure of mortars in which cement was replaced by 30% of this recycled powder. It was confirmed that the pozzolanic activity is relative to the concrete/clay brick ratio. For this, the clay brick content and the replace-
ment percentage should be controlled for target specific strength and consistence. Mortar samples made of cement and hybrid powder at 30% cement replacement at water to binder ratio of 0.5 were tested for strength and were also Atomic Force Microscopy probed at the nanoscale. With the help of nanotechnology, a representative region containing one hybrid particle and one fine aggregate (sand) was compared with another region with no hybrid particle or fine aggregate, whose main constituent is the C-S-H gel. The stiffness of the first region is significantly lower than that of the second region. A weaker bond of C-S-H gel around the hybrid powder was observed. The interfacial transition zones (ITZ) around the fine aggregates and hybrid powder was measured to be weak with similar modulus. Further research on the effect of the packing density of the hybrid powder on the hydration reactions and products and the durability of the pastes is suggested.

Finally, they reviewed techniques presented to date for improving the properties of RCSs. They distinguished: (i) the incorporation of mineral admixtures, assisting mainly as fillers at various scales, (ii) the coating of RACs to seal the inherent cracks and pores and (iii) the modification of the mixing process (two stage, double mixing).

**Concrete science and design with RA / RCA.**

The physical and mechanical properties of recycled aggregates (RA) and recycled concrete aggregates (RCA) have been recently reviewed by Behera et al. [12] and Silva et al. [13] with respect to their use in recycled aggregate concrete (RAC). Behera et al., in addition, reviewed the green state properties; consistence, wet and bulk density and water absorption with respect to the size, shape, surface texture of the RCA. Furthermore, they reviewed studies on the hardened state RAC properties; compressive strength, split tensile strength, flexural strength, drying shrinkage, modulus of elasticity, creep, and bond strength with respect to water binder ratio of the formulation, engineering and physical properties of RCA used in concrete design. Finally, studies on the micro-structure or RAC were discussed showing the effect the effectively two interfacial transition zones (of the RCA and of the new concrete around the RCAs) have on the strength and porosity of RAC.

In the review published by Papatzani and Paine [14] more studies expanding from 1999 to 2015 have been discussed, showing that:

(i) adjustment to the water/cement ratio can compensate for strength losses at higher RCA contents [15]. The mix design contained coarse and fine RCA.

(ii) compressive and splitting tensile strength up to 365 days of samples made of RCA did not show reductions compared to those consisting of natural aggregates for the same slump. The tested concrete was made of (a) 100% Portland or blended Portland cement (containing 65% Portland cement and 35% blast furnace slag), (b) fine sand and (c) crushed basalt rock and 0% or 100% RCA for a standard slump of 80 ± 15 mm. Water absorption and carbonation rates were found similar for both natural and crushed aggregate concrete samples [10].

(iii) chloride conductivity, oxygen permeability and water sorptivity were less favourable as the quantity of RA increased, but improved with curing time for concrete disks of 68 mm diameter and 25 ± 2 mm thickness made of (a) CEMI, (b) fine sand and (c) crushed granite rock and 0%, 50% or 100% recycled aggregate at 0.5 water to cement ratio, tested for durability at 3, 7, 28 and 56 days [5]. It was also concluded that cracks induced by the crushing of RCA increased the diffusion, permeation and absorption characteristics of RAC. This hypothesis was neither verified by a comparative study of scanning electron microscopy studies on samples of the granite rock and recycled aggregates, as well as helium pycnometer density and porosity measurements nor crosschecked with consistence or mechanical strengths tests.

(iv) early age consistence and compressive strength of concrete produced with RA at 28 days is similar to those of concretes produced with natural coarse aggregates. Water absorption and pore volume increased, whereas the carbonation depth decreased as the amount of RA increased. 39 different concrete mixes consisting of (a) blended Portland cement (containing 65% Portland cement and 35% blast furnace slag), (b) fine sand and (c) crushed granite rock and 0%, 20%, 50% or 100% fine or coarse recycled (concrete or masonry) aggregate for a constant consistency by slump test were compared in this study [16].

(v) water absorption, carbonation depth and chloride penetration of the concrete samples increased with higher fine RCA replacement, after studying concrete specimens containing 30% or 100% fine RCA, CEM I and 70% or 0% river sand and coarse aggregate at a water/cement ratio of about 0.4, variations accounting for the great water absorption of the crushed aggregates [17]. These results were related to the inherent properties of the recycled aggregates, which being more porous caused a subsequent increase in the open porosity of the concrete. It was concluded that low replacement recycled aggregate concrete can indeed be used for structural purposes and that higher replacement could be feasible with blended binders.

(vi) RCA can be incorporated in concrete mix design irrespective of their constituents (unbound stone, crushed concrete, crushed brick) and source and eliminated the relating technical barriers [17]. Paine and Dhir also provided a critical review of the results of research on recycled aggregates originating from crushed concrete, crushed brick or unbound stone. A performance-related approach was developed after designing concrete mixes and casting and testing specimens containing various combinations.
of the three recycled aggregate constituents. It was concluded that an envelope of feasible concrete mixes could be developed by imposing four requirements in the various combinations of RA constituents: (a) Los Angeles coefficient ≤ 40, (b) particle density ≥ 2600kg/m³, (c) water absorption ≤ 3.5% and (d) drying shrinkage volume ≤ 0.075%. With the satisfaction of these criteria, similar values to those delivered by natural aggregate concretes in terms of cube strength, static modulus of elasticity, initial surface absorption, carbonation rate, chloride ingress, and drying shrinkage can be achieved as long as the water to cement ratio is adjusted.

Another interesting application recently presented, regards the use of fine RCA for self-compact ing concrete [18]. Rheology by flow curve test (FCT) and stress growth test (SGT) in the ICAR rheometer at 15, 45 and 90 minutes was measured along with compressive strength at 3, 7 and 28 days for concretes. Empirical tests were also performed; slump flow + T50, V-funnel, J-Ring, L-Box, sieve segregation analysis at 15, 45 and 90 minutes. The mixes with 50% and 100% recycled sand lost their self-compacting characteristics at 90 minutes. The mixes in which sand was replaced by 20% by recycled sand maintained acceptable passing and filling ability and the compressive strength reduced by less than 10%.

Lastly, the carbonation behaviour of RAC has been studied by Silva et al. [19] by means of statistical analyses on carbonation depth of 600 coarse RCA and 360 fine RCA concrete mixes sourced from 10 studies. The factors affecting carbonation of RAC were determined; the recycled aggregate replacement ratio, the crushing procedure employed for the production of RCA, the quality of RCA, the exposure to different curing conditions and the effect of the water reducing admixtures. It was concluded that carbonation depths increase with replacement levels. In fact, the use of 100% coarse RCA can double the carbonation depth with respect to natural aggregate mixes. Fine RCA tend to increase carbonation when compared to coarse RCA. Crushing in several stages, produces more round RCA and removes some of the adhered mortar, leading to lower carbonation depths. It is interesting to note that the strength of the original material was not correlated with the carbonation depth. In order to produce RAC with similar target strength and carbonation depth to conventional mixes it is suggested that either greater amounts of cement should be used or a lower water to cement ratio retaining cement content. It is acknowledged that in this case superplasticizers will also be used.

To sum up, it has been experimentally confirmed that the use of high amounts (over 50% by mass) of recycled concrete aggregates yields a number of complications for both fresh and hardened concrete; With respect to the former, consistency drops in some studies [12], while remains similar to that of natural aggregates in others [16], bleeding may occur [12] and higher water absorption [16] and carbonation [19] can be expected if a number of parameters are not taken into account. Lastly, lower bulk density is also reported [12].

As for the hardened recycled aggregate concrete, the use of over 50% RCA by mass lowers the compressive strengths and doubles the carbon-ation for the same water to cement ratio [12], [14]. It is reported in recent studies that at 100% RCA content the concrete strength decreases about 24% and that the relation between density and water absorption is inverse at higher RCA content [20 21]. Problematic durability impact has also been identified by Lotfi et al. [21 22] in terms of porosity, freeze-thaw and carbonation resistance and water and oxygen permeability. If taking into consideration that no accelerated abrasion tests have been presented on RAC in order to determine the predicted life-span of structures made of RAC, it could be sustained that an upper limit has been reached and other solutions should be sought. It could be sustained that an upper limit has been reached and other solutions should be sought.

Lastly, the use of recycled glass [23] or granulated foam glass [24] as aggregates in concrete design can offer greater recycling potentials, however its review is beyond the scope of this paper.

Production of non-structural members with RA/ RCA. Recycled aggregates (masonry/concrete) have been recently used in precast concrete products such as building [25] and paving [26] blocks and pavement flags [27]. Soutsos et al. studied the effect of the use of recycled aggregates obtained from masonry demolition waste (RMA) and RCA. RMA contained higher content of dust than RCA, however water absorption was similar for both. Compressive and tensile splitting tests performed at day 7 and 28 showed significant variability for replacements of over 60% coarse RMA or 40% fine RCA. It was found that no more than 20% of RMA should be used for either coarse or fine fractions since it was found to be unfavourable to mechanical performance. In addition, the coarse RCA fraction should be limited to 60% and the fine RCA fraction to 20%. Water absorption was identified as a limiting parameter [25].

Further bibliography is discussed in Rajab et al. [28]. In their study, air-entrained sidewalk concrete mix containing up to 30% of coarse recycled aggregate or up to 20% of coarse and fine RCA was tested. Density, consistency, air retention, compressive and flexural strength, freeze-thaw resistance and chloride permeability and strengths were tested. Equivalent levels of performance were recorded between the 30% replacement and a conventional concrete control mix. The recycled coarse aggregate may have created higher hardened air voids and salt surface scaling was detected for the 20% coarse and fine RCA replacement. It is noteworthy that the authors of this research belong to the Lafarge research and development group, a clear indication of the interest
of the industry in the use of RCA.

Still, accelerated abrasion tests should be performed on such elements in order to gain an insight into the life span of such products.

Production of structural members with RCA. Several applications of RCA in structural beams, beam-column joints, 2D frames or scaled structures have been reported in the past, as summarized in Pacheco et al. [29] and in columns as reported in Papatzani and Paine [14]. However, only Pacheco et al. have published results on destructive testing on full scale recycled aggregate concrete structures. Four two-floor, 3D frame structures were constructed and tested. One was made with conventional concrete (0% coarse RCA), and three at 25%, 100% coarse RCA and 100% coarse RCA+high range water reducing admixture. The geometry and reinforcement layout was exactly the same in all four of them and their design complied with Eurocode 2, 7 and 8. A number of conclusions were drawn the most important of which were that:

- The use of RCA does not comprise hindrance to ductile behavior, as long as conventional concrete design codes are adopted
- The performance of the structures made of RCA can be predicted by finite element analyses
- The use of RCA does not compromise the seismic behavior of RAC structures

Lastly, a separate study has been recently published in which recycled aggregate concrete beam elements have been designed according to Eurocode 2 [30]. It was concluded that a slightly higher nominal cover is required in order to achieve similar service life as for conventional concrete beams. The cross section also had to be increased to restrain maximum deflection within acceptable limits.

FURTHER CONSIDERATIONS & DISCUSSION

Most research is focused on the mechanical properties and durability issues of the resulting concretes, there is still lack of knowledge in the material characterization of the individual aggregates or powders. Apart from chemical checks, it would be beneficial to carry out density and porosity measurement and scanning electron microscopy analyses, to determine the extent of cracking in the crushed samples.

Furthermore, it could be interesting to investigate the combined effect of the crushed powders and recycled aggregates in composite binders’ concrete mixes, containing significant amounts of supplementary cementitious materials and low Portland cement content. Rate of hydration, water absorption, consistence, rheology and mechanical properties should be considered.

Although some experimental data is provided with respect to the effect of mineral additions on recycled coarse aggregate concrete [20] or even new concrete recycling technology [21] in order to overcome barriers in high RA usage, there is still a long way to cover until performance based design criteria are met. Such results can be reversed with the advancement of “nanotechnology”. It should be noted that the term nanotechnology covers two main streams (A) the use of nanoparticles i.e. particles with one or more external dimensions in the size range 1 nm-100 nm and (B) the use of methods and techniques to study matter at the nanolevel, i.e. sizes and dimensions below 100 nm. Indeed, no research on nanomodified recycled aggregate concrete has been presented up to date.

The addition of nanoparticles in cement, mortar and concrete formulations expands the field of vision in research and industry. In fact, nanotechnology is considered to bring about the next industrial revolution, since the addition of nanoparticles and observation of the resulting changes at the nanolevel is a much promising development.

The introduction of nanoparticles in formulations affects hydration, strength, durability and microstructure in a number of ways, as discussed by Papatzani and coworkers [31]-[36]. Practically nanoparticles may play the role of nanofillers, reducing the nanoporosity within the hydrated paste, nanoreinforcements, increasing the tensile/flexural strength and consistency of the paste, catalysts and nucleation sites for the reaction products due to their high specific surface area and the unsaturated bonds on the surface of the particles and/or highly reactive pozzolanas, consuming Ca(OH)₂ to produce additional C–S–H.

Furthermore, weakness in the interfacial transition zone (ITZ) between the aggregate and the cement paste have been identified as core reason for poor performance. Given the physical characteristics of recycled aggregates, creating a compact ITZ when RCA are used is very demanding. The use of mineral additions, is advised to compensate for slump or strength loss, however can complicate the performance of the concrete formulations even further. Nanoparticles, with the aforementioned characteristics are expected to strengthen the ITZ, hence more research is required. In addition to this, research findings on the microstructure of RAC suggest that the pores and cracks on the surface of RACs cannot be filled by cement paste, resulting into further weakening of the bond between the old ITZ and the new one [12]. The filling nature of the nanoparticles may assist in counteracting this effect, either directly, or indirectly by the formation of secondary C–S–H around the nanoparticles filling the nanosized pores.

Lastly, if assumptions as the one made by Liu et al. [11] with respect to the weaker bond of C–S–H gel around the hybrid powder hold, the nanostructure of C–S–H of such paste could be enhanced with the addition of nanoparticles and assessed by a number
of nanotech experimental methods [27], [28]. Research is required to assess these potentials in nano-modified recycled aggregate concrete mixes.

CONCLUSIONS

All in all, legislative and technical barriers in encouraging the broader use of recycled aggregates (RA) and recycled concrete aggregates such as the absence of a relevant legislative framework and governmental support, the lack of appropriate technology in the recycling facilities, the lack of technical awareness and relevant standards have been largely eliminated in recent years. Research has shown that there is a significant profit margin can be achieved by recycling CDEW as construction materials, as they can be used, apart from road construction in structural applications and architectural finishes (claddings, surfacing, mortars) apart from road construction. Therefore, the possibility of fulfilling the EU 2020 objective of 70% of CDEW being recycled, can be considered realistic and achievable if appropriate planning and monitoring take place.

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KINETIC MODELS’ EVALUATION OF PHOSPHORUS REMOVAL IN WASTEWATER STABILIZATION PONDS UNDER MEDITERRANEAN CONDITIONS

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ABSTRACT

Phosphorus removal is one of the most difficult issues to be achieved in natural wastewater treatment systems according to the opinion of many researchers. There is currently no established design to increase phosphorus removal in waste stabilization ponds (WSPs). This occurs because there are no mechanisms for the complete phosphorus removal by WSPs systems or wetlands. These removal mechanisms depend on the phosphorus form in the sewage. The present paper examines the phosphorus removal kinetics presented in three full-scale WSP systems in Greece. The investigated WSP systems consist of one facultative pond, one or two maturation ponds in series and a limestone rock filter before the final discharge. The systems treat municipal wastewater and were monitored for a year for this work proposes. Their average mass removal efficiency ranged from 16% to 43%. The kinetic constants of phosphorus removal were determined based on the first order kinetic model, the Stover-Kincannon model, the Grau second order kinetic model, the Kadlec and Knight model and the Reed model were used. The models’ assessment, as well as the accuracy and reliability of the results are evaluated by comparison with existing real data. Furthermore, the model models better representing total phosphorus kinetic in the WSP systems is determined. The factors influencing the kinetics are also examined. Reed model correlates the best. The biodegradation rate constant (kTP) of TP ranges from 0.0030 to 0.0146 md⁻¹. The 1st order kinetic model applied to wetlands also gives very good results. According to this model the biodegradation rate constant ranges from 0.0116 d⁻¹ to 0.0392 d⁻¹. The estimated parameters can effectively be applied in sizing WSPs under Mediterranean or similar climatic conditions. The constant kTP has a strong positive correlation with the removal of TSS.

KEYWORDS:

municipal wastewater, stabilization ponds, phosphorus removal kinetics, biodegradation rate constant.

INTRODUCTION

Wastewater Stabilization Ponds (WSPs) are natural systems with significant advantages, such as simplicity, low construction and operating costs and high efficiency in organic matter and pathogens removal [1], [2]. However, phosphorus removal from municipal wastewater by WSPs is poor and ranges from 15% to 50% [3-8]. Mara [9] proposed that the best way to increase the phosphorus removal from wastewater by WSPs is to increase the number of maturation ponds. Generally, the phosphorus removal is one of the most difficult issues to be achieved in natural wastewater treatment systems according to the opinion of many re-searchers [10]. There is no existed an established method for the wastewater stabilization ponds’ (WSPs) design for phosphorus removal up to now. This occurs because there are no mechanisms for the complete phosphorus removal by WSPs systems or wetlands [11], [12], [2]. These removal mechanisms depend on the phosphorus form in the sew-age. Phosphorus (P) in wastewater appears almost entirely in the form of phosphates, which include organic phosphates and inorganic phosphates poly-phosphates and orthophosphate [13]. In wastewater the organic phosphorus is about one fifth of the total phosphorus (TP). At the outlet of WSPs the organic P is one third of TP approximately and the inorganic P is two-thirds of TP [2]. Orthophosphates are available for biological metabolism without further analysis. Usually polyphosphates undergo hydrolysis and are converted to orthophosphate form. This process is usually very slow [14]. Inorganic P is easily consumed by aquatic organisms. Some organisms are capable of storing the excess of phosphorus in the form of polyphosphates for future use. Simultaneously, a part of the organic phosphates constantly disappears in sediments. It is trapped in an insoluble form of precipitate [13]. In a WSP system, phosphorus removal from domestic wastewater is associated with hiring of the algal biomass, precipitation and sedimentation. Since the alkalinity increases, during daylight hours, the phosphate is incorporated with TSS and precipitates out off wastewater [13], [14].

Several studies in the international literature
suggest that phosphorus removal mechanisms and pathways differ spatially and temporally on a global level. Moreover, although a lot of the WSPs design tools and models have been adopted, there is not enough information about the dynamics of pollutants in these systems [15-19]. Lack of such information and the fact that the use of these systems is limited in Greece and therefore relevant information is insufficient, were the impetus for this work.

The aim of the present research is the determination of TP pollutant removal reaction rate; the biodegradation rate constants \( k_{TP} \) of three full-scale WSPs systems situated in the North part of Greece, treated municipal wastewater, pertaining to local conditions. The knowledge of the constant \( k_{TP} \) is very useful for the systems’ design. One of the objectives was to determine the suitability and usefulness of different models, available in the literature. The models were compared by using statistic efficiency criteria, by which the models’ fit (adaptation) and therefore the suitability was evaluated.

MATERIALS AND METHODS

Study area. The three systems are situated in a lowland area in mainland of northern Greece in latitude \( \phi: 41^\circ \) up to \( 41^\circ 15' \) N, longitude \( \lambda: 23^\circ 21' \) up to \( 23^\circ 36' \) E and altitude from 14 m to 52, in a Mediterranean climate. The mean monthly air temperatures are among 4°C to 29°C with average annual temperature equal to 15.2 °C and an average annual rainfall equal to 37.37 mm. The winds in the region are not more than 6 km/h [20].

They treat only domestic wastewater and consist of one facultative pond of 2.40 m in depth, one maturation pond (N. Skopos) or two (Vamvakofito, Charopo) of 1.50 m deep in series and a limestone rock filter before the final discharge for algae filtration. The wastewater discharge becomes through an open channel of 0.75m² vertical section. The entrance and exit of the wastewater in each pond are from one point respectively, in a diagonal arrangement. Every system has a different total hydraulic retention time (HRT). Skopos’s HRT is 18.6 d for Vamvakofito it is 68.7 d and for Charopo it 72.4 d. The inflow is considered constant for each WSPs system and equal to the outflow. Each WSPs system has different design and functional features (Table 1, Figure1).

Data. To determine the TP, BOD₅ and TSS concentrations for each system, instantaneous samples were taken from the inflow of the 1st pond and the outflow of the last pond, from October 2006 to September 2007 twice a month at least. On January and June - with the lowest and highest temperature respectively sampling was done with a weekly frequency [21]. The samples were collected approximately at the same morning period, while meteorological data were recorded. The samples were placed into 1000 (mL) polyethylene bottles and were transferred immediately to the wastewater laboratory of Serres City [21]. To enhance the range and accuracy of the data, each sample was analyzed separately twice, implementing methods proposed

|TABLE 1| WSP systems: Inflow, total area and volume, loading rates (Current situation) |
|---|---|---|---|
|WSP system| Vamvakofito (V)| N. Skopos (N.S.)| Charopo (Ch)|
|Inflow (m³/d)| 121| 152| 137|
|Total Area (m²)| 6016| 2112| 7415|
|Total Volume (m³)| 8311| 2827| 9921|
|m² facultative/PE| 2.65| 0.67| 1.77|
|m² maturation/PE| 3.86| 0.67| 5.23|

PE: equivalent population
by the Simplified Laboratory Procedures for Wastewater Examination [22], and considering the averages. The inflow and outflow rates were measured with handheld electromagnetic flow meter, with the assumption that wastewater supply was constant during the day. In parallel, pH values were also measured by potentiometric method using pH/Cond340i. Daily meteorological data were obtained from the National Meteorological Service (NMS). The water temperature was recorded in situ, during the days of sampling.

The WSPs as open natural systems are subjected to the laws of nature and are influenced by local weather conditions. Thus their operation and performance are affecting. So, the outflow data were corrected by mass balance method, to eliminate errors from atmospheric precipitation and evapotranspiration, as many researchers believe that the mass balance is the most authoritative method to evaluate the performance of natural systems and the changes occurring in these [23-25]. The mass balance is described by the general expression [26]; mass accumulation is equal to mass input minus the mass output + mass generation or mass consumption. The water balance estimation described by the equation 1, uses the principles of conservation of mass in a closed system.

\[ Q_{\text{out}} = Q_{\text{in}} + I - \text{PET} \]  
(Eq.1)

Where \( Q_{\text{out}} \) is the wastewater outflow quantity (m³/d), \( Q_{\text{in}} \) is the wastewater inflow quantity (m³/d), \( I \) is the water quantity which enters the system via precipitation (m³/d) and PET is the water quantity which is lost from the system via evapotranspiration (m⁴/d).

The height of precipitation \( H_{\text{rain}} \) was obtained by Hellenic Meteo Service, Bureau of Serres, and the height of evapotranspiration, \( H_{\text{PET}} \) was calculated with customizing Thornthwaite’s method due to the small number of required data for its implementation, compared to the model of Peman-Monteith, which is considered more reliable [26]. The Thornthwaite model, accordance with other researchers, gives a very good estimation of the water balance for the purposes of this research [27].

The corrected data were fed into mathematical models to calculate the phosphorus kinetic constant \( k_{TP} \). The parameters of the data statistical analysis were calculated by the use of Microsoft Office EXCEL 2007.

**Kinetics Models and their Evaluation.** The kinetics study can be an effective tool for the investigation of the pollutant removal mechanisms and can help the design of WSPs too [28]. Different macrokinetics models have often been used to simulate the removal of various contaminants in the kinetics study. These typically used models are the 1st order kinetic model [17], [29-31], the Stover-Kincannon model [17], [32], the Grau 2nd order kinetic model [17], [28], [32], the Kadlec and Knight model [33-35] and the Reed et al model [36], [12]. It is interesting to ascertain whether the models, applied on several other occasions, are also able to be applied in WSPs’ TP removal. In this study these macrokinetics models were selected to simulate the TP removal.

The first order kinetics model is usually applied to simulate the BOD removal [37]. In the case where the WSPs have a complete mixing flow, the general equation with modifications [30] can be written as follows [12]:

\[ k_1 = \frac{C_{\text{in}} - C_{\text{out}}}{t \cdot C_{\text{out}}} \]  
(Eq. 2)

In the case where the WSPs have plug flow the equation 2 is written as [38]:

\[ \ln \left( \frac{C_{\text{out}}}{C_{\text{in}}} \right) = -k_2 \cdot t \]  
(Eq. 3)

Where \( C_{\text{in}} \) and \( C_{\text{out}} \) are the inflow and outflow pollutant concentration (mg/L) respectively, \( t \) is the retention time of pollutant in the WSPs, \( k_1 \), \( k_2 \) are the first order constants of pollutant removal rate (d⁻¹) for complete mixing flow and plug flow, respectively.

The Stover-Kincannon model [39] which has been structured in order to connect the removal rate of one component with its mass load is commonly used for biological filters, CBR and MBBR systems. It has suggested by Khosravi et al [40] in the case of stabilization ponds, having a good adaptation. After linearization it could be expressed as follows [41]:

\[ k_3 = \frac{1}{U_{\text{max}} \cdot t} \cdot \frac{C_{\text{in}} - C_{\text{out}}}{C_{\text{in}} \cdot U_{\text{max}}} \]  
(mg L⁻¹ d⁻¹)  
(Eq.4)

where \( U_{\text{max}} \) is the maximum removal rate (mg L⁻¹ d⁻¹).

The 2nd order kinetic Grau model [42] was developed for biofilters. It was based on the assumption that the removal rate along the installation is reduced as the contaminant is passed through it [28]. After the integration of the basic 2nd order kinetics equation and its linearization then [30] the equation could be expressed by follow form:

\[ k_4 = \left( \frac{C_{\text{in}} \cdot t}{C_{\text{out}} \cdot C_{\text{in}} - C_{\text{out}}} - t \right) \cdot \frac{X}{C_{\text{in}}} \]  
(Eq.5)

where \( X \) is the mean biomass concentration in the system (mg/L), and \( k_4 \) is the 2nd order substrate removal rate constant (d⁻¹).

The Kadlec and Knight model was developed for wetlands [33]. It is a combination of the basic equation of the plug flow model and the aqueous mass balance. As the examined stabilization pond systems have characteristics similar with wetlands - no sludge removal throughout the years of operation and simultaneously a significant growth of self-sown reeds at the banks of the ponds (Figure 2) - this model it was assumed that can be used.
FIGURE 2

General view of WSP systems where apparent the plants growth

The Kadlec and Knight model is written as in the equation 6:

\[ k_s = \frac{Q}{A}\ln\left(\frac{C_{in} - C^*}{C_{out} - C^*}\right) \]  
(Eq.6)

Where \( k_s \) is the first-order kinetic constant \( \text{m}^{-1}\text{d}^{-1} \) and \( C^* \) is non-zero background (mg/L). \( Q \) is the input flow rate (m\(^3\)/d), \( A \) is the pond’s surface (m\(^2\)). The values of \( C^* \) for wetlands, according Kadlec and Knight [33], are among 0.02 to 1. In this research, the value of \( C^* \) was examined in the range of 0.1 to 1. This model describes better the removal of pollutants, as they cannot be reduced to zero in wetlands or in the ponds, due to the subsequent release of pollutants from the ponds into the treated water. The non-zero background concentration represents in more realistic way the pollutants resulting from transformation processes within the sediments and from the interactions between the sediments and the wastewater. The main reason of these processes is the production of organics from the decomposition of organic materials and the endogenous autotrophic processes [43], [44].

The Reed model [36] is applied usually to simulate the TP removal in wetlands [12] and has the following expression:

\[ C_{out} = C_{in}e^{-\left(\frac{k_s A}{C_{in}}\right)} \quad \text{or} \quad k_s = -\frac{\ln C_{out} + C_{in}}{C_{in}} \quad \text{(md}^{-1}) \]  
(Eq.7)

Where \( C_{in}, C_{out} \) are the WSPs inflow and outflow TN concentration (mg/L) respectively, \( Q \) is the input flow rate (m\(^3\)/d), \( A \) is the pond’s surface [m\(^2\)].

The models’ evaluation was assessed by comparing the real observed values \( C_{out} \) of WSPs collected data with the predicted by the models’ equations values \( F(C_{out}) \). To evaluate model performance, efficiency criteria are defined as mathematical measures of how well the model simulation fits the available observations [45]. For each WSPs system, the “\( k_{TP} \)” values were obtained after the predicted values function optimization. The predicted values were generated from the applied models.

The used efficiency criteria, in this study, were (i) the coefficient of determination \( R^2 \), defined as the squared value of the coefficient of correlation according to Bravais-Pearson. It provides a measure of how well observed outcomes are replicated by the model, as the proportion of total variation of outcomes explained by the model. The range of \( R^2 \) lies between 0 (no correlation) and 1.0 (the dispersion of the prediction is equal to that of observation). The fact that only the dispersion is quantified is one of the major drawbacks of \( R^2 \) and if it is considered alone it is advisable to take into account additional information which can cope with that problem. (ii) The Nash-Sutcliffe efficiency \( E \). The range of \( E \) lies between 1.0 (perfect fit) and - ∞. An efficiency of 0 \((E = 0)\) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero \((E < 0)\) occurs when the observed mean is a better predictor than the model or, in other words, when the residual variance (described by the numerator in the expression above), is larger than the data variance (described by the denominator). Essentially, the closer the model efficiency is to 1, the more accurate the model is. (iii) The unitized risk or coefficient of variation \( CV \) that is defined as the ratio of the standard deviation \( \sigma \) to the mean \( \mu \). It shows the extent of variability in relation to the mean of the population. \( CV \) measures are often used as quality controls for quantitative laboratory assays. The closer to zero \( CV \) value is the better the fit. The combination of the above criteria gives more information about the efficiency of used equations.

For the statistical and mathematical data analysis the Microsoft Office EXCEL 2007 was used.

RESULTS AND DISCUSSION

The pH values ranged from 6.76 to 8.22 and TP load concentrations at the entrance of the WSPs ranged from 2.10 mg/L to 14.60 mg/L. The average values of pH, the concentrations of TP, input and output in mg/L measured in three WSP systems and TP removal rate are presented in Table 2. The ponds’ temperature ranged from 5 °C to 30 °C and it was similar in all the three systems with an average temperature of 16.3 ± 9.7. The TSS and BOD\(_5\) removal efficiency are shown in Table 3.
The k values of the total phosphorus biodegradation rate constant, as generated from the mathematical simulation of the measurements, according to the models mentioned above and the reliability coefficients of each model $R^2$ and E, are presented in Tables 4, 5, 6.

Taking into account all the statistic criteria ($R^2$, E, CV) for evaluating the suitability of models for all the three WSP systems, the simple model of Reed gives the best results for "$k_{TP}$" expressed in $\text{md}^{-1}$. Every WSPs system, as a separate ecological system, operates with different rates. The $k_{TP}$ values of the three systems ranged among 0.0030 $\text{md}^{-1}$ to 0.0146 $\text{md}^{-1}$ based on the Reed’s model, and are within the limits described in the literature. The values of k referred to TP removal in wetlands ranging from 0.0027 to 0.033 $\text{md}^{-1}$ according to Kadlec and Knight [33]. So, for Vamvakofito WSPs system $k_{TP}$ value is 0.0112 $\text{md}^{-1}$, for N. Skopos WSPs system $k_{TP}$ value is 0.0146 $\text{md}^{-1}$ while for Charopo WSPs system the $k_{TP}$ proposed value is equal to 0.0030 $\text{md}^{-1}$. The first order kinetics model is quite reliable too. The $k_{TP}$ values obtained from this model for plug flow are for the Vamvakofito WSPs system equal to 0.0392 $\text{d}^{-1}$, the N. Skopos system equal to 0.0145 $\text{d}^{-1}$ and for the Charopo one 0.0116 $\text{d}^{-1}$.

There is a significant positive correlation between the kinetic coefficient $k_{TP}$ and TSS removing with a coefficient of determination $R^2$ more than 0.91 (Figure 3).

### TABLE 2
The pH means value, inflow-outflow TP concentrations, efficiency

<table>
<thead>
<tr>
<th>WSPs system</th>
<th>n</th>
<th>$\text{In-}$</th>
<th>$\text{Out-}$</th>
<th>$\text{In-}$</th>
<th>$\text{Out-}$</th>
<th>Efficiency</th>
<th>$\text{Eff.}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vamvako fito</td>
<td>34</td>
<td>7.47±1</td>
<td>7.62±1</td>
<td>6.50±2</td>
<td>5.31±1</td>
<td>44.83</td>
<td></td>
</tr>
<tr>
<td>N. Skopos</td>
<td>34</td>
<td>7.03±1</td>
<td>7.08±1</td>
<td>3.55±1</td>
<td>2.67±1</td>
<td>23.55</td>
<td></td>
</tr>
<tr>
<td>Charopo</td>
<td>34</td>
<td>7.29±1</td>
<td>7.39±1</td>
<td>4.51±2</td>
<td>3.49±1</td>
<td>22.32</td>
<td></td>
</tr>
</tbody>
</table>

n: number of samples

### TABLE 3
The Mean Efficiency of BOD$_5$ and TSS removal

<table>
<thead>
<tr>
<th>WSPs system</th>
<th>Vamvakofito</th>
<th>N. Skopos</th>
<th>Charopo</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD$_5$ removal (%)</td>
<td>64.95</td>
<td>43.47</td>
<td>49.66</td>
</tr>
<tr>
<td>TSS removal (%)</td>
<td>60.01</td>
<td>36.83</td>
<td>17.18</td>
</tr>
</tbody>
</table>

### TABLE 4
Vamvakofito WSPs - biodegradation rate constant $k_{TP}$

<table>
<thead>
<tr>
<th>Model</th>
<th>1st order</th>
<th>2nd order</th>
<th>Kincannon</th>
<th>Kadlec - Knight</th>
<th>Reed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>1st order</td>
<td>Plug flow</td>
<td>Kincannon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d^1$</td>
<td>$d^2$</td>
<td>$\text{mgL}^{-1}d^{-1}$</td>
<td>$d^3$</td>
<td>$\text{md}^{-1}$</td>
<td>$\text{md}^{-1}$</td>
</tr>
<tr>
<td>$k_{TP}$</td>
<td>0.0126</td>
<td>0.392</td>
<td>1.7933</td>
<td>0.0843</td>
<td>0.0112</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.829</td>
<td>0.979</td>
<td>0.849</td>
<td>0.829</td>
<td>0.849</td>
</tr>
<tr>
<td>E</td>
<td>0.949</td>
<td>0.966</td>
<td>0.948</td>
<td>0.927</td>
<td>0.974</td>
</tr>
<tr>
<td>CV</td>
<td>0.565</td>
<td>0.445</td>
<td>0.690</td>
<td>0.572</td>
<td>0.018</td>
</tr>
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</table>

### TABLE 5
N. Skopos WSPs - biodegradation rate constant $k_{TP}$

<table>
<thead>
<tr>
<th>Model</th>
<th>1st order</th>
<th>2nd order</th>
<th>Kincannon</th>
<th>Kadlec - Knight</th>
<th>Reed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>1st order</td>
<td>Plug flow</td>
<td>Kincannon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d^1$</td>
<td>$d^2$</td>
<td>$\text{mgL}^{-1}d^{-1}$</td>
<td>$d^3$</td>
<td>$\text{md}^{-1}$</td>
<td>$\text{md}^{-1}$</td>
</tr>
<tr>
<td>$k_{TP}$</td>
<td>0.0166</td>
<td>0.014</td>
<td>13.497</td>
<td>0.020</td>
<td>0.0146</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.823</td>
<td>0.813</td>
<td>0.928</td>
<td>0.823</td>
<td>0.928</td>
</tr>
<tr>
<td>E</td>
<td>0.982</td>
<td>0.990</td>
<td>0.994</td>
<td>0.919</td>
<td>0.997</td>
</tr>
<tr>
<td>CV</td>
<td>0.481</td>
<td>0.477</td>
<td>1.014</td>
<td>0.524</td>
<td>0.0177</td>
</tr>
</tbody>
</table>

### TABLE 6
Charopo WSPs - biodegradation rate constant $k_{TP}$

<table>
<thead>
<tr>
<th>Model</th>
<th>1st order</th>
<th>2nd order</th>
<th>Kincannon</th>
<th>Kadlec - Knight</th>
<th>Reed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>1st order</td>
<td>Plug flow</td>
<td>Kincannon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d^1$</td>
<td>$d^2$</td>
<td>$\text{mgL}^{-1}d^{-1}$</td>
<td>$d^3$</td>
<td>$\text{md}^{-1}$</td>
<td>$\text{md}^{-1}$</td>
</tr>
<tr>
<td>$k_{TP}$</td>
<td>0.0130</td>
<td>0.011</td>
<td>6.370</td>
<td>0.0153</td>
<td>0.0030</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.653</td>
<td>0.648</td>
<td>0.687</td>
<td>0.653</td>
<td>0.687</td>
</tr>
<tr>
<td>E</td>
<td>0.960</td>
<td>0.978</td>
<td>0.981</td>
<td>0.979</td>
<td>0.981</td>
</tr>
<tr>
<td>CV</td>
<td>0.501</td>
<td>0.999</td>
<td>8.110</td>
<td>1.130</td>
<td>0.0275</td>
</tr>
</tbody>
</table>

### CONCLUSION

Each of the WSP systems has different characteristics and behavior, due to its complicated and multi-parameter ecosystem. Hence, every WSPs system as a separate ecological system operates with different rates. To estimate the kinetics coefficient (KTP) the Reed model, proposed for wetlands, gives the best results in the case of WSPs too. Knowing the appropriate KTP the Reed model can be used to estimate the WSP area requirement, given the TP concentrations in the input and output of WSP and the daily flowrate. This knowledge im-

![FIGURE 3](Image)
proves the WSPs system design under Mediterranean conditions. The first order kinetics model is quite reliable too. The kTP values of the three systems ranged among 0.0030 md-1 to 0.0146 md-1 and among 0.0116 d-1 to 0.0392 d-1. The proposed values are within the limits described in the literature. In particular for Vamvakofito WSPs system kTP value is 0.0112 md-1, for N. Skopos system kTP value is 0.0146 md-1, while for Charopo WSPs system the kTP proposed value is equal to 0.0030 md-1. The kTP values obtained from 1st order kinetic model for plug flow gave for the Vamvakofito WSPs system a kTP value equal to 0.0030 d-1, for N. Skopos system equal to 0.0145 d-1 and for the Charopo system equal to 0.0116 d-1. There is a significant positive correlation between the kinetic coefficient kTP and TSS removal (R2 =0.91).

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NUTRIENT REMOVAL FROM DOMESTIC WASTEWATER BY STABILIZATION PONDS TREATMENT IN NORTHERN GREECE

Maria Gratziou*, Maria Chalatsi

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ABSTRACT

The paper presents the effectiveness of tree waste stabilization pond (WSP) systems, operating in Northern Greece, on nutrient removal. The systems treat only domestic wastewater and consist of one facultative pond, one or two maturation ponds and a rock filter before the final discharge for algae filtration. Significant differences have been noticed among the three systems concerning their concentrations, as well as their efficiencies. During the estimation of mass efficiency, it has been observed that in most cases, mass efficiencies were almost identical to the concentration efficiencies. Yet, this was not the case during summer months, when there was a drop in mass efficiencies. The three systems were recorder to operate smoothly during the study. Moreover, the correlations between influent – effluent mass were satisfactory. The correlations between nutrient removal, pH, temperature, BOD₅, HRT, ponds’ surface and area, were investigated.

KEYWORDS:
Wastewater, stabilization pond, nutrient removal, nutrient mass efficiency

INTRODUCTION

Domestic wastewater contains high concentrations of both nutrient and pathogens, which can affect public health and have harmful impacts on the environment [1], [2]. The Directive of the European Union framework (2000/60/EC) requires at least 75% phosphorus and nitrogen removal, in case of large scale wastewater treatment plants discharges into sensitive aquatic receivers. Current mainstream wastewater treatment technologies, such as activated sludge process with nitrogen and phosphorus removal, are very costly in providing satisfactory results for the growing wastewater problems [3], [4]. The phosphorus removal processes in conventional wastewater treatment systems are expensive, energy consuming and require specialized staff [5]. These procedures are reliable and reasonable for large sewage treatment plants, but they are unaffordable for small wastewater treatment plants that serve rural communities and settlements, due to the economies of scale.

Waste stabilization ponds (WSPs) are an inexpensive method to achieve good pathogen and organic pollutant removal [6]. However, for nutrient removal, such as nitrogen and phosphorus, they have not been very effective. In fact, most operating ponds and wetlands remove little phosphorus and there is no established method for designing ponds for phosphorus removal [7]. Phosphorus removal from municipal wastewater via stabilization ponds is often poor, ranged among 15-50% [8], [9], [10], [11], [12].

Many researchers, in various case studies, provide information about nutrient removal by WSPs in different climatic conditions [13],[14], [15], [16], [17], [18]. In Greece, the use of WSP systems and the research on them is limited; information found in the international literature does not always conform to Greek data, as there are different climatic conditions and living standards, affecting the quality and quantity of produced wastewater.

The research reported herein was held in northern Greece. Three full-scale WSP systems, treating municipal wastewater were monitored for approximately three years. Nitrogen and phosphorus removal were estimated. Moreover, the correlations between influent – effluent mass were determined and equations were performed, correlating the pollutants’ effluent concentrations Cₑ with the influent concentrations Cᵢ. In addition, the correlations between nutrient removal and other parameters, such as pH, temperature, BOD₅, HRT, ponds’ surface and area, were investigated.

MATERIALS AND METHODS

All three systems are established in a lowland area in the mainland of northern Greece in latitude φ: 41° up to 41°15’ N, longitude λ: 23°21’ up to 23°36’ E and altitude from 14 m to 52, in a Mediterranean climate. They treat exclusively domestic wastewater and consist of one facultative pond, one (N. Skopos) or two (Vamvakofito, Charopo) maturation ponds and a limestone rock filter before the final
discharge for algae filtration. The bottom and the walls of the ponds are insulated with compacted clay, in order to avoid losses and leaks in the subsoil. Wastewater discharge takes place through an open channel of 0.75 m² vertical section, from the upper 0.40 m of the last pond, with the assistance of gravity. Every system has different characteristics (Table 1). Operation of Vamvakofito WSP system began in 1989, of N. Skopos in 1980 and of Charopo in 1994. The systems have been monitored for approximately three years. The climate is classified as dry with deviation to the semi-humid with surplus of water during the winter. The average annual temperature is 15.2 °C and the average annual rainfall is 37.37 mm, the mean peak temperature is 26.3 °C and the mean lower one is 3.9 °C in January. The absolute maximum temperature and the lowest rainfalls have observed in July. The winds of the region are not more than 6 km/h [25].

The outflow data were corrected with the mass balance method in order to eliminate errors from atmospheric precipitation and evapotranspiration, since many researchers believe that the mass balance is the most authoritative method to approach mechanisms and parameters that determine the performance of natural systems and the subsequent changes occurring in them [28], [29], [30]. The mass balance is described by the general expression [31]:

\[
\text{mass accumulation} = \text{mass input} - \text{mass output} \pm \text{mass generation or mass consumption} \quad (\text{Eq. 1})
\]

The water balance estimation, described by equation 2, uses the principles of conservation of mass in a closed system:

\[
Q_{\text{out}} = Q_{\text{in}} + Q_{\text{PET}} \quad (\text{Eq. 2})
\]

Where \(Q_{\text{in}}\) is the wastewater outflow quantity [m³/d], \(Q_{\text{in}}\) is the wastewater inflow quantity [m³/d], \(I\) is the water quantity which enters the system via precipitation [m³/d] and PET is the water quantity lost from the system via evapotranspiration [m³/d]. The height of precipitation \(H_{\text{rain}}\) was obtained by the Hellenic Meteo Service, Bureau of Serres and the height of evapotranspiration \(H_{\text{PET}}\) was calculated by customizing the Thornthwaite method [26], [30], due to the small number of the data required for its implementation, compared to the model of Perman-Monterith, which is considered more reliable [32]. The Thornthwaite model, in accordance with other researchers, gives a very good estimation of the water balance for the purposes of this research [32]. Moreover, the high reliability of the method was supported by Alkaeed et al [33].

From the measured concentrations of nutrients, in the input (\(C_{\text{in}}\)) and in the output (\(C_{\text{out}}\)) of the three systems, the removal efficiency of nutrient concentrations is calculated based on the equation:

\[
\text{Removal efficiency}(\%) = \frac{C_{\text{in}} - C_{\text{out}}}{100/C_{\text{in}}} \quad (\text{Eq. 3})
\]

Having estimated, with the Thornthwaite method, the height of evapotranspiration \(H_{\text{PET}}\) knowing the amount of \(H_{\text{rain}}\) precipitation, the change of ponds’ water level \(\Delta H\) [cm] can be calculated. Multiplying \(\Delta H\) with the surface of each system, the changes in volume \(\Delta V\) [m³] are estimated. Dividing \(\Delta V\) with the number of days of each month, the term \(\Delta V/d\) [m³/d] is resulting, i.e. the daily change of the ponds’ volume for each month. The term \(\Delta V/d\) is subtracted from the initial daily flow \(Q\) and thus results a new term \(Q'\).

\[
Q' = Q - (\Delta V/d) \quad (\text{Eq. 4})
\]

Multiplying the new daily flow \(Q'\) [m³/d] with the mean of the concentrations [mg/L] \(c_{\text{in}} < c_{\text{out}} < c_{\text{in}}\) and with the number of days elapsed between sampling (\(\Delta t\)), the final output mass \(\text{Mass}_{\text{out}}\) [kg] is estimated - with appropriate conversion of units.

### Table 1

<table>
<thead>
<tr>
<th>WSP system</th>
<th>Vamvakofito (V)</th>
<th>N. Skopos (N.S.)</th>
<th>Charopo (Ch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow (m³/d)</td>
<td>121</td>
<td>152</td>
<td>137</td>
</tr>
<tr>
<td>HRT (d)</td>
<td>68.7</td>
<td>18.6</td>
<td>72.4</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>F: 1.00-2.40</td>
<td>F: 0.75-2.40</td>
<td>F: 0.80-2.40</td>
</tr>
<tr>
<td></td>
<td>M: 0.75-1.50</td>
<td>M: 0.70-1.50</td>
<td>M: 0.70-1.50</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>6016</td>
<td>2112</td>
<td>7415</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>8311</td>
<td>2827</td>
<td>9921</td>
</tr>
<tr>
<td>m³/e.p.</td>
<td>8.9</td>
<td>2.4</td>
<td>9.4</td>
</tr>
<tr>
<td>m³/m²p.</td>
<td>6.5</td>
<td>1.8</td>
<td>7.0</td>
</tr>
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</table>

To determine the TN, N-NH₄⁺, N-NO₃⁻, TP, BOD₅ and DO concentrations for each system, instantaneous samples were taken from the inflow of the 1st pond and the outflow of the last pond, during the years 2006, 2007 and 2012, at least twice a month [26]. The samples were collected approximately during the same morning period, when meteorological data were recorded. The samples were placed into 1000 [mL] polyethylene bottles and were transferred immediately to the wastewater laboratory of the City of Serres [26]. To enhance the range and accuracy of the data, each sample was analyzed separately twice, implement-ting methods proposed by the Simplified Laboratory Procedures for Wastewater Examination [27] and considering the averages. The inflow and outflow rates were measured with handheld electromagnetic flow meter, with the assumption that wastewater supply was constant during the day. In parallel, pH values were also measured by potentiometric method using pH/Cond340i. Daily meteorological data were obtained from the National Meteorological Service (NMS). The water temperature was recorded in situ, during the days of sampling.

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Mass efficiency (%) = \frac{\text{Massin} - \text{Massout}}{\text{Massin}} \times 100\% (Eq. 7)

\text{Massin} = Q \times \Delta t \times \frac{c_{\text{out}} - c_{\text{in}} + c_{\text{out}} + c_{\text{in}}}{2} \times 10^{-3} \quad (\text{Eq. 5})

\text{Massout} = Q \times \Delta t \times \frac{c_{\text{in}} + c_{\text{max}}}{2} \times 10^{-3} \quad (\text{Eq. 6})

The difference \text{Massin} - \text{Massout} determines the variation of mass throughout the study period. Having estimated the input and output mass of nutrients, the mass efficiency is calculated based on the equation:

Mass efficiency (%) = \frac{\text{Massin} - \text{Massout}}{\text{Massin}} \times 100\% (Eq. 7)

The parameters of the data statistical analysis were calculated for both the concentration and the mass of TN, N-NH\textsuperscript{4+} and N-NO\textsubscript{3}\textsuperscript{-}, TP, with the use of Microsoft Office EXCEL 2007. The calculated parameters are the maximum observed value (max), the minimum observed value (min), the average value (mean) of the inflows (in) and the outflows (out), the standard deviation (STDEV) and the average value of the absolute deviations from the average \(\bar{x}\) (AVEDEV) = \frac{1}{n} \sum_{i=1}^{n} |x_i - \bar{x}|. The performed equations have been evaluated by the coefficient of determination R\textsuperscript{2}, defined as the squared value of the coefficient of correlation according to Bravais-Pearson. It provides a measure of how well the observed outcomes are replicated by the model, as the proportion of the total variation of outcomes explained by the model. The range of R\textsuperscript{2} lies between 0 (no correlation) and 1.0 (the dispersion of the prediction is equal to that of the observation).

### Results and Discussion

The TN, N-NH\textsuperscript{4+} and N-NO\textsubscript{3}\textsuperscript{-} concentrations differ in the three WSP systems; differences were also recorded for the same system due to the different characteristics of the systems’ inflow (i.e. real wastewater). However, no significant deviations in their concentrations were recorded. Tables 2, 3 and 4 present statistical data for TN, N-NH\textsuperscript{4+} and N-NO\textsubscript{3}\textsuperscript{-} inflow and outflow concentrations. Based on the inflow concentration measurements, the systems are classified as low load. The output concentration measurements are satisfactory compared to values of similar WSP systems operating in South Europe [34].

The standard deviations of the output concentrations are particularly small, indicating that the systems’ operation is stable. TN and N-NH\textsuperscript{4+} removal efficiencies are considered satisfactory (Table 5), when compared to similar systems operating in similar climatic conditions, but this is not the case for N-NO\textsubscript{3}\textsuperscript{-} removal [34], [35], [36]. The highest TN and N-N H\textsuperscript{4+} removal efficiencies were recorded in Vamvakofyto in August 2007 and were 93.21\% and 95.82\% respectively. The performance of TN, N-N H\textsuperscript{4+} and N-NO\textsubscript{3}\textsuperscript{-} removal was nearly constant over the years and during the seasons, with only minor variations recorded. The Vamvakofyto WSP system presented by far the best performance for TN and N-N H\textsuperscript{4+} removal, followed by the Charopo WSP system. The lowest TN and N-N H\textsuperscript{4+} removal efficiency values (33.08\% and 33.48\% respectively), were recorded during winter period in the N. Skopos WSP

### Table 2

The TN inflow and outflow concentrations in the three WSP systems [mg/L]

<table>
<thead>
<tr>
<th>WSPs</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>STDEV</th>
<th>AVEDEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>V*</td>
<td>38.3</td>
<td>4.7</td>
<td>12.6</td>
<td>1.1</td>
<td>24.7</td>
</tr>
<tr>
<td>N.S</td>
<td>24.3</td>
<td>14.3</td>
<td>20.6</td>
<td>13.9</td>
<td>22.5</td>
</tr>
<tr>
<td>Ch.</td>
<td>23.5</td>
<td>10.4</td>
<td>22.9</td>
<td>10.2</td>
<td>23.2</td>
</tr>
</tbody>
</table>

*V = Vamvakofyto, N.S = N.Skopos, Ch = Charopo

### Table 3

The N-NH\textsuperscript{4+} inflow and outflow concentrations in the three WSP systems [mg/L]

<table>
<thead>
<tr>
<th>WSPs</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>STDEV</th>
<th>AVEDEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>30.0</td>
<td>3.3</td>
<td>9.7</td>
<td>0.6</td>
<td>19.5</td>
</tr>
<tr>
<td>N.S.</td>
<td>19.2</td>
<td>10.8</td>
<td>16.2</td>
<td>10.6</td>
<td>17.7</td>
</tr>
<tr>
<td>Ch.</td>
<td>18.2</td>
<td>8.10</td>
<td>17.9</td>
<td>7.9</td>
<td>18.1</td>
</tr>
</tbody>
</table>

### Table 4

The N-NO\textsubscript{3}\textsuperscript{-} inflow and outflow concentrations in the three WSP systems [mg/L]

<table>
<thead>
<tr>
<th>WSPs</th>
<th>Max</th>
<th>Min</th>
<th>Median</th>
<th>STDEV</th>
<th>AVEDEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>1.0</td>
<td>0.9</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>N.S.</td>
<td>0.7</td>
<td>0.6</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Ch.</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

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system, when the recorded temperature was at its lowest. Monthly air temperatures ranged from -4 °C to 37 °C and water temperatures from 5 °C to 30 °C.

There were no significant deviations in mass removal efficiencies compared to the concentration ones (Table 5). In some cases they were almost identical (Figure 1). During the summer period, there was a decrease in mass removal efficiency in relation to the concentration efficiency (Figure 1 and Figure 2), due to the strong evapotranspiration, as a result of increased sunlight and high temperatures. This phenomenon was more evident in the case of TN removal in the Charopo WSP system. The latter can be attributed to its greater overall surface, compared to the other two systems, which is related to increased evapotranspiration and increased TN, N-NH$_4^+$ and N-NO$_3^-$ mass in the effluent. In the Vamvakofyto and Charopo systems in particular, negative N-NO$_3^-$ removal efficiencies were recorded, due to the larger ponds’ surface (Figure 2). The present research identified that the removal of TN and N-NH$_4^+$ is associated positively to the facultative ponds’ retention time and to the ratio of the ponds’ surface per m³ wastewater supply too (Table 6), with strong correlation R² (0.974, 0.975 and 0.971, 0.973 respectively). This conclusion is supported by the results of other researchers [20, 37].
The pH values, although lower than 8, in more cases (Table 7), indicate positive association with TN and N-NO$_3^-$ removal (Table 6), with strong correlation $R^2$ (0.946 and 0.947 respectively). It is observed that the pH output was slightly increased. This usually occurs due to algal activity, as reported in the literature [38, 39]. The pH values in the three systems never fell outside the proposed ranges (6-9) for the proper functioning of the lagoons [39, 40].

The maximum, mean and minimum inlet and outlet concentrations of TP in three WSP systems are presented in Table 8. The standard deviations of the output is very low (0.48-1.38 mg/L), indicating their stable operation. The average values of output concentrations are much lower than those of similar systems in Europe [34]. However, the removal efficiency of N.Skopos (23.55%) and Charopo (22.32%) systems is much lower than the efficiency recorded in other similar systems [34]. The lowest TP removal efficiencies of N. Skopos and Charopo systems compared with Vamvakofito one (44.83%) can be attributed to smaller surfaces of facultative ponds since Mbwell [41] showed 90% of TP removal in WSP systems is achieved in facultative ponds.

FIGURE 2
Seasonal variation of mass and concentration efficiency (%) on TN (a) and N-NO$_3^-$ (b) removal.
TABLE 5
The mean efficiencies of TN, N-NH\textsubscript{4}\textsuperscript{+} and N-NO\textsubscript{3}\textsuperscript{-} removal

<table>
<thead>
<tr>
<th>WSPs</th>
<th>TN Concentration</th>
<th>Mass</th>
<th>N-NH\textsubscript{4}\textsuperscript{+} Concentration</th>
<th>Mass</th>
<th>N-NO\textsubscript{3}\textsuperscript{-} Concentration</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>88.13%</td>
<td>87.52%</td>
<td>90.02%</td>
<td>89.48%</td>
<td>15.53%</td>
<td>11.18%</td>
</tr>
<tr>
<td>N.S</td>
<td>35.25%</td>
<td>33.83%</td>
<td>35.57%</td>
<td>34.12%</td>
<td>14.36%</td>
<td>12.48%</td>
</tr>
<tr>
<td>Ch.</td>
<td>54.21%</td>
<td>50.41%</td>
<td>55.27%</td>
<td>51.66%</td>
<td>19.48%</td>
<td>13.02%</td>
</tr>
</tbody>
</table>

TABLE 6
TN and N-NH\textsubscript{4}\textsuperscript{+} removal performance in correlation with qualitative and design factors

<table>
<thead>
<tr>
<th>Facultative ponds’ HRT (d)</th>
<th>Vamvakofito</th>
<th>N. Skopos</th>
<th>Charopo</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.63</td>
<td>7.08</td>
<td>7.39</td>
</tr>
<tr>
<td>Ponds’ surface per wastewater supply per day (m\textsuperscript{2}/m\textsuperscript{3}/d)</td>
<td>20.24</td>
<td>6.95</td>
<td>13.69</td>
</tr>
<tr>
<td>TN Efficiency (%)</td>
<td>88.13</td>
<td>35.25</td>
<td>54.21</td>
</tr>
<tr>
<td>N-NH\textsubscript{4} Efficiency (%)</td>
<td>90.02</td>
<td>35.57</td>
<td>55.27</td>
</tr>
</tbody>
</table>

TABLE 7
Max, min, mean pH values in three WSP systems

<table>
<thead>
<tr>
<th>WSPs system</th>
<th>n</th>
<th>Max in</th>
<th>Min in</th>
<th>Mean in</th>
<th>STDEV in</th>
<th>AVEDEV in</th>
<th>Max out</th>
<th>Min out</th>
<th>Mean out</th>
<th>STDEV out</th>
<th>AVEDEV out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vamvakofito</td>
<td>49</td>
<td>8.09</td>
<td>8.22</td>
<td>6.86</td>
<td>7.09</td>
<td>7.47</td>
<td>7.63</td>
<td>0.32</td>
<td>0.30</td>
<td>0.26</td>
<td>0.26</td>
</tr>
<tr>
<td>N. Skopos</td>
<td>34</td>
<td>8.17</td>
<td>7.95</td>
<td>6.67</td>
<td>6.78</td>
<td>7.03</td>
<td>7.08</td>
<td>0.40</td>
<td>0.32</td>
<td>0.29</td>
<td>0.22</td>
</tr>
<tr>
<td>Charopo</td>
<td>34</td>
<td>7.92</td>
<td>8.08</td>
<td>6.90</td>
<td>7.04</td>
<td>7.29</td>
<td>7.39</td>
<td>0.24</td>
<td>0.24</td>
<td>0.18</td>
<td>0.19</td>
</tr>
</tbody>
</table>

TABLE 8
The TP inflow and outflow concentrations in the three WSP systems [mg/L]

<table>
<thead>
<tr>
<th>WSPs</th>
<th>Max In</th>
<th>Min In</th>
<th>Mean In</th>
<th>STDEV In</th>
<th>AVEDEV In</th>
<th>Max Out</th>
<th>Min Out</th>
<th>Mean Out</th>
<th>STDEV Out</th>
<th>AVEDEV Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>14.60</td>
<td>8.10</td>
<td>2.80</td>
<td>1.30</td>
<td>6.50</td>
<td>3.51</td>
<td>2.42</td>
<td>1.38</td>
<td>1.70</td>
<td>1.03</td>
</tr>
<tr>
<td>N.S</td>
<td>5.10</td>
<td>3.70</td>
<td>2.10</td>
<td>1.67</td>
<td>3.55</td>
<td>2.67</td>
<td>0.78</td>
<td>0.48</td>
<td>0.62</td>
<td>0.39</td>
</tr>
<tr>
<td>Ch.</td>
<td>6.20</td>
<td>4.90</td>
<td>2.10</td>
<td>1.60</td>
<td>4.51</td>
<td>3.49</td>
<td>1.32</td>
<td>1.00</td>
<td>1.07</td>
<td>0.82</td>
</tr>
</tbody>
</table>

The effectiveness of TP removal depends on the amount leaving the water column and entering the lake sediments. This occurs due to the precipitation of the organic P, the setting of the mass of algae and the precipitation of the mineralization as compared to the amount that is returned to the water column through the mineralization and redissolution. This effect becomes more intense at pH levels above 9.5. The pH of ponds ranged from 6.7 to 8.2 with an average value of about 7 to 7.5 (Table 7), therefore redissolution of P is higher. This fact could explain the low P removal efficiency of the three systems [40]. The low performance can also be attributed to the fact that the sludge of the ponds’ sediment hadn’t been removed during their years of operation. Part of the inorganic and of mineralized P, located in the sediment, redissolved and was present in the effluent. The effect of temperature on the performance is evident. As it is shown in Figure 3 all the three systems were more efficient in summer, when the temperatures were higher. The highest efficiency value (71 \%) was recorded in Vamvakofyto system in August 2007.

The TP mass removal efficiencies, overall, had no significant deviations from the concentration ones; in some cases they were almost identical. Only during the summer a reduction of TP mass removal efficiency, compared with the concentration one, was recorded, due to the intense evapotranspiration resulting from greater sunshine and higher temperatures. This phenomenon was more evident in the case of TP removal in Charopo WSPs system (Fig. 4), for the reasons previously mentioned.
TABLE 9
The TP mass and concentration removal efficiencies of the WSP systems %

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Vamvakofito</th>
<th>N. Skopos</th>
<th>Charopo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>68.95</td>
<td>45.22</td>
<td>30.68</td>
</tr>
<tr>
<td>Min</td>
<td>22.29</td>
<td>4.54</td>
<td>-10.27</td>
</tr>
<tr>
<td>Average</td>
<td>42.59</td>
<td>21.38</td>
<td>15.53</td>
</tr>
<tr>
<td>STDEV</td>
<td>8.81</td>
<td>6.41</td>
<td>8.80</td>
</tr>
</tbody>
</table>

In Table 9 the mass efficiencies of the three systems, as calculated using the mass balance method, and the concentration ones, as resulting from sampling and measurements are presented.

It was also noted, that the TP removal following BOD5 removal (Figure 5-6). In systems of N Skopos and Charopo the TP removal efficiency was about half the BOD5 removal, reaffirming [11].

FIGURE 5
TP and BOD5 removal efficiency %

Equations were derived correlating the pollutants’ effluent concentrations \( C_{\text{out}} \) with the influent concentrations \( C_{\text{in}} \). The effluent concentrations have been adjusted using the mass balance method, in order to remove atmospheric precipitation and evapotranspiration, as previously mentioned. The correlations between influent—effluent mass were satisfactory. The equations expressing the relationship of TN, N-NH\( \text{\textsubscript{4}} \), N-NO\( \text{\textsubscript{3}} \) and TP effluent concentrations with the influent concentrations for each system are presented in Table 10. It should be noted that these simple models work in annual or seasonal basis, but it is difficult to use them in momentary basis. First, because there is a nominal delay of a residence time between inflows and outflows and secondly, because the temporary increases and decreases in the storage systems can easily affect the instantaneous performance. The low, in some cases, coefficients of determination, indicate the importance of other factors, not included in this analysis, as the systems’ performance is a multi-parametric subject.

Figure 6 presents, indicatively, some of the linear regressions relating the TN and N-NO\( \text{\textsubscript{3}} \) effluent corrected concentrations with the influent concentrations of Vamvakofito’s WSPs system.

FIGURE 6
Relationships of TN and N-NO\( \text{\textsubscript{3}} \) effluent concentrations versus influent concentrations case of Vamvakofito’s WSPs system
CONCLUSION

The three WSP systems have stable operation. The TN, N-NH₃⁺, N-NO₃⁻ and TP recorded concentrations [mg/L] of the three WSP systems had no significant divergences. The input TN, N-NH₃⁺, N-NO₃⁻ and TP concentration values classify the three systems in low nutrient load class. The output concentration values are deemed to be satisfactory, when compared with values of similar WSP systems which operate in South Europe. The TN and N-NH₃⁺ removal efficiencies were 88.13%, 35.25%, 54.21% and 90.02%, 35.57%, 55.27% respectively in Vamvakofito, N. Skopos and Charopo WSP system and are considered satisfactory, compared to those of similar systems operating under similar climatic conditions. However, the outflow values do not render the outputs suitable for reuse, according to the Greek Legislation. The results are not satisfactory for the N-NO₃⁻ and TP removal, where the efficiencies were 15.53%, 14.36%, 19.48% and 45%, 24%, 22% respectively in Vamvakofito, N. Skopos and Charopo WSP system. The facultative ponds’ retention time, the ratio of the ponds’ surface per m³ wastewater supply and the pH values too seem to have a strong positive correlation with TN and N-NH₃⁺ removal efficiencies, with R² > 0.97 and 0.94 respectively. The highest TN, N-NH₃⁺, and TP removal efficiencies were 93.21%, 95.82% and 70.83 % respectively and were recorded during hot summer period in the system with the highest retention time and the highest ratio of the ponds’ surface per m³ wastewater supply. The lowest TN, N-NH₃⁺ and TP efficiency values were 33.08%, 33.48% and 12.83% respectively and were observed during cold winter period in the system with the lowest retention time and the lowest ratio of ponds’ surface per m³ wastewater supply. The performance of TN, N-NH₃⁺ and N-NO₃⁻ removal in each WSP system was nearly constant over time and during the seasons, with minor variations. The phosphorus removal efficiencies of N. Skopos and Charopo WSP systems are about the half of BOD₅ removal efficiencies. This relationship is confirmed by other researchers in similar systems. The reduced TP performance can be attributed to the increase of the sediment in the ponds since the sludge did not removed during the years of systems’ operation as a part of the inorganic and of mineralized P, located in the sediment, redissolved and is presented in the effluent. As well as, the lowest phosphorus removal efficiency of N. Skopos and Charopo systems attributed to fewer surfaces of facultative ponds and to lower pH value as the role of pH is important in TP removing. The pH was ranged from 6.7 to 8.2 with an average value from 7 to 7.5, which partly explains the low TP systems’ efficiencies inasmuch as these values the phosphorus redissolution is higher, according to the literature. The mass removal efficiencies had not significant deviations from the concentration ones. Exception to this was the summer period, where there was a decrease in mass removal efficiency in relation to the concentration efficiency due to the strong evapotranspiration. This phenomenon was more evident in the system with the greater ponds’ surface, where negative efficiencies were recorded. Equations expressing the TN, N-NH₃⁺, N-NO₃⁻ and TP effluent concentrations as a function of the influent concentrations for each system were derived.

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CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

REFERENCES


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MULTIPURPOSE HYDROPOWER PROJECTS ECONOMIC ASSESSMENT UNDER CLIMATE CHANGE CONDITIONS

Charalampos Skoulikaris*, Jacques Ganoulis

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ABSTRACT

Large-scale hydraulic projects and water infrastructures have direct impacts on the social and ecological landscape in which they are located and vice versa. In accordance to the sustainable development concept, multipurpose hydroelectric plants apart from power generation and thus profitability, should cover socioeconomic and environmental services. In the proposed methodology, the aforementioned services are attributed in monetary terms in order to trigger a custom economic tool that is based on the Net Present Value rule so as to assess the economic viability of a new hydropower plant. Moreover, the impact of climate change on the natural resources feeding the plant is considered as an externality that should be evaluated and introduced in the feasibility study of a new renewable energy project. The results from the coupling of mathematical models such as hydrological, hydropower plants' operation, climate change and capital investment models, revealed that the projected meso and macro timescale decrease of water discharges will have direct negative effect on the investment profitability and thus the planned payback period. Moreover, the coupling of climate change with electricity wholesale prices fluctuations could completely jeopardize the project and consequently have a deterrent effect rather than attracting investors.

KEYWORDS:
climate change; project financing; hydroelectric plants; wholesale electricity prices; water resources management.

INTRODUCTION

A project economic sustainability is linked to sufficient cash flows that can provide a return payment of the initial project expenditures within a predefined time period, commensurately cover the operational costs while the generated returns meet a sufficient target benchmark. The net present value (NPV) method is one of the most popular methods [1] in the process of planning for and deciding upon capital investments, also known as capital budgeting, with positive-NPV projects to be the more attractive investment in terms of profitability [2]. However, capital budgeting not only focuses on the evaluation of cash flows based on the time-value of money relation [3], but also thoroughly investigates potential risks which might jeopardize the viability of projects and thus the investment [2]. When dealing with renewable energy projects, intrinsic risk, among other types of risks, regards unforeseen problems that may emerge after a project's completion and corresponds to overestimation of the natural resources under exploitation [4]. In the case of hydropower plants where the fuel is the water, variations caused by climate change in this natural resource might affect the project viability. Especially, projects that are located in the Mediterranean zone, where the frequency and intensity of drought is likely to be increased, and increased surface temperatures with parallel decreased annual precipitation, particularly in terms of precipitation days, is very likely to be observed [5], will have to cope with the negative effects of climate change. The aim of the current study is to evaluate the economic sustainability of a multipurpose hydro-power project due to the hydrological risk as derived by climate change impact to basin hydrology. Particular attention is also paid to the margins of the wholesale prices of electric power and its impacts during project's life cycle.

MATERIALS AND METHODS

Case study: The Nestos river basin. The Nestos river basin is a transboundary basin in South Eastern Europe that is shared between Bulgaria, upstream country, and Greece, downstream country. Figure 1. The river both in terms of catchment's extent and river's length is almost equally shared between the two countries, i.e. 46% of 6,219 km² and 51% of 255 km are located in Greek territory [6]. In the Nestos basin, the different socio-economic conditions prevailing in each country result in having different development preferences and objectives at each part of the borders [7]. In 1972, the mean annual runoff gathered in the Bulgarian part of the basin has been estimated up to 47.0 m³/s, while the water flow entering Greece was 39.43 m³/s. More recent data revealed that the averaged interannual total water volume which enters Greece is 39.43 m³/s. More recent data revealed that the averaged interannual total water volume which enters Greece is 39.43 m³/s. More recent data revealed that the averaged interannual total water volume which enters Greece is 39.43 m³/s.
Competitive water uses are obvious even at national level, with the Greek part of the basin being a representative example. Hydropower use and future investments, agricultural water demands and riparian/coastal environmental needs aim at harnessing the same natural resource. In particular, the coastal deltaic area of approximately 550.0 km² is attributed with both socioeconomic and environmental services. Agriculture in the delta of the river Nestos is a highly developed industry with great importance to the regional/national economy, while the river estuaries and delta’s mouth are protected by environmental legislations [9]. On the other hand, since the late 1990s, in the mountainous Greek part of basin, 2 large hydroelectric power stations, namely Thisavros and Platanovrisi, regulate the water for energy production and irrigation purposes. A new multipurpose hydropower plant, namely Temenos, Table 1, downstream of the two other, is planned to be constructed in a relatively short time period.

Hydrological modeling. The simulation of the hydrological behavior of the Nestos basin was conducted with the use of the spatially distributed hydrologic model MODSUR [7, 10]. It is a grid-cell based model which utilizes a progressive mesh with varying rectangle cells ranging from 250 m for the smallest to 2000 m for the largest, Figure 1. Grid cells, which are more refined, are used for the representation of the river and tributaries beds as well as areas with complex relief and land use. Homogeneity in terms of terrain, soils, vegetation and land use is attributed by larger mesh cells, such as in the deltaic area of the basin or plain areas. For the delineation of the hydraulic and topographic characteristics of the basin, such as stream definition and accumulation, watershed and streams delineation, slopes computation, a global digital elevation model (DEM), with a horizontal grid spacing of 30 arc seconds, namely GTOPO30, was successfully processed. The specific approach and the spatial resolution of the DEM is suggested when dealing with large catchments, such as the Mekong [11] and the Senegal [12] river basins. Apart from the topography and the land uses, meteorological data consisted of precipitation and temperature parameters and obtained by a dense monitoring network of more than 20 stations both in Bulgaria and Greece, Figure 1, together with the computed evapotranspiration with the use of the Turec method [13], were used as input data for the simulation of the river runoff. The model calibration was based on monthly river flow measurements in both countries for the period 1987 to 1992, while the model validation was conducted for the period 1993 to 1995. Finally, the simulated river discharges were used for triggering the dams’ simulation model, while the calibrated hydrological model was used in order to simulate river runoffs under climate change conditions.

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of existing and future hydropower plants in the Nestos River</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Existing infrastructure</th>
<th>Future project</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thissavros dam</td>
<td>Platanovrisi dam</td>
</tr>
<tr>
<td>Upper operation</td>
<td>380</td>
<td>227.5</td>
</tr>
<tr>
<td>level (UOL) (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume in UOL</td>
<td>750</td>
<td>84</td>
</tr>
<tr>
<td>$10^6$ m³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Useful volume</td>
<td>565</td>
<td>11</td>
</tr>
<tr>
<td>$10^6$ m³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reservoir surface</td>
<td>18</td>
<td>3.25</td>
</tr>
<tr>
<td>in UOL (Km²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>175</td>
<td>95</td>
</tr>
<tr>
<td>Number of units/Total power (MW)</td>
<td>3/300</td>
<td>2/100</td>
</tr>
</tbody>
</table>

Simulation of hydropower operation. The current and future hydroelectricity power stations operation was evaluated with the use of the WEAP21 model. The model requires two types of input data: i) the technical characteristics of the dam project, Table 1, and ii) the inflow discharges to the reservoirs which are derived by the hydrologic model. The simulation processing is based on a linear programming (LP) solver which allocates the available water resources across the hydrosystem, Figure 2 [14]. The hydrosystem is composed by specific supply and demand nodes that represent the subcatchments draining into the river and the irrigation and environmental water requirements.
FIGURE 2
Illustration of the Nestos river hydrosystem under WEAP model, with green and red dots representing the supply (subcatchments) and demand (irrigation and environmental flow) nodes respectively [14].

TABLE 2
Characteristics of the utilized Regional Climate Model

<table>
<thead>
<tr>
<th>Model</th>
<th>Acronym</th>
<th>Sponsored Institute</th>
<th>Parent GCM</th>
<th>Resolution (km)</th>
<th>Lower left corner (lat/lon)</th>
<th>Upper right corner (lat/lon)</th>
<th>Emission Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLM-RCM</td>
<td>CLM</td>
<td>Max Planck Institute for Meteorology</td>
<td>ECHAM5/MPIOM</td>
<td>20*20</td>
<td>34.6/-10.6</td>
<td>69.8/36.8</td>
<td>B1</td>
</tr>
</tbody>
</table>

respectively. The LP solver’s objective function is to maximize satisfaction of demands, subject to demand priorities, mass balances and other constraints [14]. In order to coincide with the national environmental legislation of a constant environmental flow requirement equal to 6.0 m³/s, and by taking into account the importance of agricultural activities, the demand priorities of environmental flow, irrigation and hydropower production were set to 1, 2 and 3, respectively as the priority operational rules of the dams.

Regional climate models. The investigation of the climate impacts to the river runoff was conducted with the use of a European Regional Climate Model (RCM), namely Climate Local Model (CLM). The version of the model used in this research is the CLM-22 [15], i.e. it has a spatial resolution of 22Km, with the details on this non-hydrostatic model dynamics and physics to be demonstrated in the literature [16]. The outputs of the CLM are generated at a 0.2° regular step (177x278 grid points in latitude per longitude), while the model incorporates 32 vertical atmospheric layers. CLM uses as forcing conditions, i.e. boundaries conditions, those derived by the General Circulation Model ECHAM5/ MPIOM [17]. This technique which is occurred in order to simulate finer-scale physical processes consistent with the large-scale weather evolution is known as dynamic downscaling technique. Information relative to the utilized RCM, such as utilized emission scenarios etc, are presented in Table 2. The required variables to the hydrological model, i.e. temperature, precipitation and evapotranspiration were retrieved for the whole simulation period i.e. from 1960 to 2100. As far as the evapotranspiration is concerned, it doesn’t being simulated by the climatic model but it is computed based on the averaged surface latent heat flux [16]. All the aforementioned climatic variables were intersected to the hydrologic model grid with the use of proper geographic information system techniques.

Discounted cash flow. In order to estimate the attractiveness of the investment opportunity on the Temenos project, a custom tool based on the discounted cash flow (DCF) concept was developed and applied over the project life cycle, which in case of hydroelectric plants is more than 50 years. DCF analysis uses future free cash flow projections and discounts them to arrive at a present value in order to investigate the project economic viability, a methodology which is routinely being used for project financing evaluation and decision making [18]. The sum of the series of discounted cash flows was implemented with the quantitative criterion of the Net Present Value (NPV) [5] as given in Equation 1,

\[ NPV = \sum_{n=0}^{N} \frac{I_n-C_n}{(1+r)^n} \]

where I are the incomes, C are the costs, r is the discount rate of return and n is the number of years from final return payment, i.e. the project’s life time.

The project revenues, i.e. incomes in the NPV equations, are summarized as i) the wholesale of electricity, ii) the sale of water for irrigation, and iii) the sale of water from the pump storage procedure with the upper dam. On the other hand, the project expenditures, i.e. costs in the NPV
equations, consist of the i) capital expenditure, ii) operational expenditure, iii) compensations to farmers in case of inadequate water volumes for water demands, and iv) cost of rehabilitation of the environment when environmental flow is unmet.

RESULTS

Assessment of climatic variability. The alteration of future climate (2021-2050) in terms of temperature \((T)\), precipitation \((P)\) and evapotranspiration \((ETP)\) are presented in Figure 3, where future projections as derived by the CLM model for the B1 emissions scenarios are compared with hindcast data (known as control data) also derived by the climatic model for the period 1971-2000.

Regarding the precipitation, the illustrations of the first row in Figure 3 demonstrate the percentage variation between the future and control data normalized by the control period data, i.e. \((P_{2021-2050} - P_{1971-2000})/P_{1971-2000}\). An averaged significant decrease of future rainfalls of approximately 12.9% was revealed for the whole future period at basin scale, with the middle parts of the basin to be more affected. The quarterly analysis demonstrated that rainfalls during the summer period (JAS) present an average decrease of 15.2% while the maximum decrease for the same period is estimated at 38.4% at the deltaic area of the basin. In terms of temperature, where the 2nd row of illustrations gives the absolute difference between future and control data, the model outputs indicate a potential average increase of 0.9 °C - 1.0 °C at basin scale, with the Bulgarian and mountainous part of the basin to be more influenced. During spring period (AMJ) the basin will be influenced by the smaller average increase of 0.5 °C - 0.6 °C, while the larger increase of approximately 1.2 °C - 1.3 °C to be predicted for autumn and early winter period (OND). Finally, the ETP variations, i.e. future minus control data normalized by control data, which are presented in the 3rd row, do not follow a specific spatial pattern. Moreover, ETP is the only variable that presents negative values, i.e. there are geographic areas where predicted evapotranspiration is lower than the historic one. It can be said that the middle part of the basin is an area of negative ETP.

Impact of climate change to river’s runoff and hydroelectric operation. According to available historic monthly time step discharges at the borders of the two countries from 1975 to 1995, the average water inflows in the Greek territory was approximately 20.6 m³/s [8]. The simulated runoffs at the borders, with the use of the control period data and the future climatic data for B1 emission scenario, were assessed at 22.5 m³/s and 16.9 m³/s respectively. Thus, the climatic variations result on a significant decrease of 24.8% of the river’s runoff entering into Greece in comparison with the control data period. The reduced surfaced discharges have direct impact to the Temenos reservoir’s stocked water volumes and thereafter to the produced hydropower as indicated in Figure 4. The reduced
Apart from the expected seasonal variations, i.e. less stocked waters in dry than wet months of the year, there are long term periods with decreased reservoir storage. The interannual reservoir storage for the 30 years period is estimated at 69.6%, while during the extended water stressed period of 2037 to 2046 the Temenos reservoir's storage fell to 52.8%. At intermonthly time scale, the higher and lower reservoir storage of 80.8% and 61.0% are expected during the AMJ and JAS quarterlies, nevertheless these figures are turning to 66.2% and 40.4% respectively for the aforementioned water stress period. Moreover, the dam's upper operational level (UOL) is met less than the half years of the simulated period, while during the dry period of 2037-2046 there are the times where the reservoir's water level gets lesser than the lower operational level (LOL) of the plant.

In terms of produced energy, the interannual produced energy corresponds to 34.4 GWh which is mainly produced during the wet months, i.e. the produced energy fluctuates between 3.6 GWh to 4.3 GWh and between 3.6 GWh to 4.1 GWh for the JFM and AMJ quarterlies respectively. On the other hand, during the JAS, the average intermonthly energy cannot exceed the 1.6 GWh. During the water stressed period of 2037 to 2046, the averaged produced energy is almost 2.0 GWh mainly due to important disability of refilling the reservoir with water during the winter.

Discounted cash flow tool. The results of the DCF model for different wholesale electivity prices that were retrieved in the literature [21] for the fifteen years period of 2001-2014 are illustrated in Figure 5. The figure, in particular, demonstrates the project economic viability expressed through the NPV for selective historical wholesale prices. The 15-year average price was 63.5 €/MWh with the maximum and minimum prices to be 78.0 €/MWh and 45.8 €/MWh respectively, while the prices present by and large decreasing trend, with a standard deviation of 19.71% and a variance of 3.89%. The further data analysis revealed that the amount of water volumes is also bound to have severe impacts to the agricultural sector, since agriculture is the prime consumer of water and the associated consumption, it is projected to be six times the consumption of the early 20th century [19].
68.84 €/MWh is the crucial price for selling electricity in the wholesale market in order to achieve positive NPVs. The larger NPV and thus the highest profitability of the project equal to 3.86 M€ coincides with the maximum electricity price. On the other hand, it is observed that after the year 2007 the project presents constantly negative NPVs with losses of more than 11.5 M€ to be presented in the years of 2010 and 2013 where the price is lower than 53.0 €/MWh.

**DISCUSSION**

The proposed methodology evaluates the climatic variability on the hydropower industry, a thematic that has not been thoroughly investigated especially when social and environmental criteria are inserted in the feasibility study of a new project. Compared to the research on emissions from or mitigation by the energy sector, research on the impacts of climate change on the energy sector has been surprisingly scant [20]. It was only the last few years that there have been some regional and sectoral reviews [21]; nevertheless any broad review of the impacts of climate change on the electricity sector has not been conducted [20].

The methodological sequence of models or individual parts can be applied to any hydropower project. The custom developed economic tool, in particular, can be universally implemented since the net present value (NPV) is the preferred way to evaluate the profitability of any investment [22]. Of course, the internal rate of return (IRR) to evaluate the prospective investments is also used as a universal practice, however both NPV and IRR methods are functionally equivalent and are preferred over all other capital budgeting methods [23]. In addition to the initial investment cost, the annual operation and maintenance costs can be retrieved in the literature for similar type of projects, and introduced in the tool. The incomes are also computed by manually selecting the electricity and water selling prices. As for the water selling price, for the specific case study the data were retrieved by the River selling price, for the specific case study the data were retrieved by the River Water District Plan of Thrace Water District [24].

As for the use of climate change data, direct application of the output from General Circulation Models (GCMs) is rather inadequate due to the limited representation of mesoscale atmospheric processes, topography, and land-sea distribution in GCMs [25]. Moreover, and of particular concern to precipitation, GCMs exhibit a much larger spatial scale than is usually needed in impact studies. Thus downscaling techniques, such as the dynamic downscaling, which is adopted in this work, could be considered as interoperability bridges for the amelioration of the inconsistencies that result from applying large scale and coarse resolution data at regional scales. Concentrating on the utilized CLM model, the analysis of the bias derived by the model implementation at European scale [26] indicated the acceptable biases at the Mediterranean zone. In terms of produced results, the model projects an overall increase of temperature and a significant decline of rainfalls. The latter results on decreased river discharges and consequently to potential water stress situation, mainly during the summer period due to augmented agricultural demands on water. Focusing on the mountainous Bulgarian part of the basin, impacts on snowpack coverage and duration and thereafter reduction of the summer river baseflow could be produced by the foreseen temperature change. The alteration of snow cover due to climate change in the Southern Bulgaria has been also demonstrated in the literature [27] where there are presenting objective evidences for an increasing annual mean temperature, longer vegetative periods and local droughts in spring and autumn.

The intersection of the various scales of the models inputs and outputs, i.e. 0.2° mesh of the climatic model, variable mesh of 250-2000 m of the hydrological model, was conducted with the use of Geographic Information System (GIS) technology. The specific approach has regularly been used in various scientific sectors, such as in modelling soil erosion and deposition when spatial data of different scales are available [28] or when assessing the local permafrost dynamics by coupling RCMs with local regional topographic characteristics [29]. As for the point source data, i.e. data from the meteorological stations, distribution over the basin’s area, the literature presents a comprehensive analysis of geostatistical approaches, such as kriging and its variants, other techniques based on splines or generic algorithms [30]. In the present case study, the Ordinary Kriging was the selected interpolation method.

The proposed methodology evaluates the fluctuation of the wholesale electricity market based on historic values in order to produce a sensitivity analysis that is a key element of project appraisal. Critical variables, such as the energy price, that present a degree of uncertainty while having a critical role to the project returns and the investment are varied in order to evaluate their impacts. On the other hand, the literature presents case studies where climatic variables are also induced in sensitivity analysis by altering historic precipitation and temperature levels by amounts similar to those indicated by GCMs [31]. The analysis indicates that there is a unique price limit below which it is never optimal to invest, but above this limit investment is bound to be prosperous. Moreover, the analysis demonstrates a negative covariation between the electricity price, similar to other case studies in EU [32]. Evidence of this is strongest during the AMJ quarterly, where for the specific period the prices usually are at their lowest value, due to negligible surplus energy demands, while water inflow and production reaches their
maximum level. During that period, the weather conditions are mild, thus no extra energetic loads are required for covering heating or cooling demands. Geographical location also affects prices which are determined by the local supply-demand conditions. There are cases that these prices are approximately equal, but when a bottleneck arises there might be significant divergence between the different geographic areas [32]. Moreover, countries having lower than optimal interconnection capacities to their neighbours (e.g. some of the Baltic states, Greece or Ireland) tended to have significantly higher prices than most of other European peers [33].

The large differences in the wholesale price among the reference years is based on the liberalisation of the electricity market in the European Union that was activated in the early 2000s and set new standards for electricity prices. In accordance to the Electricity Market Directives, a system of competition was developed to auction spare capacity through a central system. Consequently the day-ahead market yields the reference price for the industry, as it constitutes the major component on which generators’ cash-flows are based. This is the reason why the electricity price in reference year 2001 is much higher than in the period after the directives implementation. Furthermore, climatic parameters play an important role in electricity price fluctuations. The fact that years 2009 and 2010, for example, were two successive years of intense wet conditions resulted in excess storage capacity of the reservoirs and consequently the substantial capacity surplus in the market set pressure on the electricity price. The price of 2010 indicates this pressure. On the other hand, water scarcity conditions of 2011 exerted an upward pressure on wholesale prices, due to the need for substitution by more expensive energy, resulting in a 12.4% increase of prices between 2010 and 2011. This is the reason why in cases of drought periods it is proposed as a further research topic the utilization of hedging rules to mitigate the impact of droughts and thus to minimize the economic damage [34].

CONCLUSIONS

Apart from new technological approaches, investments in the water sector and particularly in large scale hydraulic projects, such as hydropower plants, globally accepted environmental concepts, which are derived from the Millennium Development Goals (MDGs), should be encompassed and foster water management and sustainable development. Furthermore, current challenges such as those imposed by climate change should also be taken into consideration.

Inspired by the aforementioned, this specific work proposed a sequential water resources modelling approach for the development of an integrated, coherent and flexible tool for assessing the viability of large scale water projects. Specific emphasis has been given to the assessment of the economic viability of new dam projects and the evaluation of the sustainable operation of projects generating renewable energy from water under climate change conditions. The proposed methodology is suggested to be complementary to new investments related with high cost hydraulic projects.

ACKNOWLEDGEMENT

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THE IMPACT OF THE URBAN ROAD NETWORKS’ FUNCTIONAL AND TRAFFIC CHARACTERISTICS ON AIR POLLUTION: THE CASE OF THE CENTER OF THESSALONIKI, GREECE

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ABSTRACT

The road transport system has been developed at the urban and interurban level creating appropriate networks in order to service traffic safely and efficiently. The increase of urban traffic flows leads directly to a rise of the externalities associated with motorized traffic. One of the major impacts is the atmospheric damage caused by pollutant and greenhouse gas emissions from vehicles contributing to negative atmospheric phenomena, global warming and climate change. Traffic emissions pose a serious threat because although they do not cause large numbers of direct victims, serious consequences may arise in the long term which are both local and universal in character. In the present study the effects of the urban road networks’ functional and traffic characteristics on traffic as well as on the produced emissions are investigated along selected road segments in the city of Thessaloniki, Greece. Towards this purpose, the road network was first categorized according to the road characteristics, based on in-situ surveys. Then, traffic volume and composition field measurements were conducted and the collected data were used for the CO₂, CH₄, N₂O, NOₓ and PM₁₀ emission calculation due to motorized traffic using the COPERT4 emission estimation model. Finally, the findings are presented, evaluated and associated with the characteristics of each road category.

KEYWORDS:
emissions, transport externalities, traffic characteristics, greenhouse gases, sustainability, urban mobility.

INTRODUCTION

The transport sector is inextricably linked to daily human activities and has a major impact on socioeconomic development as distances are bridged, making it possible for people and goods to be transported efficiently across the urban space. Motorized transport plays a key role in the level and form of urban development, providing ways to serve more complex mobility needs, initially through public transport and lately through the rapid expansion of private car use [1]. The shift made towards motorized mobility during the last decades becomes obvious by observing the temporal change of the private car ownership index. The problems arising in urban areas vary and have serious impacts on the natural and built environment and the overall life in cities. Extended use of transport can have serious impacts on the environment and also to people who suffer daily from congestion, traffic noise and increased pollutant and greenhouse gas emissions. The transport sector is responsible for 30.40% of the total CO₂ emissions in Europe [28], while the road transport sector participates with 71.10% in European CO₂ transport emissions with an estimated 40% of road transport coming from urban road traffic [2, 3]. In the late 20th century, the concept of sustainable development was integrated in all European policies [4]. Thus, the principles of contemporary transportation planning require a sustainable urban mobility plan accompanied by the addressing of the aforementioned negative effects. Inherent to this effort towards sustainability, is the control of pollutants produced by urban traffic and therefore numerous studies and research efforts have been conducted within this framework [5–11]. As the role of gas emission estimation models is instrumental for a sustainable urban transportation, the scope of this paper is the assessment of the urban mobility impact on the environment through a case study at the city of Thessaloniki, Greece.

METHODOLOGY

Serious efforts are nowadays directed towards the identification and minimization of the environmental problems emerging from motorized urban mobility and emission estimation models constitute a useful tool for a sustainable transportation planning, evaluation and policy making. Towards this aim, an assessment of the impact of urban mobility on the environment is attempted for the city of Thessaloniki, where rising car ownership combined with non-integrated transport planning and lack of adequate law enforcement apply constant pressure on
the urban road network. In this context, traffic data were collected from representative road segments of the categorized urban road network in order to generate reliable and systematically acceptable data for CO₂, CH₄, N₂O, NOₓ and PM₁₀ emissions after the appropriate processing with the COPERT4 emission estimation model.

The COPERT (Computer Programme to Calculate Emissions from Road Transport) software embodies technological research results concerning road vehicle emissions and has been developed as a European tool for calculating road transport emissions and fuel consumption. It was designed for use by the European Union member states but in recent years its use has been extended to various countries worldwide. The version of the program used in this study is COPERT4 which is the fourth revised version. COPERT is an important tool for assessing the effects of traffic on air by calculating emissions from all major traffic polluters including all vehicle categories in circulation. Since their environmental behavior differs, vehicles are divided into classes, including passenger vehicles, light commercial vehicles, heavy duty trucks, buses, mopeds and motorcycles. The emissions calculated are distinguished into regulated and non-regulated types, including CO, NOₓ, VOC, PM and N₂O, NH₃, SO₂, NMVOC respectively. For the calculation, the pollutants are separated into four categories: the first includes pollutants for which a fixed analytical methodology and emission factors exist and cover a variety of traffic environments also taking into account the engine conditions; the second category includes pollutants whose emissions are based upon fuel consumption, while the level of detail of the results is similar to the first category. The third category includes pollutants whose emissions are based upon a simplistic methodology due to lack of data. The fourth category includes pollutants that are a fraction of the total NMVOC emissions [12, 13].

The methodology that was developed comprises a series of steps leading to the production of results concerning the correlation of traffic emissions with the functional and traffic characteristics of an urban road.

Initially, a search for available data sources and the selection of appropriate data from the most relevant sources is conducted. The road network of the study area is categorized hierarchically according to its functional (i.e. road class, directions, lanes per direction, existing bus-lanes, existing traffic control island, existing signalized intersection, on-street parking) and traffic characteristics (i.e. traffic volume, vehicle speed, traffic composition), based on data gathered from relevant state or municipal agencies. The reliable categorization of the urban road network based on its functional characteristics is a prerequisite for the effective use of traffic data and for traffic analysis.

Representative segments of each category of the study area’s road network are selected according to the information collected in the previous step combined with satellite or aerial photos obtained from relevant state agencies and/or appropriate internet services. Then, for each selected road segment an on-site recording of the local functional and traffic characteristics is conducted and the data collected are stored in a database for further reference. Traffic counts, field or remote, are conducted for each selected road segment in order to collect data concerning the peak and off-peak traffic (i.e. volumes, composition, speed), followed by the primary data processing that includes the hourly traffic volumes and the average peak and off-peak traffic speed calculation and the formation of an electronic database for all the selected road segments for further reference. The data gathered through the previous steps are recorded in spreadsheets and are then used for the preparation of the COPERT4 suite input files, according to its requirements. The data are processed through the COPERT4 model and greenhouse gas and particle emissions are estimated for each road segment during the peak and off-peak period respectively. Finally, the results from the use of COPERT4 are exported and correlated to the functional and traffic characteristics of the selected road segments; the overall evaluation of their environmental performance is examined leading to conclusions.

FIGURE 1
Methodological steps of the study
CASE STUDY

Study area. The study area is situated in the center of the city of Thessaloniki, the second largest city in Greece and the administrative, financial and cultural center of Northern Greece. According to the 2011 national census it has a population of approximately 1.1 million [14]. Transportation within the study area is mainly conducted by private car or public bus, the latter being the only available public means, serving about 167 million passengers annually. However, the private car occupies first place in the preference of Thessaloniki’s citizens, with a high passenger car ownership index of 450 vehicles per 1000 inhabitants [15]. The latest general transport study for Thessaloniki shows that the center of the city is the origin and/or destination of 25% of approximately 2.3 million daily trips [16]. The concentration of population and activity in the city center along with the existing private car dependency have a major impact on traffic congestion along main arterials of the city center [17].

Application of the methodology. The methodology developed is applied in the study area, the center of the city of Thessaloniki, where there is a high pressure on its urban road network due to the concentration of a great number of various activities. In order to accurately capture the emissions from urban transport in the city center, some of the most important road axes were examined, having as a key selection criterion their functional classification so to cover all road types. Initially, the possible data sources were examined and after the provision of the necessary information concerning the functional characteristics of the central urban road network of Thessaloniki by the Aristotle University of Thessaloniki Transport Engineering Laboratory (AUTH – TEL), the road network of the study area was categorized accordingly and representative road segments from ten important urban road axes that belong to the center of Thessaloniki were used for the case study as shown in Figure 2. The selection was made in order to cover effectively the main types of urban roads of the area that make up the urban road network and serve the majority of traffic, thus contributing the most to traffic emissions.

Teams of field traffic observers conducted an on-site recording during June 2014 of the local functional characteristics of the selected road segments, including the number of lanes per direction, the existence of bus-lanes, traffic-control islands and nearby signalized intersections. The length of each road segment was measured using an on-line satellite imaging service and all the data collected were stored in a database for further reference. Moreover, observers were used for the recording of the local traffic characteristics at the selected road segments, using the appropriate traffic data collection forms. The recorded vehicles were separated into six distinctive categories (i.e. two-wheelers, taxis, private cars, light trucks, heavy trucks and buses) since the driving conditions, the engine and the fuel catalyst affect the composition of the exhaust gases emitted by various vehicles and therefore the amount and type of emitted pollutants varies depending on the
vehicle category. The vehicle categories included in this study are the ones in circulation in the study area: Passenger Cars (Gasoline, Diesel, LPG, Hybrid Gasoline – according to engine size), Light Commercial Vehicles (Gasoline, Diesel – according to engine size), Heavy Duty Trucks (Gasoline, Diesel Rigid, Diesel Articulated - according to weight), Buses (Urban Midi, Urban Standard, Urban Articulated, Coaches Standard – according to weight), Mopeds (2-stroke, 4-stroke – according to engine size) and Motorcycles (2-stroke, 4-stroke – according to engine size).

Traffic data collection took place during the summer season of 2014 for peak (08:30 - 09:30) and off-peak (10:30 - 11:30) periods for each of the selected road segments. It should be noted, however, that for two of the selected road segments (Mitropoleos and G. Papandreou) peak and off-peak periods are reversed, contrary to the rest of the segments under study. Nevertheless, we refer to the time section 08:30-09:30 as peak period as it is peak hour for the majority of the selected road segments and in the same manner for the off-peak period. This assumption does not affect the emission results that are presented categorized as peak and off-peak results, taking into consideration the corresponding hours for each road segment respectively. In addition, the recordings refer to the overloaded direction when the road is bidirectional and to the whole width when the road is unidirectional. The gradient along the examined road segments was small, while the number of lanes varied depending on the role of the road within the urban road network. The observers recorded the number and type of vehicles at the midpoint of each segment at an adequate distance from any bus stop, traffic signal or any other street features that could cause queues and stored them in a database for further reference. The speed of the serviced traffic was calculated using available volume-speed mathematical curves for each road segment for peak periods and off-peak periods, as provided by AUTH – TEL relevant research [19].

Before the data input to the COPERT4 model software, the following primary processing took place: The data from observer recordings in the field were imported in spreadsheets for each road segment, separately for the two periods and the total traffic volume was calculated separately for the two periods as well. The COPERT4 model software suite input files were prepared for each road segment; in particular, traffic volume, composition, speed and segment lengths were incorporated to the model files. Some vehicle categories included by default in the COPERT4 model input files were excluded from the study under the assumption that they are not observed on specified road segments based on existing legislation and the current public transport fleet serving the study area. Therefore, the selected road segments were divided into three categories: the first category includes Egnatia, Tsimiski, G. Papandreou, Aggelaki, Stratou Ave., Papastasiou and Mitropoleos. For this category, heavy vehicles over 14t, articulated coaches, urban natural gas buses and urban biodiesel buses were excluded from the model, since these vehicles are not observed along these road segments. The second category, includes N. Plastira. For this category, articulated buses were excluded, in addition to the vehicles excluded in the first category, since only non-articulated buses are observed along this road segment. The third category includes Mpotsari and Olympiados. For this category all buses are excluded, in addition to the vehicles excluded in the first category, since no public buses are observed along these segments. After all the model input files were prepared the model software was used for each road segment of the study for the peak and off-peak periods. Emission data concerning greenhouse gas and particulate matter emissions were exported and CO2, CH4, N2O, NOx and PM10 emissions were used as the reference pollutant emissions for the current study. CO2, CH4, and N2O were selected as three of the main greenhouse gases already monitored by the Kyoto Protocol, while NOx and PM10 emissions were added because of their negative effects on the atmosphere and public health. The results of the above case study are presented analytically in the following section.

RESULTS

The results obtained from the processing of the data collected from field measurements with the COPERT4 model are summarized in the tables and figures below. Table 1 presents the functional characteristics of each of the selected road segments, Table 2 presents the respective observed traffic compositions, while in Figure 3 the respective traffic characteristics are given.

In order to have comparable results, Tables 3 and 4 were added, where CO2, CH4, N2O, NOx, and PM10 emissions per 100m of road segment are presented for each road for peak and off-peak periods, based on the exported data from the output files of the COPERT4 emission estimation model software.

In reference to the traffic characteristics of the selected roads, a series of observations were made concerning speeds and volumes. Recorded speed values range between 24 - 32km/h, with the maximum speed observed along G. Papandreou Str. during the off peak period due to its large width that supports unhindered movement. Moreover, vehicles can develop higher speeds due to the fact that the road is unidirectional and so they do not risk collision with other vehicles moving in the opposite direction. On the other hand, the minimum speed was recorded in Stratou Ave. equally for the peak and off-peak period. This is justified because of the small width that causes the vehicles to reduce speed in order to avoid accidents and the existence of illegal
parking along the bus-lane; that forces public buses that are unable to use the bus-lane to use the remaining lane thus supporting congestion which causes drivers to reduce speed. Moreover, the selected segment is bidirectional without a traffic-control island, a fact that discourages drivers to increase speed due to higher collision risk. It should be noted that the stability of vehicle speed has a major effect on the production of emissions from traffic. More specifically, emissions are reduced when there is a smooth flow of traffic and increased with instability of vehicle speed that is caused by decelerations and accelerations of the vehicles (stop and go).

### TABLE 1

Functional characteristics per road segment

<table>
<thead>
<tr>
<th>Road</th>
<th>Road Class</th>
<th>Directions</th>
<th>Lanes per Direction</th>
<th>Existing Bus-Lane</th>
<th>Existing Traffic Control Island</th>
<th>Existing Signalized Intersection</th>
<th>Road Segment Length (m)</th>
<th>Parking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egnatia</td>
<td>Main Arterial</td>
<td>Two</td>
<td>Three</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>400</td>
<td>No</td>
</tr>
<tr>
<td>Tsimiski</td>
<td>Main Arterial</td>
<td>One</td>
<td>Four</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>125</td>
<td>No</td>
</tr>
<tr>
<td>G. Papandreou</td>
<td>Main Arterial</td>
<td>One</td>
<td>Three</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>90</td>
<td>No</td>
</tr>
<tr>
<td>Aggelaki</td>
<td>Main Collector Road</td>
<td>One</td>
<td>Three</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>313</td>
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<td>M. Mpotsari</td>
<td>Main Collector Road</td>
<td>Two</td>
<td>One</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>379</td>
<td>No</td>
</tr>
<tr>
<td>Olympiados</td>
<td>Secondary Collector Road</td>
<td>Two One</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>83</td>
<td>Yes</td>
</tr>
<tr>
<td>Mitropoleos</td>
<td>Secondary Arterial</td>
<td>One</td>
<td>Two</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>125</td>
<td>Yes</td>
</tr>
<tr>
<td>Stratou Ave.</td>
<td>Secondary Arterial</td>
<td>Two</td>
<td>Two</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>92</td>
<td>No</td>
</tr>
<tr>
<td>Papanastasiou</td>
<td>Secondary Arterial</td>
<td>Two</td>
<td>Two</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>282</td>
<td>No</td>
</tr>
<tr>
<td>N. Plastira</td>
<td>Main Collector Road</td>
<td>Two</td>
<td>One</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>463</td>
<td>No</td>
</tr>
</tbody>
</table>

### TABLE 2

Traffic composition per road segment

<table>
<thead>
<tr>
<th>Road</th>
<th>Peak Period</th>
<th>Off Peak Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Two-wheelers</td>
<td>Taxis</td>
</tr>
<tr>
<td>Egnatia</td>
<td>21%</td>
<td>12%</td>
</tr>
<tr>
<td>Tsimiski</td>
<td>21%</td>
<td>12%</td>
</tr>
<tr>
<td>G. Papandreou</td>
<td>11%</td>
<td>13%</td>
</tr>
<tr>
<td>Aggelaki</td>
<td>18%</td>
<td>11%</td>
</tr>
<tr>
<td>M. Mpotsari</td>
<td>17%</td>
<td>7%</td>
</tr>
<tr>
<td>Olympiados</td>
<td>15%</td>
<td>7%</td>
</tr>
<tr>
<td>M. Mpotsari</td>
<td>24%</td>
<td>31%</td>
</tr>
<tr>
<td>Stratou Ave.</td>
<td>21%</td>
<td>16%</td>
</tr>
<tr>
<td>Papanastasiou</td>
<td>25%</td>
<td>11%</td>
</tr>
<tr>
<td>N. Plastira</td>
<td>10%</td>
<td>8%</td>
</tr>
</tbody>
</table>

### FIGURE 3

Traffic characteristics per road segment
### TABLE 3
Estimated main greenhouse gas emissions

<table>
<thead>
<tr>
<th>Road</th>
<th>Peak CO₂ Emissions (g/100m)</th>
<th>Off-Peak CO₂ Emissions (g/100m)</th>
<th>Peak CH₄ Emissions (g/100m)</th>
<th>Off-Peak CH₄ Emissions (g/100m)</th>
<th>Peak N₂O Emissions (g/100m)</th>
<th>Off-Peak N₂O Emissions (g/100m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egnatia</td>
<td>33803.91</td>
<td>31948.09</td>
<td>24.39</td>
<td>26.35</td>
<td>4.03</td>
<td>3.87</td>
</tr>
<tr>
<td>Tsimiski</td>
<td>47673.94</td>
<td>46323.15</td>
<td>13.24</td>
<td>12.51</td>
<td>1.08</td>
<td>1.01</td>
</tr>
<tr>
<td>G. Papandreou</td>
<td>35340.48</td>
<td>26466.38</td>
<td>5.59</td>
<td>4.65</td>
<td>0.83</td>
<td>0.81</td>
</tr>
<tr>
<td>Aggelaki</td>
<td>26101.01</td>
<td>26829.21</td>
<td>16.78</td>
<td>17.62</td>
<td>2.57</td>
<td>2.68</td>
</tr>
<tr>
<td>M. Mpotsari</td>
<td>4733.84</td>
<td>5227.98</td>
<td>3.55</td>
<td>4.18</td>
<td>0.62</td>
<td>0.64</td>
</tr>
<tr>
<td>Olympiados</td>
<td>6066.75</td>
<td>6045.55</td>
<td>0.97</td>
<td>0.99</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Mitropoleos</td>
<td>11543.88</td>
<td>9727.60</td>
<td>2.83</td>
<td>1.78</td>
<td>0.39</td>
<td>0.31</td>
</tr>
<tr>
<td>Stratou Ave.</td>
<td>20675.50</td>
<td>19141.9</td>
<td>3.6</td>
<td>3.6</td>
<td>0.51</td>
<td>0.48</td>
</tr>
<tr>
<td>Papanastasiou</td>
<td>11504.26</td>
<td>6349.11</td>
<td>7.83</td>
<td>3.87</td>
<td>0.97</td>
<td>0.57</td>
</tr>
<tr>
<td>N. Plastira</td>
<td>5631.13</td>
<td>4685.64</td>
<td>4.24</td>
<td>3.77</td>
<td>0.83</td>
<td>0.68</td>
</tr>
</tbody>
</table>

### TABLE 4
Estimated NOₓ and Particulate Matter emissions

<table>
<thead>
<tr>
<th>Road</th>
<th>Peak NOₓ Emissions (g/100m)</th>
<th>Off-Peak NOₓ Emissions (g/100m)</th>
<th>Peak PM₁₀ Emissions (g/100m)</th>
<th>Off-Peak PM₁₀ Emissions (g/100m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egnatia</td>
<td>101.61</td>
<td>83.52</td>
<td>6.96</td>
<td>6.73</td>
</tr>
<tr>
<td>Tsimiski</td>
<td>97.42</td>
<td>94.93</td>
<td>9.77</td>
<td>9.62</td>
</tr>
<tr>
<td>G. Papandreou</td>
<td>80.04</td>
<td>63.87</td>
<td>6.77</td>
<td>5.77</td>
</tr>
<tr>
<td>Aggelaki</td>
<td>69.66</td>
<td>76.61</td>
<td>5.47</td>
<td>6.01</td>
</tr>
<tr>
<td>M. Mpotsari</td>
<td>8.39</td>
<td>9.6</td>
<td>0.93</td>
<td>1.07</td>
</tr>
<tr>
<td>Olympiados</td>
<td>11.88</td>
<td>13.01</td>
<td>1.12</td>
<td>1.17</td>
</tr>
<tr>
<td>Mitropoleos</td>
<td>41.07</td>
<td>42.38</td>
<td>2.81</td>
<td>2.27</td>
</tr>
<tr>
<td>Stratou Ave.</td>
<td>53.76</td>
<td>44.94</td>
<td>4.21</td>
<td>3.93</td>
</tr>
<tr>
<td>Papanastasiou</td>
<td>21.46</td>
<td>16.92</td>
<td>2.38</td>
<td>1.41</td>
</tr>
<tr>
<td>N. Plastira</td>
<td>12.74</td>
<td>11.12</td>
<td>1.01</td>
<td>0.89</td>
</tr>
</tbody>
</table>

### TABLE 5
Factors affecting emission levels per road segment

<table>
<thead>
<tr>
<th>Road</th>
<th>Emission Level</th>
<th>Factors affecting emission levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tsimiski</td>
<td>Very High</td>
<td>-Highest volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Stop and go because of signalized intersections combined with high volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Illegal parking along left lane</td>
</tr>
<tr>
<td>Egnatia</td>
<td>Very High</td>
<td>-High volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Highest bus volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Stop and go because of signalized intersections combined with high volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Illegal parking along bus-lane</td>
</tr>
<tr>
<td>G. Papandreou</td>
<td>Very High</td>
<td>-High volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Highest heavy vehicle volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Stop and go because of signalized intersections combined with high volume</td>
</tr>
<tr>
<td>Aggelaki</td>
<td>High</td>
<td>-High bus volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Stop and go because of signalized intersections combined with high volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Illegal parking along left lane</td>
</tr>
<tr>
<td>Stratou Ave.</td>
<td>High</td>
<td>-Stop and go because of signalized intersections combined with high volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Bidirectional road without traffic control island, not allowing stable speeds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Illegal parking along bus-lane</td>
</tr>
<tr>
<td>Mitropoleos</td>
<td>Moderate</td>
<td>-Illegal parking along right lane forcing all traffic to bus-lane</td>
</tr>
<tr>
<td>Papanastasiou</td>
<td>Moderate</td>
<td>-Illegal parking along bus-lane</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Stop and go because of signalized intersections and bus-stops</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+Traffic control island dividing two directions allows stable speeds</td>
</tr>
<tr>
<td>Olympiados</td>
<td>Low</td>
<td>+Low volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+Traffic control island dividing two directions allows stable speeds</td>
</tr>
<tr>
<td>N. Plastira</td>
<td>Low</td>
<td>+Lowest volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+Stable speeds supporting a normal traffic flow</td>
</tr>
<tr>
<td>M. Mpotsari</td>
<td>Low</td>
<td>+Low volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+No bus volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+Stable speeds supporting a normal traffic flow</td>
</tr>
</tbody>
</table>

Contrary to speed, there was a wider range in observed volumes because of the various traffic and functional characteristics recorded. The minimum volume was observed along N. Plastira Str. during the off-peak period, which is a bidirectional road segment with one lane per direction without any traffic congestion. On the contrary, the highest volume
was observed along Tsimiski Str. during the peak period, where vehicles are served by three lanes and a bus-lane. It should be noted that Tsimiski Str. is the main arterial that crosses the central business district of the city and it is reasonable to present high demand. As far as the relation of emissions with traffic characteristics is concerned it was found that for the road segments with similar values of traffic volumes and speeds the emission level depend on the traffic composition. If there is no significant compositional variation between the two periods, gas emissions in both periods are similar. A typical example is Olympiados Str. where the volume (291 vehicles during peak and 280 vehicles during off-peak period) and composition of traffic (68% passenger vehicles, 15% motorcycles, 7% taxis, 7% light trucks, 2% heavy trucks 1% buses during peak period and 66% passenger vehicles, 18% motor-cycles, 3% taxis, 10% light trucks, 2% heavy trucks 1% buses during off-peak period) as well as the traffic speed (28km/h both during peak and off-peak period) have similar values in peak and off-peak period resulting to pollutant emissions with no significant variations between the two periods: CO2 emissions: 6066.75g during peak, 6045.55g during off-peak period; CH4 emissions: 0.97g during peak, 0.99g during off-peak period; N2O emissions: 0.16g during peak and off-peak period; NOx emissions: 11.88g during peak, 13.01g during off-peak period; PM10 emissions: 1.12g during peak, 1.17g during off-peak period). The estimated emission levels for the ten road segments under study as well as the factors affecting them and the overall environmental performance are presented analytically in Table 5.

CONCLUSIONS

From the above analysis the following findings concerning the impact of road characteristics on the traffic emissions were derived. Concerning the traffic characteristics, traffic volume plays the main role in the emission of gaseous pollutants from the vehicles, as in all cases emissions rise accordingly to the traffic volumes. An important observation is also that along the road sections where traffic volumes are not significantly different, emissions depend on traffic composition with heavy vehicles (trucks and buses) having a noticeable effect on the emission of gaseous pollutants; high percentage of heavy vehicles in traffic composition has a significantly negative effect on emissions, while two-wheelers hardly affect total traffic emissions. Traffic speed is another important traffic characteristic which significantly influences traffic emissions. More specifically, emissions are reduced when there is a regular traffic flow and increase along with vehicle deceleration and acceleration (stop and go). Thus, it is of critical importance to maintain a normal and stable driving speed along urban roads and to facilitate the decongestion of the network.

Regarding the functional characteristics, in the ten selected road segments the emissions are proportional to the road category. More specifically, emissions are particularly high on main arterials, while on secondary arterials emissions are generally limited. In addition, the road direction has a serious impact as the majority of the roads that are unidirectional, have more limited emissions compared to bi-directional roads, because the former support the development of higher and more stable speeds and facilitate decongestion, resulting in lower emissions. Moreover, the existence of a traffic-control island separating the two directions supports higher and more stable speeds and reduces emissions. More lanes per direction favor higher volumes, but also the development of higher speeds during off-peak periods. Road segments with lower traffic volumes, even with only one lane per direction can support higher speeds, undisrupted vehicle flow and lower emissions. It should be noted that illegal parking reduces drastically the effective width of the section of the road, contributing to increased congestion and emissions. Moreover, it was observed that the existence of bus-lanes in road segments contributes to the smooth flow of traffic and the reduction of greenhouse gas emissions. More specifically, it was observed that along road segments where the bus-lane was illegally occupied by parked vehicles, buses had to interfere in the general traffic, causing more cases of traffic saturation, lower speeds and overall higher emissions. The existence of signalized intersections combined with high volumes contributes to high traffic emissions as vehicles are subjected to decelerations and accelerations (stop and go). However, the existence of signalized intersections, when configured adequately in order to facilitate a smooth traffic flow, lead to lower air pollutant emissions due to the maintenance of stable vehicle speeds, while misconfigured signalized intersections, in conjunction with high volumes, contribute to high traffic emission as vehicles undergo frequent decelerations and accelerations (stop and go).

REFERENCES


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EXAMINING THE CORRELATION OF NOISE LEVELS WITH TRAFFIC CHARACTERISTICS IN AN URBAN AREA: THE CASE OF THESSALONIKI

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Department of Civil Engineering, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece

ABSTRACT

Transportation systems comprise one of the main pylons of economic and social development in urban areas, while motorized transportation has historically played the key role in this context. In addition to the positive effects of motorized transportation, a series of negative externalities arises including congestion, delays, pollutant emissions and traffic noise. The purpose of this paper is to examine traffic noise, a major externality in urban centers, both as an environmental problem and a transportation planning challenge. Specifically, an investigation of the correlation of traffic noise with the traffic characteristics of an urban area is carried out through a diachronic observation. Towards this aim, a case study was conducted along selected road axes of the categorized urban network of Thessaloniki’s central business district in Greece, where noise levels along the road axes are associated with traffic and urban characteristics of the surrounding area over a seven-year period. Findings concerning the correlation between traffic noise, the existing traffic characteristics and the permanence of the phenomenon are given and possible measures and solutions to deal with the problem are proposed.

KEYWORDS:
Traffic noise, traffic characteristics, sustainable mobility, urban degradation, urban traffic.

INTRODUCTION

Noise pollution is a growing concern and is a major environmental and health problem in Europe. It is caused by a varied number of sources and is widely present not only in the busiest urban environments, but is also pervading natural environments. In this framework, traffic noise imposes a public health threat affecting the psychological and physical state of the urban population and is characterized by its permanence, contrary to other sources of noise pollution. The European Commission estimate that up to 80 million people in the European Union (EU) suffer from unacceptable noise levels. Additionally, 170 million citizens live in so-called “grey areas” where noise levels are such as to cause serious annoyance during the daytime. The economic damage of environmental noise in the EU could reach as much as 38 million €, while it has been estimated that for each 1 dB(A) increase in noise levels, average property values in Germany fall by 0.5%. Road traffic is the most dominant source of environmental noise with an estimated 125 million people affected by noise levels greater than 55 dB L_{den} (day-evening-night level) [1, 2].

The entry into force of the European Directive on Environmental Noise 2002/49/EC known as the Environmental Noise Directive requires Member States to produce strategic noise maps followed by action plans. At national level, approaches differ slightly from country to country [3]. While taking into account increasing concerns about excessive costs, the road designer should evaluate existing or potential noise levels and estimate the effectiveness of reducing highway traffic noise through location and design considerations. Source control strategies include quieter vehicles and tires, speed control, additional building insulation, more building codes for new construction, and noise-reducing pavements.

METHODOLOGY

Traffic noise prediction is based on a number of influencing parameters and thus it is very useful, as it helps the appropriate preventive mitigation measures to be taken for reducing noise impact. In this framework, many researchers have carried out studies aiming at the development of traffic noise prediction models. Although these models differ from country to country according to the traffic and environmental conditions, all of them present a strong correlation of traffic noise with traffic parameters, such as speed, volume and composition [4, 5]. Specifically, traffic composition was found to be a determinant factor in the estimation of traffic noise [6, 7].

The basic purpose of this paper is the investigation of the above correlation through a diachronic observation of both i.e. traffic noise and traffic characteristics indicators in an urban network.
In order to achieve this, measurements of traffic noise for a seven-year period along selected axes of the central road network of Thessaloniki in Greece are analyzed and correlated with the respective traffic characteristics for the same period. Analysis of the above data highlights the fact that traffic noise constitutes a complex environmental problem which requires a special treatment.

**Methodological steps.** The proposed methodological approach to investigate the correlation of the existing traffic characteristics of an urban area with noise levels, includes the following stages, as presented in Figure 1:

The first stage of the methodology includes an initial collection of data relevant to the operational characteristics of the study area road network from state or municipal agencies, and the acquisition of satellite or aerial image data of the study area from the appropriate internet services if needed (i.e. satellite or aerial photo provision services).

The second stage includes the categorization of the road network under consideration according to its operational and geometrical characteristics, based on the relevant data gathered previously. The considered categories are main arterial, secondary arterial, primary collector road, secondary collector road and local road. Then, a number of representative road segments of the road network are selected for the study in order to obtain a wider view of the area’s traffic and geometrical characteristics.

The third stage of the study includes the field data collection for each selected road segment. More specifically, the field surveys include on-site recording of the local urban (operational and geometrical) characteristics, and traffic measurements, field or remote, in order to collect data concerning the peak and off-peak served traffic (i.e. volumes, traffic composition, speed). In addition, noise level measurements are also conducted simultaneously using a special electronic noise measuring device and all the data collected are stored in a database for further reference.

The final stage of the study includes the analysis of the data collected during the previous stages. The standard UK method for the calculation of road traffic noise (CRTN) prediction model is used for the estimation of noise levels in the selected road segments during peak and off-peak periods as a verification mode and the results are presented graphically. Pertinent factors are traffic characteristics (speed, volume, composition), topography (vegetation, barriers, distance) and roadway characteristics (configuration, pavement type, grades, type of facility). The basic level at a reference distance of 10 meters away from the nearside carriageway edge is calculated and then it is corrected taking into account different parameters [8].

The noise level results of the sound metering and the CRTN model processing are exported and correlated with the operational and geometrical characteristics of the selected road segments; the overall evaluation of their performance is examined leading to conclusions and possible interventions.

**CASE STUDY**

**Study area.** The study area is situated in the central business district of the city of Thessaloniki in Greece; It is the country’s second largest city and serves as the administrative, financial and cultural center in northern Greece and a transport node for the greater southeastern Europe, a fact that supports the development of activities related to the movement of people and goods at an urban, regional and international level. Thessaloniki maintains a population of 1,110,312 with a density of 301.49 inhabitants per km² [9]. Motorized traffic in the city center is relatively high as the private car dominates citizens’ travel choices: 1,800,000 out of 2,300,000 or 78.26% of the city’s daily trips are conducted using the private car, while the private car ownership index reaches the value of 45%. Public transport in the city currently includes only one mode, the bus, and it is run by the Organization of Urban Transportation of Thessaloniki with 79 lines and 618 vehicles, that serve the city’s urban and suburban areas with an estimated volume of 167 million passengers annually [10].
Application of the methodology. Some of the most important road axes in the city were examined in order to capture the urban transportation effects on noise levels in the central business district. The Transport Engineering Laboratory of the Aristotle University of Thessaloniki provided the necessary information concerning the operational characteristics of the central urban road network of Thessaloniki, while satellite images of the study area were acquired from an appropriate on-line provider. Thus, the road network of the study area was categorized accordingly and representative road segments from five important urban road axes of the central business district were used for the case study.

A series of in-situ surveys was conducted during the period 2008–2015 in the framework of the Postgraduate Course ‘Environmental Protection and Sustainable Development’. More specifically, field measurements of traffic characteristics (traffic volume, traffic composition and average travel speed) as well as traffic noise measurements using sound metering devices were conducted along the selected road segments during these years. Moreover, the characteristics of the surrounding urban area were recorded in order to be used for the study, and for the identification of the population share exposed to noise effects.

Specifically, the Bruel&Kjaer Type 2237 Noise Level Analyzer was used, according to the recommendations of the International Standard Organization for the measurement of traffic noise, for each point measurement, together with a calibration device used to guarantee measurement accuracy. The noise level meters were programmed to continuously measure the A-weighted noise level and store the energy-equivalent noise level (Leq). The acoustic survey was carried out over two consecutive working days. The time interval of each measurement was 10 min, long enough for the statistical levels to remain stable in this type of measurement and situation. The level of noise (Leq) was measured three times consecutively, for each point, of the same 10-minute period. The final value (Leq) is the average of the three 10-minute periods.

Field data were collected by observers who conducted an on-site recording of the local network operational characteristics and the urban morphology including the number of directions and lanes per direction, the existence of bus-lanes, traffic-control islands, nearby signalized intersections, sidewalk width and nearby building heights. The length of each road segment was measured using the above-mentioned on-line satellite imaging service and all the data collected were stored in a database for further use. In addition, the observers recorded the local traffic characteristics at the selected road segments during peak and off-peak periods. Concerning traffic composition, vehicles were separated into six categories (i.e. two-wheelers, taxis, private cars, light trucks, heavy trucks and buses). The speed of the served traffic along each road segment was calculated using the moving observer method, while the overall traffic data collection took place during peak and off-peak periods. It should be mentioned that the above measurements were performed on the most overloaded lane. The gradient along the examined road segments was small, while the number of lanes varied depending on the role of the road within the urban road network. The observers recorded the number and type of passing vehicles at the midpoint of each segment at an adequate distance from any bus stops, traffic signals or any other street features that could cause queues, and stored them in a database for further use.

In addition, the CRTN noise level estimation model was used in order to verify the field data of traffic noise. The derived noise levels along the examined road axes during peak and off-peak periods are presented graphically and associated with the traffic characteristics (volume, percentage of heavy vehicles, traffic speed) and the characteristics of the surrounding urban area.

### RESULTS

The recorded geometrical and operational characteristics of the selected roads are presented in Table 1. All five roads are principal arterials and they constitute an important part of the urban road network of Thessaloniki. The first three roads (V. Olgas, Mitropoleos and Tsimiski) have a commercial and residential character, while the other two roads (M. Alexandrou and V. Georgiou) have a mainly residential character.

### TABLE 1
Geometrical and operational characteristics of selected roads

<table>
<thead>
<tr>
<th>Road</th>
<th>Directions</th>
<th>Number of Lanes</th>
<th>Bus-Lane</th>
<th>Lane Width (m)</th>
<th>Center Island</th>
<th>Signalized Intersections</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. Olgas Ave.</td>
<td>1</td>
<td>4</td>
<td>YES</td>
<td>3.00</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Mitropoleos Str.</td>
<td>1</td>
<td>2</td>
<td>YES</td>
<td>3.20</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Tsimiski Str.</td>
<td>1</td>
<td>4</td>
<td>YES</td>
<td>3.50</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>M. Alexandrou Ave.</td>
<td>1</td>
<td>6</td>
<td>NO</td>
<td>3.00</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>V. Georgiou Ave.</td>
<td>1</td>
<td>4</td>
<td>YES</td>
<td>3.00</td>
<td>NO</td>
<td>YES</td>
</tr>
</tbody>
</table>
The noise levels estimated using the CRTN methodology and those recorded using the sound metering devices for the selected roads are presented in Figures 2 and 3 against the recorded traffic volumes and the percentage of heavy vehicles respectively. The latter presentation was considered pertinent as it has been shown in previous studies [6, 7, 11] that the effect of traffic composition, and in particular that of heavy vehicles, is quite significant on noise levels along the urban signalized arterials, under various geometric characteristics.

From the observation of the recorded noise levels, for the selected roads, it can be seen that noise levels are in the region of 75-82 dB during the peak period and 70-75 dB during off-peak. The above levels of noise exceed the allowable limits of 67 dB (Leq (8-20 h)). Comparing the estimated levels of noise using the CRTN methodology and those recorded using the sound metering devices, it can be seen that, in most cases, there is a slight underestimation by the model noise levels in comparison with the recorded ones. These differences in values which are less than 5% for the majority of observations (65% of the observations) and less than 8% for 80% of the observations can be attributed to the fact that some environmental (i.e. wind speed) or street design elements (canyon effect etc.) which may lead to the increase of noise levels are not incorporated appropriately in the CRTN methodology.

From Figure 2, it can be observed that there is a reduction in traffic volumes during the examined seven-year period due to the economic crisis (less trips/person) which varies from 25% -45% according to the operation of the road as a link to the city’s road network. Meanwhile, the recorded reduction in noise levels through these years is not of the corresponding magnitude when compared to the volumes; a fact that can be attributed to the changes in traffic composition (i.e. more heavy vehicles and motorcycles) (Figure 3).

![FIGURE 2](image_url)

Recorded and estimated noise levels and traffic volumes
Concerning mean speed variation during the years under analysis, it was found that it does not follow any trends. It was only observed that the mean speed during off-peak periods was slightly increased in comparison with that of the peak period due to lower traffic volumes. It should be pointed out, however, that there are many factors along an urban network that have an effect on driver behavior and therefore on mean driving speed, apart from the traffic volume, such as the geometric characteristics, parking availability, type of traffic control and the type of adjacent land uses.

CONCLUSIONS

Noise pollution has become a critical issue in the assessment of transport system sustainability. The diachronic observation of this problem in an urban area, in parallel with the parameters most significant for its creation, provides a useful tool for its remedy. Towards this goal, in the present study the elaboration of a 7-year database including the traffic characteristics as well as the noise levels along selected axes of the categorized central urban network of Thessaloniki in Greece, led to some interesting results regarding: i) the correlation of noise levels with the traffic characteristics of the urban road network and ii) the permanence of the phenomenon through the years. More specifically, it was found that traffic composition plays a significant role in the recorded noise levels, as for the same traffic volumes or even less (during off-peak hours) the recorded noise levels along specific roads were found to be greater when there was variation in traffic composition and the other elements remained stable. Concerning the permanence of the phenomenon through these years, despite the significant reduction in traffic due to the economic crisis, it is also justified by the increased percentages of motorcycles and heavy vehicles in the total traffic, the poor maintenance of the vehicle fleet as well as driving behavior.

This analysis indicates the complex effects of traffic on noise levels and highlights traffic noise as an environmental problem whose remedy should be achieved through a holistic transport planning approach.
REFERENCES


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FORMING THE FRAMEWORK FOR SUSTAINABLE COMMUTING TO HIGHER EDUCATION: THE CASE OF THE TECHNOLOGICAL EDUCATIONAL INSTITUTION OF THESSALY, GREECE

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ABSTRACT

Since the late 20th century, academic institutions have conducted extensive research towards the promotion of sustainable mobility in cities and urban areas. However, a lack of an organised framework of policies and measures can be observed when looking at attempts to strengthen sustainability in the transport system of academic campuses, apart from limited cases of institutions implementing travel plans regularly. In this paper, a methodology is proposed for the development of an appropriate framework in order to improve the accessibility and sustainability of the daily transport activities to/from the campus and to upgrade the interaction between the campus and the urban network. The methodology is based on international experience taking into account necessary adjustments to local conditions. Its added value derives from the ability to be implemented by institutions with limited experience in travel plans and the prospect of enhancing the students’ experience in the process. The methodology was tested through a case study at the Technological Educational Institution of Thessaly, Greece. The findings of the study suggest there is a limited awareness of sustainability issues in the travel culture mainly among staff members, while it proposes a comprehensive framework of short and long-term solutions.

KEYWORDS:
Commuting, sustainability, accessibility, higher education, academic campus.

INTRODUCTION

Cities are connected to academic institutions through the daily action of people travelling to campuses and vice versa for accessing specific resources and activities. Researchers of these institutions often provide evidence concerning the influencing factors and impacts of the aforementioned interaction. However, there are limited efforts towards the implementation of coordinated policies and measures for the integration of the city-campus network and the upgrade of commuting conditions with regard to accessibility, sustainability and reduction of environmental impacts. While several universities in the United Kingdom conduct regular travel plans, the number of relevant projects elsewhere is limited. Therefore, a gap in know-how and experience is created between the academic institutions. Taking for granted that these institutions should pioneer the promotion of a socially inclusive, economically competitive and environmentally friendly transportation system, this paper addresses the aforementioned gap by proposing a methodology which extends beyond the investigation of the features regarding daily accessibility between the campus and the city, to the prioritisation of the appropriate goals and the formulation of the framework of policies and interventions for sustainable commuting to higher education. In the context of the proposed methodology, “commuting to higher education” refers to systematic (mainly daily) travel from the place of residence to the campus for the purposes of work or study. The methodology takes advantage of a review of the available travel plans and projects worldwide in order to provide the means for institutions with no such experience, to build upon their own scientific capacity for the adaptation of the appropriate policies and measures. The applicability and suitability of the methodology are tested through the case study of the Technological Educational Institution (T.E.I.) of Thessaly in Greece leading to interesting conclusions regarding travel choices and mobility conditions.

THEORETICAL BACKGROUND

The overview of international research activities forms the background for the analysis of the factors that affect the travel behaviour of university commuters and the impacts on mobility conditions as well as the quality of the environment. Tolley [1] outlines the impacts of transport on the envi-
METHODOLOGY

The proposed methodology combines a thorough analysis of the commuting conditions and choices for a specific campus with the systematic overview of international policy and practice for the allocation of the framework of strategies and interventions which are most suitable to the campus. The steps of the methodology are presented in Figure 1 and described in the following sections.

On-site observation and collection of information. The step is essential in order to better understand the study area and to identify the major features that should be further analysed through the following steps of the methodology. More specifically, the step involves the collection and organisation of information concerning the following issues: a) Location of the campus in relation to the city, b) Structure of available private (motorised and not motorised) and public transport infrastructure and networks and c) Alternative travel choices for campus-city commuting. The above information can be obtained by the following activities according to the case examined:

- On-site observations with the support of audits, such as walkability and bike-ability audits, maps and designs and holding a small number of indicative interviews with students and staff members where they are asked to freely express their opinion about commuting to/from the campus.

FIGURE 1
Workflow of methodological approach
- Collection of existing studies, research projects and student projects concerning directly or indirectly the mobility and accessibility conditions of the campus, evaluation and extraction of useful results and conclusions
- Actualisation of measurements and counts for the quantified description of the campus’s traffic and parking features.

**Questionnaire survey.** The objective of the survey is the assessment of the choices made by the most frequent users of the transport network that services trips from the city to the campus and vice versa and the identification of their criteria towards these choices. Furthermore, it aims at the assessment of their opinions regarding the current commuting conditions and their willingness to accept alternative solutions. It should be highlighted that the target population of a higher education institution comprises a wide range of users from different age groups (all adults) and various occupations, i.e. students, teachers, administrative, technical and other staff, which also implies different levels of education and income. It is commonly accepted by the research community that age, occupation (and value of time), education and income are determinant factors in the selection of transport mode as well as in the awareness concerning sustainability issues.

The exact structure and contents of the questionnaire as well as the sample size depend on the examined case and the conclusions extracted from the previous step, i.e. local knowledge. Nonetheless, a part of the questionnaire refers to the current travel choices of the respondents for their daily trip to/from the campus and another to their willingness to change these choices in the case that one or more of the features of the current multimodal transport system would be improved (stated preference). A separate part of the questionnaire should refer to the personal data of the respondent which, as mentioned above, are crucial in the selection of a travel mode. The combined analysis of results from the different parts of the questionnaire leads to useful findings regarding the commuting patterns of students and staff, while the quantification of commuting choices will be used in a benchmarking process which takes place in a subsequent step of the methodology.

**Review of international know-how and practice.** The objective of this step is the comprehensive review of international literature which should support three discrete and inter-related steps of the methodology: a) Comparative analysis and benchmarking, b) SWOT analysis and c) Proposal of policies and measures. The step involves the systematic assessment of international experience, i.e. campus travel plans and other relevant projects, referring to:

- The improvement of transport infrastructure for campus-city commuting and the promotion of sustainability in the transport mode choices of students and staff.
- The application of methodologies and instruments for the promotion of sustainable commuting.
- The implementation of specific policies and interventions for the improvement of the campus’s accessibility and mobility conditions.

**Comparative analysis (benchmarking).** The analysis aims at the comparison of the conditions and patterns of accessibility between the examined institution and other institutions at national and international level. The selection of academic institutions to be included in the comparative analysis is based primarily on the review of international experience and good practice identified during the previous step but also on the availability of relevant data. The analysis can be conducted in the form of a benchmarking survey at regular time periods provided there is a definition of benchmarks compatible to the specific characteristics of the study area and appropriate targets in the context of a suitable time horizon are set.

Indicative criteria that can be used for the comparative analysis are given below:

- Location of the campus in relation to the city
- Available transport modes that service commuting trips
- Share of commuting trips conducted by students or staff members
- Distribution of commuting trips by transport mode for students and staff members

**SWOT analysis.** The conclusions from the previous step should allow the description of the main features of commuting between the examined campus and the city in comparison to the corresponding features of other campuses worldwide. Thus, it can be used as a basis for the evaluation of the advantages (strengths) and disadvantages (weaknesses) of the current conditions regarding campus-city commuting and for the identification of the external trends (opportunities and threats) which are expected to affect these conditions in the context of a SWOT analysis. These external trends refer to the following:

- Changes in the institution’s or campus’s infrastructure, organisation and operation, such as the development of a new department or the reduction of personnel.
- Planning and implementation of interventions and policies affecting the city’s transport infrastructure and services, such as the operation of a new transport mode, the setting of urban tolls or the development of a low emission zone, and influ-
encing especially the transport links to the campus or the travel habits of the campus’s commuters.

- Changes in the socio-economic and environmental conditions and relevant policies affecting the way of life of the campus’s commuters, such as the economic crisis and global warming.
- Strategic priorities and practices for the promotion of sustainable development of academic institutions, such as energy management schemes.

Framework of policies and measures. The SWOT analysis is expected to lead to a series of conclusions which will contribute towards the allocation of the appropriate solutions based on the review of good practices which was conducted earlier. These solutions are adjusted during the current step in order to formulate the framework of policies and measures for the improvement of sustainable commuting to/from the examined campus. The framework should provide clear and comprehensive time horizons, i.e. a short-term period for the implementation of urgent and low cost solutions and a long-term period for the development of large scale interventions.

Prioritisation and commitment. The methodology aims at the development of a framework of policies and measures for the improvement of the conditions of daily commuting for an academic institution’s students and staff members. However, the finalisation of the framework should take into account the prioritisation and commitment of the commuters and stakeholders, i.e. university and city authorities and transport service providers, to contribute towards sustainable commuting to higher education. Furthermore, the stakeholders should enter into a long-term discussion to evaluate the impacts from the implementation of the framework’s policies and measures. The main objective of this process is the on-time identification of the opportunity or necessity for the re-implementation of the above methodology and the upgrade of the framework for sustainable campus commuting.

CASE STUDY

The applicability and suitability of the methodology are tested through the case study of the Technological Educational Institution (T.E.I.) of Thessaly. It should be highlighted that the students of the class of 2012-2013 in the course: “Traffic engineering/Railways” participated in the conduct of the on-site observations and the questionnaire survey.

Study area. The T.E.I. of Thessaly comprises 15 departments, 11 of which are located within the main campus while the rest are located in nearby cities. The T.E.I.’s main campus also accommodates other facilities, such as administrative and auxiliary buildings, students’ dormitories, restaurants and recreational spaces. The campus is situated at the outskirts of the city of Larissa, which is the administrative capital of the prefecture of Larissa, and the biggest city in the region of Thessaly with a population of 144,651 inhabitants within the municipality’s boundaries and 284,325 inhabitants in the wider urban area [12].

Local knowledge and on-site observation. The campus is closely linked to the city as the majority of students and staff members are residents of Larissa. Safe access to the campus is available only by car, motorcycle and bus through a signalised intersection with the main road network. There is no cycling or walking infrastructure linking the campus to the city, despite the fact that the city centre is equipped with pedestrian ways and a bicycle network. Regarding accessibility to long-distance travel, the campus is directly connected by bus to the city’s railway station but not to the interurban bus terminal.

The campus’s transport infrastructure includes mainly private car and public bus facilities, i.e. 489 car parking spaces, a taxi-stand with 6 parking spaces and a parking shelter for motorcycles. Parking in the campus is free and there is no parking management system in operation. Despite the adequate parking supply, direct access to the destinations within the campus is not provided due to the location and arrangement of the available spaces. The corresponding study during a typical workday revealed a mean occupancy of 57% and 62 illegally parked cars.

There is one bus stop at the centre of the campus. Among the two lines that service the campus, the first leads to the city centre with a scheduled frequency of 10 minutes (min) and a mean occupancy of 36.75 passengers/hour during the peak period and the second leads to the railway station with a scheduled frequency of 60 min and a mean occupancy of 25 passengers/hour. Students have a discount on the ticket price.

Questionnaire survey. It is not obligatory for academic students in Greece to be present in all lectures while the schedule of academic teachers varies and thus the number of every day commuters is not fixed. In order to define the population of daily commuting students, the hourly variations of the aforementioned bus’s occupancy was taken into account in order to define the morning peak-period of arrivals to the campus by bus during a typical workday. On-site surveys in classes, offices and laboratories during the hour after the aforementioned morning peak-period were conducted in order to assess the number of students and staff members who accessed the campus during the peak-period or before. The above were considered as campus com-
The questionnaire was divided into two sections: a) Personal choices and features of the daily trip to/from the city, e.g. current mode of choice, allocation of the trip's origin (residence) etc., and b) Stated preference of the intention to change mode of choice if an improvement of the accessibility towards an alternative transport mode is provided. In this section the following information was extracted according to each respondent's answers in the previous section:

i. The two main reasons (rating from 1 to 2 according to their significance, where 1 stands for the most significant) from a pre-defined set of reasons for not using a transport mode different from the one they usually use.

ii. The willingness of changing their current choice of mode for commuting and shift to an alternative transport mode if the network of this transport mode would service their area of residence. The possible answers are: very probable, probable, unlikely and never.

iii. The distance that they are willing to walk in order to access the network of an alternative transport mode. The possible answers are: less than 200 meters, from 200 – 400 meters and more than 400 meters. The distance of 400 meters is considered an acceptable daily walking distance (approximately 5 minutes of walking at a speed of 1.4 miles/second).

The second part of the questionnaire concerns the personal data of the respondent, i.e. sex, age group, position in the "institution", i.e. the T.E.I. of Thessaly, number of household members and number of students in the household, number of private cars owned by the household, range of income managed by the household and years of studies or work in the institution. These questions provide essential information for the respondents which are expected to affect their mode choice for commuting to/from the campus. It should be highlighted that the household for both the staff members and the students refers to the "usual residence", i.e. the place where the respondent normally lives (aside from temporary absences for the purposes of recreation, holidays, visits to friends and relatives, business, medical treatment etc.) [14].
(2) Results. Due to the high concentration of students (Figure 2) in the sample, the distribution into different age groups shows that 65.5% of the population is 18–25 years old and 14.3% is 26–35 years old, while a total of 20.2% is over 35 years old with the majority of this share corresponding to the age class of 46–55 years old. In the same context, almost 71% of the respondents work or study at the institution for a period of 4 years or less and the rest for more than 4 years. Taking into account that the duration of undergraduate studies in the Greek Technical Educational Institutions is 4 years, it can be conducted that the specific ratio corresponds to the ratio of Figure 2.

In Table 2, there is a presentation of the household characteristics of the respondents in terms of household members, number of employees and students, and number of privately owned cars. It can be observed that private car ownership in students’ households is relatively higher than one would expect, which is explained both by the car-oriented culture of Greece and by the fact that a significant number of students are permanent residents of the wider urban area of Larissa and live in their parents’ house throughout their academic years. Furthermore, an interesting finding derives from the distribution of the annual income managed by the household. There is a differentiation of income between students and staff members, with approximately 55% of students’ households managing an annual income of 10,000 € or less and approximately 50% of the staff members declaring an annual household income of 20,001 to 30,000 €.

The distribution per transport mode for daily trips to the campus is presented in Figure 3 for the overall population, the students and the staff members. Despite the close distance of the campus to the wider urban area of Larissa, the trip origin of 165 of the respondents, it can be seen that over 30% of the trips are conducted by car, either as drivers or as passengers. The share for private cars exceeds 85% for the staff members’ trips, while more than 82% of the students select the public bus or active transport (cycling or walking) for their daily access to the campus. It is worthwhile mentioning the absence of the use of taxis for daily access to the campus, which is due to the high cost of the fare and the existence of competitive alternatives.

![FIGURE 2](image_url)

**Role in the academic institution**

**TABLE 2**

<table>
<thead>
<tr>
<th>Household characteristics</th>
<th>Average value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>Number of members</td>
<td>2.20</td>
</tr>
<tr>
<td>Number of employees</td>
<td>1.01</td>
</tr>
<tr>
<td>Number of students</td>
<td>0.59</td>
</tr>
<tr>
<td>Number of private cars</td>
<td>1.13</td>
</tr>
</tbody>
</table>
FIGURE 3
Distribution per mode of daily access to the campus

FIGURE 4
Reasons for not selecting the bus/bicycle/private car for daily access to the campus-Total
Regarding the time distribution of the trips, 3 out of 4 respondents stated that they arrive at the campus during the morning peak period (07:00-10:00 a.m.). Almost 80% conduct a trip of perceived duration of less than 20 minutes. The trip duration varies depending on the transport mode with the bus trips being the longest, with an average of over 24 minutes compared to an average duration between 11 and 14.5 minutes for the rest of the available transport modes.

Another interesting fact refers to the comparison of the cost per trip by different modes, as perceived by the respondents. The average value of the perceived cost per trip by car is equal to the cost by bus, i.e. 2.42€, and double the cost of the trip by motorcycle. Walking and cycling trips are considered as trips of no cost by the respondents. The participants in the survey who do not use the public bus for every day commuting were asked to rank the two main reasons for their choice from a preselected set of statements. The corresponding questions were asked to the respondents that do not use the private car and the bicycle. The total results are presented in Figure 4, while the results for students and the other commuters are presented in Figure 5.

It is confirmed from Figure 4 that the main reason for not using the bus is the long distance to the origin bus stop closely followed by the long trip
duration and the high cost. On the other hand, commuters do not choose cycling because of the lack of infrastructure, trip duration and the safety level. One third of commuters not using the car consider the fuel and maintenance costs prohibitive, while almost an equal percentage of non-drivers would shift to the use of private car if they had access to one. The duration of the car trip is rated significantly lower compared to the use of bus and bicycle, while the respondents seem not to take into consideration neither safety and security issues nor the negative environmental impacts from private car daily usage.

Respondents are conflicted as to their shifting to public bus, if there was a bus line that would service their area of residence. The corresponding statements to the question are almost equally distributed among the options: Very probable, probable, unlikely and never. On the other hand, bicycle use seems to be more attractive as approximately three out of four people that do not currently use the bicycle find it very probable (30%) or probable (47%) to shift to bicycle, if the bicycle network would service their area of residence. In order to define what the above respondents consider as adequate service for their area of residence, they were asked about the longest distance that they would be willing to walk in order to reach the public bus and bicycle networks. Most of them (81% in the case of the bus network and 69% in the case of the bicycle network) are willing to walk less than 400m.

**Analysis of international know-how and practice.** The following reports and documents were reviewed: a) The Travel Plans and relevant initiatives of the universities of Birmingham [15], Bournemouth [16], Bristol [17], Essex [18], Exeter [19], Florida [20], Greenwich [21], Lancaster [22], Leeds [23], Loughborough [24], Monash [25], Newcastle [26], Oxford Brookes [27], Sheffield [28], Sunderland [29], York [30] and b) documentation from The International Sustainable Campus Network (ISCN) [31]. The different approaches and various interventions presented in the above documents were analysed in order to formulate the comprehensive framework which is presented in Table 3. The framework can be used as an inventory of good practices according to the specific needs of the examined case.

**TABLE 3**
Inventory of good practice

<table>
<thead>
<tr>
<th>Phase</th>
<th>Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Setting the policy</td>
<td>Development of a dedicated organisation or office within the University with the role of supporting sustainable mobility and managing the following interventions Integration of the principles of sustainable mobility and accessibility to the University’s sustainable development policy framework Participation in the exchange of international experience and development of benchmarking processes Synergy with the city’s transport and urban development policy framework Committing stakeholders in an ongoing process of changing travel culture Safeguarding the economic viability of the schemes and interventions</td>
</tr>
<tr>
<td>2. Conducting the study</td>
<td>Modal split, O/D (Origin/Destination) analysis and time distribution of trips to/from/into the campus Analysis of travel behaviour and commuting characteristics of staff and students Impact assessment: Accessibility, health and safety, emissions, energy efficiency and built environment</td>
</tr>
<tr>
<td>3. Developing the infrastructure</td>
<td>Complementarity of the campus’s and the urban transport network Compliance with international design standards Inclusive mobility services within the campus and accessible activity areas for all with focus on VRUs (vulnerable road users) Supplementary facilities (information, guidance, parking, lockers) for the support of active transportation, i.e. walking and cycling Aesthetic quality of the infrastructure design to increase its attractiveness</td>
</tr>
<tr>
<td>4. Promoting the concept</td>
<td>Carry out of training and social awareness campaigns Provision of discounts for public or/and University transit Personal motivation (economic and other) for commuters that use active transport on daily trips to/from the campus. The same may apply for car sharing schemes. Provision of bike rental and repair services</td>
</tr>
<tr>
<td>5. Monitoring the impacts</td>
<td>Standard evaluation process for changes in travel patterns, demand features and impacts of the campus’s transport system</td>
</tr>
</tbody>
</table>
Table 3 indicates that the review of recent Travel Plans and cooperative initiatives of universities may lead to a common framework of good practice. At the same time, the review led to the conclusion that the aforementioned plans and initiatives are not based on a common methodology for the quantified assessment of the mobility and accessibility conditions of campuses. It is highlighted that the formulation of such a methodology would facilitate the development of a common benchmarking mechanism in order to evaluate the level of mobility and accessibility provided by the campuses’ transport infrastructure and services.

The fact that the Travel Plans do not follow common specifications obstructs a comparative analysis of the accessibility and mobility conditions between different campuses because different kinds of data are collected with different spatial and/or time references. In the context of the specific case study, an effort was made to highlight a series of main remarks concerning the comparison of the campus of the T.E.I. of Thessaly to other campuses, i.e.: i. Aristotle University of Thessaloniki [32], which is located in a campus adjacent to the city centre of Thessaloniki, Greece, and ii. University of York, where a Travel Plan has been conducted regularly since 2000 with prioritisation towards the promotion of active transportation for access to/from the campus [30]. It should be noted that the campus of the University of York is located at the city outskirts. According to data for 2011, the share of active transportation (walking and cycling) to/from the campus of the University of York was 69.3%, a share approximately 3.4 times higher than the share of active transportation for the T.E.I. of Thessaly. It is also worth mentioning that, according to data of 2012, the share of private motorised trips (including taxi) to/from the campus of the T.E.I. of Thessaly is 38.1%, a share approximately 1.4 times higher than the relevant share for the University of Thessaloniki, which is serviced by the city’s public and active transport networks due to its central location.

**SWOT analysis.** Based on the conclusions from the above steps, a SWOT analysis concerning sustainable commuting to/from the campus of the T.E.I. of Thessaly was conducted. The process for developing the SWOT analysis involved the following steps: i. Students of the class of 2012-2013, who conducted the questionnaire survey, in cooperation with the project’s supervisor prepared a presentation of the questionnaire results, ii. The supervisor prepared the review of international know-how and practice, iii. A presentation of the above was conducted in class in order to launch a class debate with the purpose of discussing the strengths, weaknesses, opportunities and threats for sustainable commuting to/from the campus of the T.E.I of Thessaly. The supervisor collected the results of the class debate in the SWOT analysis presented per thematic field in Table 4.

### TABLE 4
**SWOT analysis for sustainable commuting to/from the campus of the T.E.I. of Thessaly**

<table>
<thead>
<tr>
<th>Thematic field</th>
<th>Public transport</th>
<th>Active transport</th>
<th>Travel behaviour</th>
<th>Ability to promote sustainable commuting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strengths</strong></td>
<td>• Frequent routes to the city centre</td>
<td>• Close to the city</td>
<td>• Car-oriented culture: Staff members' behaviour is “less sustainable” than students’</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Discount policy for students</td>
<td>• Level terrain</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Weaknesses</strong></td>
<td>• Trip duration twice the car trip’s duration with the same perceived cost</td>
<td>• Lack of infrastructure</td>
<td>• Students of relevant courses can be encouraged to participate in a campus travel plan</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Low level of safety</td>
<td>• Availability of best practice in the international literature</td>
<td></td>
</tr>
<tr>
<td><strong>Opportunities</strong></td>
<td>Availability of open space for enhancing infrastructure in the campus and along the routes towards the city.</td>
<td>Students’ willingness to shift to cycling provided the appropriate infrastructure</td>
<td>• Available European funding programs.</td>
<td></td>
</tr>
<tr>
<td><strong>Threats</strong></td>
<td></td>
<td></td>
<td>• Lack of previous experience (travel plans, mobility management etc.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Limited own financial resources and constrained national funding due to the crisis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Other urgent needs and priorities for the institution</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 5
Policy priorities and interventions for the enhancement of sustainable commuting to/from the campus of the T.E.I. of Thessaly

<table>
<thead>
<tr>
<th>Policy priority</th>
<th>Intervention</th>
<th>Short term</th>
<th>Long term</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Promotion of sustainable transport</strong></td>
<td>1.1. Establishment of a unit with the participation of staff members and students responsible for the following interventions</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2. Involvement and cooperation with the stakeholders, i.e. students, staff members, local authorities, transport operators and the local community through information, awareness campaigns and active participation in the following interventions</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.3. “Cycling-to-work” subsidy based on mileage for staff members</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.4. Negotiation of a pricing policy to attract staff members to the bus system</td>
<td>X*</td>
<td></td>
</tr>
<tr>
<td><strong>2. Parking management</strong></td>
<td>2.1. Re-distribution of parking spaces in the campus</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.2. Parking management scheme for authorised entrance to parking areas and discouragement of illegal parking</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>3. Competitive public transport</strong></td>
<td>3.1. Development of bus-lanes along main corridors linking the campus to the city and prioritisation of the bus at traffic signs</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.2. Car sharing schemes for the service of areas not serviced by the current bus routes</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>4. Infrastructure for active transport</strong></td>
<td>4.1. Development of pedestrian pathways linking the campus to the city’s pedestrian network</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.2. Expansion of the city’s bicycle network, connection to the campus and development of parking shelters for bicycles</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>5. Monitoring and planning</strong></td>
<td>5.1. Regular students’ teamwork projects for the monitoring and evaluation of the campus’ accessibility and mobility conditions</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.2. Commitment of stakeholders for the development and implementation of a Travel Plan to be updated on a regular basis</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

* A precondition for the promotion of cycling to staff, a group likely to include a higher percentage of older commuters and persons with a high value of time, is the completion of long-term measures concerning a safe and effective bicycle infrastructure (see Priority 4).

**Framework of policies and measures.** Comprehensive analysis of the findings from the case study leads to an outline of the policy priorities to improve the accessibility and commuting conditions of the T.E.I. of Thessaly campus, which are presented in Table 5 in relation to the proposed interventions. The interventions are divided into short-term (2 years) and long-term (6 years) interventions, according to the time horizon for their implementation. The selection of interventions is based on the following elements:

i. Local knowledge and the results of the questionnaire survey provide a clear description of the type and extent of problems and drawbacks concerning the accessibility conditions of the campus,

ii. International literature provides directions in order to ensure the compatibility to existing University Travel Plans and good practices that can be implemented to cope with the specific problems and drawbacks of the examined campus and

iii. The SWOT analysis contributes towards the selection of specific interventions from international practice which would be expected to take advantage of existing strengths and foreseen opportunities while maximising the impact against major weaknesses and threats. It this way, policy priorities and interventions of Table 5 are appropriately adapted to international practice and the local characteristics of the T.E.I. of Thessaly.

**DISCUSSION**

The above case study leads to useful conclusions regarding the preferences and trends of the campus commuters, while providing a framework of priorities and interventions to improve sustainable commuting to/from the campus of the T.E.I. of Thessaly in Greece. The proposed interventions are based on an inventory of international good practice in a prioritised way and appropriately adjusted to the specific features of the campus, the adjacent city and the perceptions of students and staff members.

In this way, the proposed methodology has a significant added value, i.e. the capitalisation on best practices of academic institutions with extended experience promoting “sustainable travel plans” aiming at bridging the gap that separates these institutions from the institutions with limited experience in the specific domain. Simultaneously, it allows for the active involvement of the students during the process leading to an enhancement of their sustainable mobility culture and an improve-
ment of their skills in transportation planning methods and tools.

Based on the case study conclusions, the main limitation for the successful implementation of the proposed methodology is rooted in the lack of compatibility among the existing travel plans of campuses worldwide due to the absence of a common framework of specifications. This incompatibility obstructs the comparative analysis between campuses and the development of a benchmarking mechanism, which would be useful for monitoring the progress of sustainable mobility and accessibility conditions in university campuses. Towards this goal, coordinated efforts should be conducted in future to develop such a mechanism which would accelerate the uptake of university travel plans internationally.

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MINIMUM ENVIRONMENTAL CRITERIA FOR THE REDUCTION OF AIR POLLUTION DERIVING FROM PRIVATE TRANSPORT: POTENTIAL OF A CAR FLEET RENEWAL

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ABSTRACT

Transport is one of the four fields (food, housing, mobility, and tourism) of private consumption with the greatest impact on air quality and climate change. One way to reduce transport emissions is the application of green procurement criteria not only in public, but also in the private sector. The study evaluates benefits of applying selected environmental criteria for air pollution reduction for private transport, considering as an option renewal of car fleet. Different Euro emission standards are attributed to the passenger cars depending on the year of production. Four different scenarios of car fleet change for Lithuania and their potential for air pollution mitigation are analysed. Analysis showed that the best results could be reached if 50% of the cars from more than ten-year-old group are replaced with new ones; it would result in the reduction of carbon dioxide by 18%, of nitrogen oxides - about 30%, of carbon monoxide - 25% and of particulate matter - 46%. Car fleet renewal can be an option for the reduction of transport-related emissions; however, other factors should be taken into account.

KEYWORDS: transport, air pollution, Euro standards, minimal environmental criteria, Lithuania, car fleet renewal

INTRODUCTION

Transport sector is one of the most important economic activities, relating different locations, raw materials, final products, producers, and consumers. On European Union (EU) level, the transport share amounts to 4.4% of total GVA (gross value added) and this sector employs 4.3% of total employees [1]. Households’ expenditures on transport amount to 1900 EUR annually per capita on average in EU [1].

However, rapid development of the transport system inevitably has a significant adverse impact on the environment. This mainly includes energy use, air pollution, and impact on climate change [2] with related outcomes for environment and human health, especially in urban areas [3]. The energy consumption percentage for transport reached 28% of total end-use energy in 2010 and more than 50% of the energy in transport sector refers to road transport [4]. Correspondingly, land transport contributes to more than 20% of total anthropogenic greenhouse gas emissions [5]. Greenhouse gases (GHGs) emissions from the transport sector have been increasing fast since 1970 and more than 70% of them come from road transport as R. Sims et al. sum up in the IPCC report [6]. In 2010, in EU Member States road transport was responsible for 33% of NOx, for 14% of volatile organic compounds (VOCs), for 29% of CO, for 14% of PM10 and for 15% of PM2.5 emissions [7]. These pollutants contribute to ground level ozone [8] and other environmental as well as health problems (e.g., respiratory system and lung function [9; 10], brain and heart [11] disorders, preterm birth [12] and cardiovascular and respiratory diseases risk, lung cancer [13]).

Even improvement in air quality has been achieved; substantial impacts remain in EU. It is projected that not mitigated road transport emissions will continue to contribute to regional ozone exceedances and related health effects by 2025 [15]. Therefore, long-term EU objective for air pollution implies much stricter requirements for human health and ecosystem tolerance [14].

Energy consumption and pollution has decreased in Lithuanian transport sector compared to the respective figures in the early 1990’s [2]. However, recently some trends are on increasing direction [16]. Increasing motorization rates are those contributing to environmental burden resulting from the road transport. Lithuania is one of the countries with the highest vehicle imports, however importing relatively old, used cars. Though much of them are re-exported to the Belarus, Russia, Kazakhstan, and other countries [16], quite a lot remains within the Lithuanian territory. The biggest share of the passenger cars are private cars. Therefore, private road transport is one of the issues to be addressed in order to meet pollution reduction targets.

One of the ways to reduce transport emissions is the reduction of fuel consumption, and/or correspondingly reduction of emission factors. These are...
often related with the production year of the car, as corresponding emission standards come into force gradually. Before mentioned standards correspond with requirements for green public procurement defining minimum environmental criteria for a green vehicle. A good practices report indicates that applied green public procurement results in the decrease in the emissions ranging from 3g/km to 45 g/km per vehicle in the Slovenian case [17]. Dagilute and Anikanova [18] indicate that if environmental criteria had been applied to 50% of performed public procurements in the case of vehicles, 20 times more of CO2 could have been avoided additionally.

Therefore, the aim of this article is to analyse the road transport indicators and potential of the minimum environmental criteria for green public procurement in order to reduce air pollution due to private vehicles in Lithuania.

MATERIALS AND METHODS

Analysis of changes in motorization (number of passenger cars per 1000 inhabitants) and related indicators (number of first time registered passenger cars, passenger cars by age), as well as changes in transport air pollution and contribution to climate change was performed. Data from the Department of Statistics of Lithuania, the European Union's Statistical Office (Eurostat) and the State Enterprise “Regitra” were used. Based on the “The list of the 1st group of products to which public procurement is applicable” (list approved by the Ministry of the Environment in 2011 28 June, Law No. D1-508) [19], minimum environmental criteria for M1 (vehicles carrying passengers, no more than eight seats in addition to the driver’s seat) and N1 (N - vehicles carrying goods having a maximum mass not exceeding 3.5 tones) class vehicles were applied:

1. The vehicle must comply with the standard of Euro 5 emission;
2. The vehicle’s emission of carbon dioxide (CO2) must not exceed the requirements established in the green procurement thresholds.

It was presumed that cars differ in their environmental influence according to the emission levels while driving (i.e. for the assessment of the environmental impact during its product's life cycle usage/consumption stage is selected). Analysing the benefit of criteria for one passenger car it is important to pay attention to the difference of pollutant emissions, which is strongly influenced by the age factor of the car. The more modern a car is, the stricter Euro standard and CO2 requirements it meets. In our study, cars were divided into three groups according the age. Each age group was assigned to a certain EURO standard and a certain amount of CO2:

- **Under 5 years** – corresponds to the requirements of the European standard Euro - 5 (from 2009);
- **5-10 years** - corresponds to the requirements of the European standard Euro - 4 (from 2005 to 2009);
- **Over 10 years** - corresponds to the requirements of the European standard Euro - 2 (from 1992)

The difference between the emissions was calculated separately for diesel and for petrol-powered cars on the assumption, that over the year a passenger car covers 15000 km (an average of EU). Pollution calculations are based on the standards of Euro emission limit for passenger cars and mileage. Passenger cars include both passenger cars used for institutional needs (owned by company, institution) and private passenger cars (owned by persons and used for personal needs).

The CO2 emission of each age group is calculated accordingly to the mileage mentioned above and referring to the results of the European Environment Agency report “Monitoring CO2 emissions from new passenger cars in the EU: summary of data for 2011” [20]. It was assumed that one diesel passenger car assigned to the “under 5 years” group emits 145.3 g/km CO2; “5 - 10 years” group – 157.7 g/km and “over 10 years” group – 240 g/km of CO2 (the latter number is based on the results of Study on Integrated Environmental Impact of Implemented Public Procurement [21]). The petrol-powered car “under 5 years” group emits 147.6 CO2 g/km; under “5-10 years” age group – 171.7 g/km, and “over 10 years” - 240 CO2 g/km. The power of the engine is not taken into account.

Benefit of environmental criteria application separately for diesel and petrol - powered car is expressed as the difference between emissions (kg) calculated for “not green” vehicle (meeting the requirements of Euro 2 and Euro 4) and “green” vehicle meeting the Euro 5 emission standard. Differences in emissions in-between group are considered as green procurement benefit for one car.

The emissions reduction according to four scenarios (Table 1) has been estimated. For each scenario, the absolute yearly benefit (in terms of avoided emissions) is calculated by multiplying the derived values from the number of cars in a separate age group. Diesel and petrol-powered cars are calculated separately. In 2011 diesel-powered passenger cars made up 41% and petroleum-powered cars 38% of total car fleet. Factors, which may affect the emission rate, but not considered in the study, include vehicle's technical condition, fuel quality, also lack of precise data on the number of registered, but not used cars (such cars may account to about 600 000), and driving style.
RESULTS

Transport energy consumption, pollution, and car fleet trends. Currently, in the structure of total energy consumption transport sector dominates in Lithuania. 32.7% of all energy was consumed in this sector in 2010. The final consumption of fuel and energy during the period of rapid economic growth until 2007 has been growing in the transport sector (from 1056.1 ktoe in 2000 to 1848 ktoe in 2008) (Fig. 1). Accordingly, the emission of main pollutants from transport sector increased: nitrogen oxide emissions increased approximately 1.3 times, particulate matter and greenhouse gas emission from the transport sector increased 1.6 times. Afterwards due to the recession and rapid growth of fuel prices during 2008 – 2010 the total consumption of fuel and energy in transport sector considerably decreased. This decrease amounted to more than 30%. Accordingly, emissions of the majority of key pollutants decreased as well.

Transport fleet is growing very fast in Lithuania due to increasing number of road vehicles and especially private passenger cars (Fig. 1). The number of private cars is multiplied by 1.4 times during the analysed period (from 1 097 797 to 1 572 789 units). This resulted in annual growth of the motorization level (the number of cars per 1000 inhabitants). It has increased 1.6 times (from 336 to 542 cars per 1000 inhabitants) during the period of 2000-2010. Another very important factor resulting in negative outcomes for the environment is age structure of Lithuanian car fleet. The most common cars on Lithuanian roads are more than 10 years of age (85.7%) (Fig. 2) and the national average age of a car fleet is about 17 years according to 2011 data. The majority of other EU countries do not exceed the limit of 10 years. Only 4.6% of 1.7 million passenger cars were under age of five, and only 2% of 1.57 million private cars passed under this group. Therefore, the fundamental task is to reduce the age of car fleet. Recently car registration system was renewed (2014) and cars without valid technical passport and civil responsibility insurance were withdrawn from the register. However, the average age of a car remains nearly the same.

TABLE 1
Scenarios under analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I SCENARIO</td>
<td>50% of cars of &gt;10 years group are replaced with ones coinciding the emission standard EURO 5 and does not exceed the marginal values of CO₂</td>
</tr>
<tr>
<td>II SCENARIO</td>
<td>all first time registered cars coincides with the emission standard EURO 5 and does not exceed the marginal values of CO₂</td>
</tr>
<tr>
<td>III SCENARIO</td>
<td>17% of first time registered cars coincides with the emission standard EURO 5 and does not exceed the marginal values of CO₂ (the scenario is selected according to the Green procurement’s accounting results (Public Procurement Office, 2013), stating that public green procurement was applied for 17% of public vehicles procurement in 2011 (vehicles of categories M1 and N1)</td>
</tr>
<tr>
<td>IV SCENARIO</td>
<td>17% of cars of &gt;10 years group coincides with the emission standard of EURO 5 and does not exceed the marginal values of CO₂</td>
</tr>
</tbody>
</table>

FIGURE 1
Final energy consumption, air pollution, and motorization rate trends during 2000 – 2010 in Lithuania
(based on Lithuanian Department of Statistics and Eurostat data)
**Potential of application of the minimum environmental criteria for air pollution reduction.**

Based on the estimated emissions per one car in different car age groups, four scenarios of car fleet renewal were analysed. Diesel cars related pollution would be reduced most in the case of scenario I (50% of cars of >10 years group coincides with the emission standard EURO 5) (Table 2). The reduction of carbon monoxide emissions would reach 28%, nitrogen oxides – 30% and even 46% of particulate matter. Some improvement would be reached in case of scenario IV as well: reduction of carbon monoxide would reach 8%, nitrogen oxides - 10% and 15% of particulate matter.

Petrol-powered car air pollution would be reduced the most in the case of scenario I: reduction of nitrogen oxides emissions would reach – 28.4% and of carbon monoxide - almost 26% (Table 2). Other possible scenarios for the age structure of the car fleet had no significant impact on the reduction of air pollution from petrol-powered cars.

In the most desirable scenario with highest reduction, total absolute emission savings would amount to 6981 tons of CO, 1748 tons of NOx, 324 tons of PM (Table 2).

Analysis of four scenarios showed that CO₂ would be reduced mostly in the case of scenario I: for diesel cars, the reduction would reach 18.3%, for petrol - powered cars it would reach 17.8% (Table 2). Some reduction could also be achieved in the case of scenario IV: reduction of carbon dioxide emissions would reach 6.2% for diesel cars and 5.2% for

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**TABLE 2**

Total air pollution mitigation potential  
(emitted amounts; mitigated amounts, compared to base situation).

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>I Scenario</th>
<th>Savings</th>
<th>II Scenario</th>
<th>Savings</th>
<th>III Scenario</th>
<th>Savings</th>
<th>IV Scenario</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO, tons</td>
<td>Diesel cars</td>
<td>7004.3</td>
<td>25.6%</td>
<td>8884.9</td>
<td>3.1%</td>
<td>9167.3</td>
<td>0.1%</td>
<td>8431.4</td>
</tr>
<tr>
<td></td>
<td>Petrol cars</td>
<td>13782.4</td>
<td>25.9%</td>
<td>17975.7</td>
<td>3.4%</td>
<td>18585.2</td>
<td>0.1%</td>
<td>169619</td>
</tr>
<tr>
<td>Total emissions</td>
<td>20786.7</td>
<td>26860.6</td>
<td></td>
<td>27752.5</td>
<td>0.1%</td>
<td>25393.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total savings</td>
<td>6981.1</td>
<td>25.1%</td>
<td>907.2</td>
<td>3.3%</td>
<td>15.3</td>
<td>0.05%</td>
<td>2374.5</td>
</tr>
<tr>
<td>NOx, tons</td>
<td>Diesel cars</td>
<td>3183.9</td>
<td>30.3%</td>
<td>4349.2</td>
<td>30.3%</td>
<td>4567.8</td>
<td>0.1%</td>
<td>4098.6</td>
</tr>
<tr>
<td></td>
<td>Petrol cars</td>
<td>914.2</td>
<td>28.4%</td>
<td>1217.9</td>
<td>4.6%</td>
<td>1274.1</td>
<td>0.2%</td>
<td>1152.6</td>
</tr>
<tr>
<td>Total emissions</td>
<td>4098.1</td>
<td>5567.1</td>
<td></td>
<td>5841.9</td>
<td></td>
<td>5251.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total savings</td>
<td>1748.3</td>
<td>29.4%</td>
<td>279.3</td>
<td>4.7%</td>
<td>4.5</td>
<td>0.07%</td>
<td>595.2</td>
</tr>
<tr>
<td>PM, tons</td>
<td>Diesel cars</td>
<td>389.4</td>
<td>45.5%</td>
<td>660.6</td>
<td>7.5%</td>
<td>713.3</td>
<td>0.01%</td>
<td>603.8</td>
</tr>
<tr>
<td></td>
<td>Petrol cars</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total emissions</td>
<td>389.4</td>
<td>660.6</td>
<td></td>
<td>713.3</td>
<td></td>
<td>603.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total savings</td>
<td>324.8</td>
<td>45.5%</td>
<td>53.6</td>
<td>7.5%</td>
<td>0.9</td>
<td>0.01%</td>
<td>110.4</td>
</tr>
<tr>
<td>CO₂, tons</td>
<td>Diesel cars</td>
<td>1825671</td>
<td>18.3%</td>
<td>2175241.2</td>
<td>2.7%</td>
<td>2234448.7</td>
<td>0.1%</td>
<td>2096401.3</td>
</tr>
<tr>
<td></td>
<td>Petrol cars</td>
<td>1712252.7</td>
<td>17.8%</td>
<td>2022075.4</td>
<td>2.9%</td>
<td>2081770.1</td>
<td>0.1%</td>
<td>1957078.5</td>
</tr>
<tr>
<td>Total emissions</td>
<td>3537923.7</td>
<td>4197316.6</td>
<td></td>
<td>4316218.8</td>
<td></td>
<td></td>
<td></td>
<td>4053479.8</td>
</tr>
<tr>
<td></td>
<td>Total savings</td>
<td>781144.1</td>
<td>18.1%</td>
<td>121751.2</td>
<td>2.8%</td>
<td>2849</td>
<td>0.07%</td>
<td>265588</td>
</tr>
</tbody>
</table>

Own calculations
petrol-powered cars. Other possible scenarios for the age structure of car fleet had no significant impact on the reduction of CO₂.

Total emission would be lowest in the Scenario 1 and nearly 800 000 tons per year of CO₂ could be avoided if half of car fleet would be replaced with new cars (Table 2).

DISCUSSION AND POLICY OUTLOOK

Results suggest that, diesel-powered passenger car meeting minimal environmental criteria emits 1.7 times less of CO₂ (petroleum-powered 1.6-fold), two times less of CO (petroleum-powered 2.2-fold), 1.4 times less of NOx (petroleum-powered 2.5-fold) and even 16 times less of PM compared with old car per year. However, the majority of the cars (85.7%) are more than 10 years age in Lithuania, contributing significantly to air pollution. Nevertheless, the results show that the green procurement requirements, pooling on the key areas of environmental performance of the product, can contribute to the environmental pollution reduction if applied in the private sector. Other studies [22; 23] also present reduction of fuel consumption and/or of emission factors among other policies (emission trading, different taxation options, subsidies) as options for reduction of externalities from road transport.

Analysis of four scenarios showed that the highest reduction in diesel cars related pollution would be achieved in the case of scenario I (a half of the car fleet meets EURO 5 emission standards): reduction of carbon dioxide emissions would reach 18.3%, nitrogen oxides – 30.3%, carbon monoxide – 25.6% and particulate matter - 45.5%. Petrol-powered car air pollution would be reduced the most also in the case of scenario I: reduction of carbon dioxide emissions would reach 17.8%, nitrogen oxides – 28.4% and carbon monoxide - almost 26%.

Hence, significant renewal of car fleet is needed to achieve significant results in air pollution reduction in Lithuania. Therefore, to foster car fleet renewal and solving the transport related environmental pollution and climate change issues several aspects should be considered. First, transparency and credibility of car production industry should be improved as the latest air pollution tests’ manipulations indicate. Secondly, some additional measures should be applied to create incentives for purchasing a new or an alternatively fuelled car.

Taxes, tax incentives, and information provision could be the measures for renewal of car fleet and respectively for air pollution reduction. One of the measures could be vehicle taxes. It is important that the determined fee to be neutral one, especially in relation to the state budget (e.g. not supplement the state budget, but targeting air pollution issues). Vehicle tax is under considerations rather intensively in Lithuania, recently. Some prepositions discuss some 70 – 100 EUR tax depending on the age of the vehicle. In addition, vehicle registration regulation was initiated recently and number of registered passenger car decreased. However, the average age of the car remains the same (around 17). A number of European countries apply registration tax based on CO₂ emissions or annual circulation tax based on CO₂ emissions [24]. Another measure could be tax on old imported cars or tax incentives to individuals who wish to purchase a new or alternative fuelled car. Exemption of ethanol cars from Stockholm congestion tax increased purchases of such cars in 2006 and 2007 as a study indicates [25]. R. Kok [26] highlights 11% lower CO₂ emissions on average in 2013 and 3.5 million tons of CO₂ reduction between 2008 and 2013 in the Netherlands case because of car purchase tax graded by CO₂ emission. A. Sánchez-Braza et al. [27] presents drivers for road tax reduction for electric vehicles that could reach 75% reduction and could be used as an incentive to buy electric car. However, electric vehicle purchasing capacity is rather low in Lithuania [28]. In Lithuania GDP per capita in PPPs (Purchasing Power Parities – currency conversion rates that equalize the purchasing power of different currencies and eliminate the differences in price levels across the countries) amounts only to 75% to that of EU28 on average (Eurostat). In addition, as a car tax is not existent, hence, no incentives for such cars can be applied at the current situation in Lithuania. Therefore, penetration of hybrid or electric cars is very slow in Lithuania. In 2012, only two thousand electric and hybrid cars were registered within the country [28].

In addition, to the already mentioned measures, another important measure is information provision. Drivers in Lithuania pay little attention to their car’s impact on the environment. Drivers lack knowledge on how they could reduce emission of pollutants while changing driving habits. Eco-driving could save fuel and would have a positive impact on reducing automobile emissions. Ho et al. [29] indicates fuel consumption and carbon emissions savings by more than 10% due to the eco-driving practices. In general, Lithuanians still lack environmental consciousness concerning mobility. Thought 83% of Lithuanians agree, that they can play a role in protecting the environment, only 35% choose a more environmentally friendly way of traveling (public transport, on foot, by bike) [30]. On a typical day 45% Lithuanians choose a car as a transport mode, 27% use public transport, and 19% chose walking, 7% bike and 2% other means of transport [31]. Rather low overall satisfaction with urban public transport [32] might also contribute to high level of car preferences.

Of course, shift to more sustainable transport modes would be the most desirable option. However, having in mind strong society dependence on a car [31; 33], renewal of a car fleet applying minimum
environmental criteria could be a starting option. Nevertheless, other measures promoting sustainable mobility in order to achieve significant results in air pollution reduction and climate change mitigation in road transport should be also addressed and explored.

CONCLUSIONS

Promoting green procurement not only in the public sector but also in the private one might give significant results. Even under the minimum environmental criteria, environmental burden could be reduced and environmental objectives may be achieved.

However, current volume of green public procurement is not sufficient to contribute to the mitigation of air pollution problems, nor could be achieved in the private sector if only the same proportion of new vehicles would meet minimal environmental criteria. Remarkable renewal of a private car fleet is needed. Information provision and economic incentives could be discussed as possible measures. So far, Lithuania policy offers no incentives for car fleet renewal and only EU Energy End Use Efficiency and Energy Services directive (2006/32/EC) aiming at newal and only EU Energy End Use Efficiency and Energy Services directive (2006/32/EC) aiming at

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ENVIRONMENTAL IMPACTS OF ACTUATED SIGNALS ON INTERRUPTED TRAFFIC FLOW

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ABSTRACT

Surface transportation yields a significant amount of greenhouse gas (GHG) emissions annually, while concurrently being the primary energy consumer among the transportation sectors. Excessive emissions and energy consumption are typically observed at traffic congested areas and around traffic signalized intersections. At those latter locations, vehicles are frequently subjected to long idling periods and deceleration/acceleration maneuvers due to the operation of the traffic lights. Thus, the characteristics of the traffic signals are a determinant regarding traffic flow and its impacts on the environment. Within the framework of the present research, the environmental impacts of actuated signals on an 11-km signalized arterial street that connects Thessaloniki’s city center with the local airport and the eastern suburbs of the city are evaluated. The morning peak period of a typical weekday on this arterial has been simulated with the use of the traffic modelling software AIMSUN. Network-wide and section output statistics (i.e. fuel consumed, carbon dioxide (CO2), nitrogen oxides (NOx) and particulate matter (PM)) are presented in this research.

KEYWORDS:
Traffic simulation, actuated signals, environmental impact, traffic flow, AIMSUN.

INTRODUCTION

This study evaluates the environmental impacts of fully actuated control at signalized intersections with the use of microscopic traffic simulation. Fully actuated control is the mode of operation where all approaches have detectors installed and all green phases are controlled by means of detector information [1]. The green phase terminates when the headway between two vehicles is larger than a certain maximum time interval. A signalized corridor that connects the city of Thessaloniki with the suburb of Peraia has been simulated in AIMSUN [2]. Aggregate and disaggregate simulation output statistics have been obtained through the simulation experiments.

The following sections include a detailed description on materials and methods used in the framework of this paper. A brief review is presented on the operation and past deployment of actuated traffic signals. Microscopic traffic and emissions simulation modelling techniques are described for assessing traffic operations and estimating fuel consumption and traffic pollutants in a simulated road network. Results and discussion present the main results and findings of the application of the proposed methodology, while concluding remarks are also noted.

MATERIALS AND METHODS

Operation and performance of actuated traffic signals. Pre-timed signal control is the simplest type of signal control and is designed, so that it can accommodate a specific traffic demand pattern per traffic signal plan configuration. However, traffic demand varies over time and statistical analyses of traffic field data have indicated that 15 minute peak traffic volumes can trigger breakdowns of traffic flow and onset congestion [3]. Actuated signal controllers have been designed in order to respond to these traffic demand variations minimizing stops and traffic delay [4]. Actuated signals utilize real-time traffic data collected from nearby detectors to adjust green and red times automatically, based on the arrival/departure rate of vehicles and the queue evolution/dissipation process at the branches of an intersection [1].

Previous studies have developed different models regarding the operation of actuated signals, tested their applicability according to intersection geometry and evaluated their impacts on vehicular traffic flow [1, 5, 6]. These previous studies have been conducted either through analysis of empirical data or simulation modeling.

An empirical study based on traffic data collected from signalized intersections across the road of Hermanos Garcia Noblejas, in Madrid, showed...
that actuated signal control can reduce delay and emissions compared to fixed time control at small and T-shaped intersections [6]. Another study proposed proper controller-detector combinations and detectors locations for the optimization of the actuated control operation of arterial signal systems [5]. Viti and van Zuylen developed a probabilistic model for traffic at actuated control signals that assumes stochastic arrival rates of vehicles [1]. This model renders the operation of actuated traffic signals more efficient when the intersection operates near capacity. A person-based traffic responsive signal control system for arterials was tested on a four-intersection segment of San Pablo Avenue arterial in Berkeley. The findings show the system’s capability to outperform fixed-time optimal signal settings by reducing total person delay [7].

**Microscopic traffic and emissions simulation modelling.** Microscopic traffic simulators can imitate the longitudinal and lateral movement of individual vehicles as they occur in real-life. Their ability to dictate these movements is based on a set of sub-models which replicate driver’s car-following, lane changing and gap acceptance behavior. Thus, the simulators estimate each vehicle’s position, speed and acceleration for every simulation step. The trajectories of the vehicles are then utilized for the estimation of fuel consumption and emissions by the corresponding models that are integrated within the microscopic traffic simulation models. An emission model developed by Panis et al. has been integrated with AIMSUN [8]. This model is based on empirical measurements which relate vehicle emissions with the instantaneous speed and acceleration of the vehicle. Rakha and Kamalanathsharma have stressed the importance of using microscopic emission models for the assessment of the environmental impacts of traffic management and control policies, since this is complex issue that requires detailed analysis of not only their impact on average speed but also on other aspects of vehicle operation such as acceleration and deceleration [9].

**The study site – Aimsun simulation model.** A detailed microscopic simulation model has been developed, covering the signalized arterial corridor that connects the city of Thessaloniki with the suburb of Peraia. The model development has been implemented with the Aimsun microscopic traffic simulator. The simulated network is comprised of 194 sections and 17 junctions; its total length is 11-km and it is depicted in Figure 1. Among the 17 junctions, 15 are controlled by signals. Ten public transport lines have been also simulated along with their corresponding time plans.

Demand has been obtained through a macroscopic traffic assignment model developed in VI-SUM for the wider area of Thessaloniki by Stamos et al. [10]. Field traffic flow data collected from traffic sensors located throughout the road network of Thessaloniki from an one-hour morning peak period (i.e. 08:00-09:00am) of a typical weekday (i.e. Wednesday 15th October 2014) have been input to the macroscopic model, which executed the traffic assignment and produced the necessary demand information has been obtained through a previous study conducted by Mitsakis et al. [11]. According to this study the fleet in this portion of Thessaloniki’s road network is comprised 90% by private vehicles, 5% by taxis, 4% by trucks and 1% by buses.

*FIGURE 1*
Simulated network in AIMSUN
FIGURE 2
Westbound approach of Thessaloniki-Peraia Rd. and Miaouli St. intersection

FIGURE 3
Traffic conditions on the westbound approach of Thessaloniki-Peraia Rd. and Miaouli St. intersection
FIGURE 4
Fuel consumption on the westbound approach of Thessaloniki-Peraia Rd. and Miaouli St. intersection

The operation and performance of the actuated signals against the fixed time control has been assessed for three different demand levels. A total of 6 scenarios have been simulated, 3 pertaining to actuated signal control operation and 3 to fixed time control. The base case scenario corresponds to 100% demand level (i.e. initial demand input to the microscopic model). The other demand levels correspond to 150%, and 200% (i.e. medium and high demand levels) of the actual demand.

Due to the stochastic nature of AIMSUN multiple runs of each simulated scenario are necessary, so that the simulation output is statistically significant. Therefore, five simulations of the base case scenario were initially run, each with a different random seed generated by AIMSUN’s internal random number generator, and statistics (i.e. standard deviation and mean value) regarding the average network speed were collected for this sample of runs. The significance level was selected to be 95%, the tolerable error equal to 0.5km/h, and given the standard deviation of the average network speed of the initial sample, the required number of runs was determined to be five.

RESULTS AND DISCUSSION

The output of the simulation experiments pertains to traffic performance measures and environmental indicators. Simulation output statistics have been estimated both at section level (i.e. disaggregate level) and network level (i.e. aggregate level). The estimated traffic performance measures are average section and network speed. The environmental indicators are fuel consumption, CO2, NOx, VOC, and PM emissions.

Disaggregate simulation output statistics. The operation of the actuated signal control has been evaluated on the westbound intersection leg of two signalized intersections along Thessaloniki-Peraia road. Thessaloniki-Peraia Rd. and Miaouli St. intersection is a T intersection depicted in Figure 2, while Thessaloniki-Peraia Rd. and Metamorfoseos St. intersection is a four-way intersection depicted in Figure 6. The average traffic density on the westbound leg of Thessaloniki-Peraia Rd. and Miaouli St. intersection is very low irrespective of the type of the signal control and the demand level (Figure 3). On the other hand, it is rather high (i.e. higher than the jam density) on the westbound leg of Thessalo-niki-Peraia Rd. and Metamorfoseos St. when the operation of the traffic signals is pre-timed and demand is medium or high (Figure 7). Thus, the effect of actuated control on traffic operations has been assessed both in instances that pre-timed control succeeded and did not succeed to efficiently manage demand.
The implementation of fully actuated traffic signals at Thessaloniki-Peraia Rd. and Miaouli St. intersection yields positive results in terms of traffic operations on the westbound leg of the intersection. The average traffic flow speed increases by approximately 30% for all demand levels (Figure 3). Accordingly, significant energy savings are generated (Figure 4) and emissions reduce substantially as well (Figure 5). The impact of actuated signal control on the westbound leg of Thessaloniki-Peraia Rd. and Metamorfoseos St. is paramount. Traffic congestion that prevailed on this road section prior to the deployment of actuated control is fully dissolved irrespective of the demand level (Figure 7). Due to congestion mitigation energy savings become overwhelming (i.e. 5.3 times less fuel consumed for the high demand scenario compared to the pre-timed signal control operation as depicted in Figure 8) and the reduction of emissions is of the same magnitude as well (Figure 9).
FIGURE 6
Westbound approach of Thessaloniki-Peraia Rd. and Metamorfoseos St. intersection

FIGURE 7
Traffic conditions on the westbound approach of Thessaloniki-Peraia Rd. and Metamorfoseos St. intersection
FIGURE 8
Fuel consumption on the westbound approach of Thessaloniki-Peraia Rd. and Metamorfoseos St. intersection

TABLE 1
Average network Speed (km/hr)

<table>
<thead>
<tr>
<th>Demand Level/Control Type</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuated Signals</td>
<td>52.65</td>
<td>42.08</td>
<td>28.94</td>
</tr>
<tr>
<td>Pre-timed Signals</td>
<td>49.21</td>
<td>40.39</td>
<td>28.34</td>
</tr>
<tr>
<td>% Difference</td>
<td>7.00</td>
<td>4.18</td>
<td>2.10</td>
</tr>
</tbody>
</table>

TABLE 2
Average network fuel consumption

<table>
<thead>
<tr>
<th>Demand Level/Control Type</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuated Signals</td>
<td>2.847</td>
<td>4.434</td>
<td>5.923</td>
</tr>
<tr>
<td>Pre-timed Signals</td>
<td>2.912</td>
<td>4.458</td>
<td>5.928</td>
</tr>
<tr>
<td>% Difference</td>
<td>-2.22</td>
<td>-0.53</td>
<td>-0.09</td>
</tr>
</tbody>
</table>
Disaggregate simulation output statistics. The performance of fully actuated signals has been also assessed network-wide. The average network speed increases with the deployment of actuated signals irrespective of the demand level (Table 1). However, the benefit decreases with increasing demand. Fuel consumption is lower for low and medium demand levels, but increases for high demand (Table 2). This finding is contradictory compared to the increase of the average network speed observed for the high demand scenario in Table 1. On the other hand, emissions are lower regarding the implementation of fully actuated signals for all demand levels (Table 3). Overall, network-wide benefits occur in presence of actuation, but are less significant compared to the isolated intersection case previously presented for the specific actuated signals’ settings configuration of this study.
TABLE 3
Average network emissions

<table>
<thead>
<tr>
<th>Demand Level/Control Type</th>
<th>Carbon Dioxide (CO2) Emissions (tons)</th>
<th>Nitrogen Oxides (NOx) emissions (kg)</th>
<th>Volatile Organic Compounds (VOC) (kg)</th>
<th>Particulate Matter (PM) (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Pre-timed Signals</td>
<td>6.320</td>
<td>10.045</td>
<td>13.990</td>
<td>26.508</td>
</tr>
<tr>
<td>% Difference</td>
<td>-0.83</td>
<td>-3.30</td>
<td>-0.67</td>
<td>-5.33</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Pre-timed Signals</td>
<td>13.186</td>
<td>20.002</td>
<td>26.423</td>
<td>45.461</td>
</tr>
<tr>
<td>% Difference</td>
<td>-1.05</td>
<td>-1.59</td>
<td>-0.83</td>
<td>-13.63</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Actuated Signals</td>
<td>965</td>
<td>1.898</td>
<td>3.710</td>
<td>45.688</td>
</tr>
<tr>
<td>Pre-timed Signals</td>
<td>1.026</td>
<td>2.197</td>
<td>4.008</td>
<td>45.461</td>
</tr>
<tr>
<td>% Difference</td>
<td>-5.91</td>
<td>-13.63</td>
<td>-7.42</td>
<td>-17.15</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The environmental impacts of fully actuated signal control along a 11.5 km signalized arterial corridor have been evaluated with the use of microscopic traffic simulation modelling. Results have indicated that significant reduction in fuel consumption and emissions can occur with the implementation of actuated signals both locally (i.e. isolated intersection) and network-wide. The benefits of the actuated signals can be maximized with the selection of the appropriate signal settings. Thus, further experimentation is required with the settings of the actuated signals of the simulated network in order to achieve optimum network performance. Moreover, the possibility of implementing semi-actuated signal control on specific intersections instead of fully actuated control can be also investigated.

REFERENCES

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SMALL SCALE ENERGY STORAGE SYSTEMS. A SHORT REVIEW IN THEIR POTENTIAL ENVIRONMENTAL IMPACT

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ABSTRACT

Regarding Small Scale Energy Storage Systems, large Pumped Hydro should be excluded because of its “bulk” capacity characteristic. Flywheels, Super Magnetic Energy Storage and Super-capacitors are considered environmentally friendly and briefly mentioned; therefore electrochemical means of EES systems such as batteries will be the central point of this paper.

Batteries are identified as a problematic material in the waste stream. They are made from a variety of chemicals and some of these, such as nickel and cadmium, are extremely toxic and can cause damage to humans and environment. They can also cause soil and water pollution and endanger wildlife. Cadmium can cause damage to soil micro-organisms and affect the breakdown of organic matter. Other chemicals used in modern electrochemical batteries are discussed, along with any protective means of safe utilization with minimum environmental impact.

KEYWORDS:
Energy Storage; batteries; cadmium; lithium; environment.

INTRODUCTION

The process in which electrical energy from a power network is stored and then converted back to electrical energy when needed is referred to as Electrical Energy Storage (EES). This process gives us the advantage to store electricity at times of low demand, low generation cost or from other energy sources such as wind, solar and wave, to be used at times of high demand, high generation cost or when no other generation method is available [1].

Energy Storage Methods. The current energy storage systems [2] are divided into the following categories according to the means of energy storage:
- Electrochemical energy
  - Battery Energy Storage (BES)
- Lead-Acid

  - Nickel battery
  - Sodium-sulphur
  - Lithium battery
  - Metal-air battery
  - Flow Battery Energy Storage (FBES)
  - Superconducting Magnetic Energy Storage (SMES)
    - Super Capacitor Energy Storage (SCES)
    - Mechanical Energy
    - Compressed Air Energy Storage (CAES)
    - Liquid Air Energy Storage (LAES) or Cryogenic Energy Storage (CES)
      - Hydro Energy Storage (HES)
      - Pumped Hydro Energy Storage (PHES)
      - Flywheel Energy Storage (FES)
    - Chemical Energy Storage
      - Hydrogen
    - Thermal Energy Storage
      - Sensible heat storage systems
      - Latent Heat Thermal Energy Storage (LHTES)
        - Thermochemical energy storage

Small Grid Definition and Energy Storage. As mentioned by Etxeberria [3], a micro grid is a type of grid that can be characterized as weak and its formation consists of numerous small sources, power converters, loads and storage systems.

A micro grid can operate either connected to the main grid or as an autonomous system such as in the case of an island. The micro grid, when connected to the main grid, is used to overcome the stochastic nature and the uncertainty of the Renewable Energy Sources (RES), in order to create a reliable load/generation system from the main electric grid point of view. In this context, the use of the EES is a widely accepted idea, as the variability of the generated power can be smoothed, power quality problems avoided and the frequency and the voltage of the micro grid controlled.

ENVIRONMENTAL APPROACH ON ENERGY STORAGE SYSTEMS

Having in mind the International Standards and the European Union (EU) directives (Table 1)
TABLE 1
EU Directives and International Standards

<table>
<thead>
<tr>
<th>EU Directive</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009/105/ECa</td>
<td>Simple Pressure Vessel Directive</td>
</tr>
<tr>
<td>97/23/ECa</td>
<td>Pressure Equipment Directive</td>
</tr>
<tr>
<td>2006/95/ECa</td>
<td>Low Voltage Directive</td>
</tr>
<tr>
<td>2006/66/ECa</td>
<td>Batteries and Accumulators and Waste Batteries and Accumulators Directive</td>
</tr>
<tr>
<td>2000/53/ECa</td>
<td>Restriction of Hazardous Substances in Electrical and Electronic Equipment Directive</td>
</tr>
<tr>
<td>2002/95/ECa</td>
<td>End-of Life Vehicles Directive</td>
</tr>
<tr>
<td>2012/19/EUa</td>
<td>Waste Electrical and Electronic Equipment (WEEE) Text with EEA Relevance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ISO</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>14040b</td>
<td>Environmental management - Life cycle assessment - Principles and framework</td>
</tr>
<tr>
<td>14041b</td>
<td>Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis</td>
</tr>
<tr>
<td>14042b</td>
<td>Environmental management - Life cycle assessment - Life cycle impact assessment</td>
</tr>
<tr>
<td>14044b</td>
<td>Environmental management - Life cycle assessment - Requirements and guidelines</td>
</tr>
</tbody>
</table>

a Available at ec.europa.eu (European Commission)
b Available at www.iso.org (International Standards Organization)

that qualify these technologies, a short technical summary for the technologies in focus will be presented. Additionally, the environmental impacts and the regulatory issues arising with these technologies will be stated.

Electrochemical Energy Storage Methods.
As mentioned in paragraph 1.1 above, an analysis of the electrochemical energy storage methods will follow.

Battery Energy Storage. Being part of electrochemical energy storage methods, battery energy storage falls into the following categories.

Lead-Acid Batteries. Technical summary.
The batteries whose cells are based upon chemical reactions involving lead (Pb) and sulphuric acid (H2SO4) are known as Lead-Acid batteries and are based on one of the oldest and most developed battery technologies [4].

Main Chemical Reactions. The main chemical reaction [5] is shown below:

At the positive plate the reaction is:
PbO2 + 3H+ + HSO4- + 2e\text{Discharge} \rightarrow PbSO4 + 2H2O

At the negative plate:
Pb + HSO4- + 2e\text{Charge} \rightarrow PbSO4 + H+ + 2e

And the overall reaction is:
PbO2 + Pb + 2H2SO4 \leftrightarrow 2PbSO4 + 2H2O

Environmental Impacts & Regulatory Issues. The lead used in these batteries is toxic [6] and therefore must be recycled. In addition, the sulphuric acid typically used as the electrolyte is corrosive and when overcharged the battery generates hydrogen which presents an explosion risk.

Recycling Prospects. A typical spent Lead-Acid battery can be harvested for its sulphuric acid, grids, metallic parts and the battery pastes [7]. The drained acid can be used as i) commercial synthetic gypsum derived by means of membrane techniques such as nanofiltration and diffusion dialysis or chemical precipitation or ii) clean concentrated sulphuric acid (30% w/w), obtained with electro dialysis, which is suitable for filling new batteries. The battery paste can be processed as in conventional raw paste smelting, smelting without sulphur, re-smelting of soda slug and finally, with hydrometallurgical treatment, with the latter leading to obtaining pure Pb [8].

Nickel Batteries. Technical summary. Nickel (Ni) batteries are electrochemical cells. There are a number of Nickel based batteries currently available or under development, including Nickel-Cadmium (Ni-Cd), Nickel-Metal Hydride (Ni-MH), Nickel-Zinc (Ni-Zn) and Sodium-Nickel Chloride (Na-NiCl2). Ni-Cd and Ni-MH are the most developed of the Ni batteries [4].

Main Chemical Reactions. The main chemical reaction for a Ni-Cd battery [5], as an example, is shown below:

For Nickel:
Ni2+(OH)+OH- \rightarrow NiOOH+H2O+e-

For Cadmium:
Cd2+(OH)+2e- \rightarrow Cd + 2OH-

Overall reaction:
2Ni2+(OH)+Cd2+(OH) \rightarrow 2NiOOH+Cd+2H2O

Environmental Impacts & Regulatory Issues. The most significant disadvantage of Ni-Cd batteries is the highly toxic cadmium used within
them; an element that is highly recyclable but exceedingly toxic, as mentioned. Most Nickel is recovered from end-of-life batteries since the metal is reasonably easy to retrieve from scrap and can be used in corrosion resistant alloys such as stainless steel, otherwise the metallic cylinder of the cell eventually begins to corrode and the cadmium gradually dissolves, seeping into the water supply [9]. In Ni-MH batteries, both the nickel and the electrolyte are semi-toxic. European Union EU legislation is in part responsible for the supercedence of Ni-Cd batteries by Ni-MH batteries and represents a significant issue to any future development of Ni-Cd battery technologies. Avoiding fumes and dust is essential for workers in this sector [10].

**Recycling Prospects.** Before the smelting takes place, metal components are separated from plastics. The metals are then recycled through a High-Temperature Metal Reclamation (HTMR) process during which all of the high temperature metals contained within the battery (i.e. nickel, iron, manganese, and chromium) report to the molten-metal bath within the furnace, amalgamate, then solidify during the casting operation. The low-melt metals, such as zinc and cadmium, are separated during the melting, the plastic and metals are then ready to be reused in new products [11].

**Sodium-Sulphur Batteries. Technical summary.** Sodium-Sulfur (NaS) batteries are electrochemical cells. NaS batteries are the most developed type of high temperature battery. A NaS battery consists of liquid (molten) sulfur at the positive electrode and liquid (molten) sodium at the negative electrode as active materials separated by a solid beta alumina ceramic electrolyte [12]. The electrolyte allows only the positive sodium ions to pass through it and combine with the sulphur to form sodium polysulphides.

**Main Chemical Reactions.** The main chemical reaction [13] is shown below:

Anode reaction:

$$2\text{Na} \xrightarrow{\text{Charge}} 2\text{Na}^+ + 2\text{e}^-$$  
$$2\text{Na} \xrightarrow{\text{Discharge}} 2\text{Na}^+ + 2\text{e}^-$$

Cathode reaction:

$$\text{xS} + 2\text{e}^- \xrightarrow{\text{Charge}} \text{S}_x^{2-}$$  
$$\text{xS} + 2\text{e}^- \xrightarrow{\text{Discharge}} \text{S}_x^{2-}$$

Overall cell reaction:

$$2\text{Na} + \text{xS} \xrightarrow{\text{Charge}} \text{Na}_2\text{S}_x$$  
$$2\text{Na} + \text{xS} \xrightarrow{\text{Discharge}} \text{Na}_2\text{S}_x$$

**Environmental Impacts & Regulatory Issues.** The environmental concerns associated with NaS batteries are limited, since the materials used in their construction are relatively environmentally inert. We also have to mention that in order to maintain sulphur in its liquid form the battery must be operated in high temperature and that has a small risk [14]. On the other hand, isolated materials used in NaS batteries react with other materials. More analytically, sodium reacts with water and the reaction is highly exothermic, usually explosive and produces hydrogen gas and sodium hydroxide [15]. Consequently, hydrogen in the presence of oxygen is highly explosive and sodium hydroxide is poisonous when ingested and severe chemical burns can be caused. Sulphur is not as chemically reactive as sodium, as stated before for their inert state, but there are significant hazards associated with its use. Sulphur is flammable, hence the previously mentioned risk, and produces sulphur dioxide and when burned it becomes a toxic gas and a tumorigenic [16].

**Recycling Prospects.** NaS batteries can be incinerated, which is costly, reclaimed / recycled and directly recycled / reused for their materials [14].

**Lithium Batteries. Technical summary.** Lithium batteries are electrochemical cells. Lithium-Ion (Li-ion) and Lithium-Polymer (Li-pol) types are both available [17].

**Main Chemical Reactions.** The main chemical reaction [5] is shown below:

Charging: $$\text{C} + \text{xLi}^+ + \text{xe}^- \rightarrow \text{Li}_x\text{C}$$

Discharging: $$\text{LiMO}_2 \rightarrow \text{Li}_x\text{MO}_2 + \text{xLi}^+ + \text{xe}^-$$

**Environmental Impacts & Regulatory Issues.** The main environmental issue with this type of batteries is the resource depletion, Eco toxicity (mainly associated with cobalt, copper, nickel, thallium and silver) and human toxicity. Due to its materials being capable of being recycled, like the salts and the lithium oxides, Lithium batteries have limited environmental impacts [18].

**Recycling Prospects.** These batteries contain metallic lithium, which reacts violently when it contacts with moisture and must be disposed of appropriately [19]. If Lithium batteries are thrown in the landfill without being discharged first, they could be crushed by heavy equipment operating on top and the exposed lithium would ignite a fire. Landfill fires are extremely difficult to extinguish and can burn for years underground. Before recycling, it is advised to discharge to fully consume the lithium content [20].

**Metal-Air Batteries. Technical summary.** Metal-air batteries are electrochemical cells and are the most compact batteries available.

**Main Chemical Reactions.** The main chemical reaction [20] is shown below:

Anode: $$\text{Zn} + 4\text{OH}^- \rightarrow \text{Zn(OH)}_4^{2-} + 2\text{e}^-$$

Fluid: $$\text{Zn(OH)}_4^{2-} \rightarrow \text{ZnO} + \text{H}_2\text{O} + 2\text{OH}^-$$
Cathode: $\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$
Overall: $2\text{Zn} + \text{O}_2 \rightarrow 2\text{ZnO}$

Environmental Impacts & Regulatory Issues. Environmentally, metal-air batteries are relatively inert since no toxic materials are involved in their construction. Like other battery types, metals such as zinc or aluminium used within the battery should be recycled [4].

Recycling Prospects. The recycling method of these batteries is primarily dependant on the metal used as the electrode. Thus, each metal used should follow its respective recycling process. Specific guidelines for each metal are used, some of which are explained in this paper.

Flow Batteries. Technical summary. Flow batteries store and release energy through a reversible electrochemical reaction between two electrolytes. There are four types of flow battery currently being produced or in the late stages of development; zinc bromine, vanadium redox (VRB), polysulphide and cerium-zinc. The zinc-bromine system represents a type of hybrid flow battery. A leading form of the vanadium redox flow battery is a system by VRB Power Systems Inc in Canada. These systems feature the separation of chemical reactants from the electrochemical cells through which charging and discharging take place. The storage capacity depends on the size of the electrolyte tanks, whilst the power output depends on the size of the fuel cell. The vanadium redox system has an advantage over the hybrid system as the discharge time at full power can be varied [21].

Environmental Impacts & Regulatory Issues. The potential size and scale of these systems are likely to determine the extent to which environmental impacts are significant. Significant quantities of space may be required for holding tanks containing the electrolytes and although these substances may not be specifically toxic this obviously requires care at the design stage. A major advantage of the technology is the ability of the technology to perform discharge cycles indefinitely, so there are no significant waste products associated with operation [22].

Recycling Prospects. Recycling of these batteries, just like Metal-Air batteries, depend on the various processes of each technology. Special care should be given in the reclamation of the electrolytes, and since there are a variety of electrolytes used, special care should be given when handling them [23].

Superconducting Magnetic Energy Storage (SMES). Technical summary. SMES is a technology that can store electrical energy in a magnetic field within a cooled superconducting coil. The coil is cryogenically cooled beyond its superconducting temperature (-269°C). At this temperature, resistance of the material to electric currents disappears, and the limited electrical resistance allows extremely high efficiencies of up to 97% to be achieved as well as enabling storage more or less indefinitely. An additional advantage is the immediate release of power which renders the system, a property useful to customers requiring extremely high quality power output [24].

Environmental Impacts & Regulatory Issues. Extremely low temperatures are required for the superconducting system which represents a safety issue. Larger scale SMES systems could require significant protection to deal with magnetic radiation issues in the immediate vicinity of the plant [25].

Recycling Prospects. A typical SMES system consists of the superconducting coil, the power conditioning system and the cryogenically cooled refrigerator. Usually, the coil is an alloy of Niobium (Nb) and Titanium (Ti) [26], which can generally be safely recycled [27]. The power conditioning system falls under the local directives regarding the recycling of electrical and electronic equipment. For the EU, directive 2012/19/EU clarifies the details regarding the recycling of these materials [28].

Supercapacitors Energy Storage. Technical summary. Supercapacitors can store energy in the electric field between a pair of charged plates. Supercapacitors, ultracapacitors or double-layer capacitors (DLCs) as they are also known, contain a significantly enlarged electrode surface area compared to conventional capacitors, as well as a liquid electrolyte and a polymer membrane [29].

Environmental Impacts & Regulatory Issues. Supercapacitors can be employed to enhance the energy performance of automobiles, for example, through regenerative braking systems, which can therefore lead to emissions benefits. In addition, supercapacitors have a long lifecycle. Potential negative environmental impacts of supercapacitors arise from the materials and compounds used within their construction and operation [1].

Recycling Prospects. Supercapacitors are being continuously improved and are considered as an emerging technology. Materials used in these types of capacitors consist of carbon aerogels, carbon fibres, metal oxides, conducting polymers etc. [30]. In general, the recycling of supercapacitors is achievable but might require effort in separating the various materials [31].
Mechanical Energy Storage Systems. As mentioned in paragraph 1.1, an analysis of the mechanical energy storage methods will follow.

Flywheel. Technical Summary. Flywheels represent a mechanical form of energy storage in which the kinetic energy of a fast-spinning cylinder contains considerable stored energy. Recent technological advances have modernised the traditional flywheel, improving its efficiency dramatically. Modern flywheel systems are typically comprised of a massive rotating cylinder, supported on a stator by magnetically levitated bearings that eliminate wear and extend system life compared with conventional bearings. To increase efficiency, the flywheel is operated in a low pressure environment to reduce friction with the air. A flywheel energy storage system draws electricity from a primary source to spin the cylinder at speeds greater than 20,000 rpm [32].

Environmental Impacts and Regulatory Issues. With no chemical management and disposal issues to consider, flywheels have some environmental advantages over the battery systems described earlier. Design life for these devices may be only a few years or less, which is an area for future research activity. Subject to stringent safety safeguards applied to the operation of heavy, rapidly rotating objects, a flywheel system should not cause problems to the local area [4].

Compressed Air Energy Storage. Technical Summary. Compressed Air Energy Storage (CAES) systems use excess off-peak energy to compress air and inject it into a depleted natural gas reservoir and then use the compressed air to power a generator during peak periods when the energy is needed most. Traditional CAES essentially dumps the heat into the atmosphere, therefore requiring a second injection of heat prior to re-expansion [33]. Advanced Adiabatic CAES (AA-CAES), instead, aims to remove the heat and store it separately, then re-eject it at the expansion stage, thereby removing the need to reheat with natural gas [34].

Environmental Impacts and Regulatory Issues. CAES, as a means of mitigating intermittency in wind power production can be favourable in certain conditions, especially when geological conditions are well suited for implementation and no energy has to be spent on the creation of a cavern. In general, AA-CAES has a lower impact compared to the CAES, due to fact that no fossil fuel is combusted. However, the impacts for a CAES plant are lower than those from natural gas power plant. For AA-CAES, an important part is the thermal energy storage. The development of the thermal mass with high heat transfer capabilities and low environmental impact is crucial to improve overall performance of the system [35].

Liquid Air Energy Storage. Technical Summary. Liquid Air Energy Storage or Cryogenic Energy Storage works similarly as a CAES system but the difference is that the air is liquefied and stored in over ground tanks. One pilot plant is operational at the time in Slough Trading Estate, UK [36].

Environmental Impacts and Regulatory Issues. One of the concerns at the start of the pilot plant project was stratification of the liquid air in the storage tank. This could result in local oxygen enrichment of the working fluid and the risk of fire or an explosion if the enriched fluid came into contact with hydrocarbons, such as the lubricating oil for the power turbine. This was managed in the pilot plant by ensuring all parts in contact with the working fluid were oxygen cleaned. Some enrichment was observed in feed pipes to the cryogenic pumps after 5–7 days of down time through preferential boiling of the nitrogen content of the liquid air. Purging of these pipes before operation cleared the enriched fluid from the system. No evidence of stratification or enrichment of the bulk liquid air in the storage tank was observed during the project over two years of operation [37].

Chemical Storage Systems. As mentioned in paragraph 1.1, an analysis of the chemical storage methods will follow.

Hydrogen. Technical Summary. The hydrogen production pathways [38] include: Steam Methane Reforming using natural gas as feedstock, Gasification of Coal and other hydrocarbons, Electrolysis using conventional grid or renewable power, Gasification of biomass and Nuclear Power. Then, hydrogen can be stored in underground caverns, salt domes and depleted oil and gas fields [39]. Stored hydrogen can then be used in fuel cells or injected directly to natural gas pipes to boost the calorific value and thus lead to better combustion in gas turbines.

Environmental Impacts and Regulatory Issues. Each pathway has its own environmental considerations and can be found in Table 2 [38]. Regarding small scale storage, like gasification of biomass and electrolysis through Renewable Energy Sources (RES), for remote consumers, it is considered as a pretty clean technology.

Thermal Energy Storage. Thermal Energy Storage refers to the conversion and storage of energy to heat or cold. This can be achieved through
TABLE 2  
Hydrogen Production Pathways and Environmental Considerations

<table>
<thead>
<tr>
<th>Method</th>
<th>Positives</th>
<th>Negatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Methane Reforming</td>
<td>(-) Burning natural gas contributes to global warming</td>
<td>(-) Extracting and transporting natural gas could harm sensitive landscapes</td>
</tr>
<tr>
<td>Gasification of Coal</td>
<td>(-) Making H₂ from coal or heavy oil would generate large amounts of carbon emissions</td>
<td>(-) Coal mining can degrade land and water quality</td>
</tr>
<tr>
<td>Electrolysis</td>
<td>(+) Use of renewable power would produce low to zero-emissions</td>
<td>(-) Use of conventional grid power would generate more global warming pollution than steam methane reforming with natural gas</td>
</tr>
<tr>
<td>Gasification of Biomass</td>
<td>(+) If feedstock are sustainably cultivated, process has low to no net global warming emissions</td>
<td>(-) Large scale production of feedstock and collection and transport of crops and residues may raise air, land and ecosystem concerns</td>
</tr>
<tr>
<td>Nuclear Power</td>
<td>(+) Low global warming emissions</td>
<td>(-) Issues of waste management and disposal and extraction and processing of uranium</td>
</tr>
</tbody>
</table>

heat exchangers and heat pumps and the storage vessel can be either underground tanks or cavities or over ground tanks. Verein Deutscher Ingenieure (VDI) Guideline VDI 4640 Part 1 [40] also analyses the various underground minerals that can store thermal energy that can be later retrieved. Finally, thermal energy storage is widely used in the forms of building air conditioning systems and solar heating for domestic water usage. The combination of photovoltaic panels along with solar heating from the same panel can greatly reduce greenhouse gases [41] thus making it an ideal solution for small scale heat storage solution with minimum to non-existent environmental impacts. The main environmental concern regarding the Ice Thermal Energy Storage lies within the refrigerant used in the freezing cycle [42].

CONCLUSIONS

No matter the magnitude of the energy storage system, certain environmental aspects should be considered. In the context of promoting smart grids, as in small scale and distributed energy generation in remote communities, the major aspects of batteries’ environmental impacts must be considered. Consumers should have the means and proper information on recycling of the batteries, thus a proper recycling network must operate flawlessly. In general, energy storage systems are environmentally inert during their operation and the major impacts are found during their construction and decommission. As in all chemical and mechanical devices, the installation must be made in secure rooms with all the necessary precautions, lighting, accident prevention automations and emergency exits.

The future need for energy storage will be increased but also the technologies used, in means of materials, will shift towards more environmentally friendly materials. Lead-Acid batteries, for example, are the current pinnacle of energy storage in many sectors, and because they can be recycled up to 90% they are the best choice in means of operation capabilities and environmental aspects.

An important issue that could be subject to further investigation includes the environmental impacts of DLCs, as it is an emerging technology and the recent and future developments in materials have to be studied.

REFERENCES


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INDUSTRIAL FURNACES/BURNERS.
A REVIEW ON THE ENVIRONMENTAL LEGISLATION
FOCUSING ON ECODESIGN

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ABSTRACT

The main aim of this paper is to demonstrate briefly, the diachronic course of the European Eco-Design legislation, regarding the industrial furnaces and the associated equipment such as burners, in terms of its environmental aspects. Simultaneously, the potential mandatory future requirements and policy options assessed by the European Union’s authorities will be depicted, launching the first discussions for the final official measures.

More specifically, in 2005, the initial version of the Eco-Design Directive for Energy using Products (EuPs), was published. After this, a Working Plan in 2008 listed the product groups which were considered as a priority for implementing measures for the 2009-2011 time period. Ten product groups were prioritized, due to certain specifications: i) the volume of sales and trade of units per year within the European Community, ii) considerable environmental impact, including high energy consumption, long operating time, emissions, waste generation and other, iii) significant potential for improvement. The ‘industrial and laboratory furnaces and ovens’ product group, was included. Subsequently, in 2009, the recast of the initial (2005) Directive was presented, setting the basic policy framework affecting Energy-related Products (ErPs) in the European Union’s 27 Member States. On this cause, a preparatory study was launched in 2010 resulting to a final report that was published in September 2012.

The abovementioned directives, escorted by the corresponding preparatory studies, working plans and recasts, compose the environmental legislation focusing on Eco-Design. The literal target of this legal process is to set the frame of the mandatory minimum requirements for each product group, leading to specific implementing measures for each product group after a certain procedure. At the outset, the background data are compiled in the preparatory study. A working document is drafted by the European Commission with a discussion in the Consultation Forum following. A Draft Implementing Measure is voted by the Regulatory Committee and is sent to the European Parliament for audit. Finally, the Mandatory regulation is published in the Official Journal of the European Union. [4]

The Eco-design Directive’s target is to set the frame of the mandatory minimum requirements for each product group, leading to specific implementing measures for each product group after a certain procedure. At the outset, the background data are compiled in the preparatory study. A working document is drafted by the European Commission with a discussion in the Consultation Forum following. A Draft Implementing Measure is voted by the Regulatory Committee and is sent to the European Parliament for audit. Finally, the Mandatory regulation is published in the Official Journal of the European Union. [4]

There is a lot of research regarding the European Commission’s Eco-design Directives and their
prioritized product groups that are set under investigation, especially the ones related to the domestic sector. As regards the ‘industrial and laboratory furnaces and ovens’ product group, there is a complete EU’s preparatory study, building on the Eco-design Directive. However, an absence of a summary concerning the industrial furnaces specifically and the notable proceedings to date, can be observed. In this paper, this ‘gap in knowledge’ will be attempted to be covered, along with a first review on the proposed measures.

**LEGISLATION ROUTE, FUTURE REQUIREMENTS AND POLICY OPTIONS**

**Legislation route to date.** The above mentioned legislative procedure which starts with the suggestions and trends of a Community Directive and produces a specific compulsory and pan-European regulation, is reflected in detail in the next chart (Figure 1).

**FIGURE 1**

The standard legislative procedure that concludes to an EU Mandatory Regulation

In 2005, the initial version of the Eco-design Directive for Energy-using Products (EuPs) was published, while on 21 October 2009, a recast, the Eco-design Directive 2009/125/EC for Energy-related Products (ErPs), was drafted. Before this fundamental Directive and following the first general Directive, the Commission contracted preparing studies on selected product groups [5], prepared a working programme (Working Plan) [6], with the prospect for revision after three years determining the product groups to be covered (firstly for the years 2009-2011). There were involved representatives of the Member States and interested parties (industry and business, trade, environmental protection and consumer organizations etc.) via a consultation forum which was assisted by representatives from the Member States in a regulatory committee. [7]

The Commission preparing study regarding the preparation of the Working Plan, listed 57 product groups which fall within the scope of the Eco-design Directive, against the principal environmental impact – primary energy consumption in the use phase – to determine the product groups with the highest potential for reduction of GHG emissions. Systematic identification of these product groups, was based on the PRODCOM product list, in order the Working Plan to be drawn. Finally, the Commission drafted the Working Plan for 2009-2011 (COM/2008/660) and prioritized ten product groups that have a volume of sales and trade of more than 200,000 units per year within the Community:

- Air-conditioning and ventilation systems;
- Electric and fossil-fuelled heating equipment;
- Food-preparing equipment;
- Industrial and laboratory furnaces and ovens;
- Machine tools;
- Network, data processing and data storing equipment;
- Refrigerating and freezing equipment;
- Sound and imaging equipment;
- Transformers;
- Water-using equipment.

The industrial furnaces/burners, are included in the “Industrial and laboratory furnaces and ovens” group, indicated also as “furnace burners”, along with products that, except a high volume of sales are also of significant environmental impact: High energy consumption (>1,000 PJ/year), long operating time (very high: up to 24 hours a day or high: about 8 hours a day), related emissions and waste generation and other environmental impacts of materials used. However, there is a significant potential for improvement with high potential for energy savings (estimated average > 20%) and potential for other environmental improvements (e.g. improved heat transfer systems or reduction of mass, etc.). The above prioritization occurred due to the need to fulfil the criteria of the Article 15 of the initial Eco-design Directive regarding the energy-using products’ volume of sales and trade within the Community, the level of their environmental impacts during their lifecycle within the Community and the potential for improvement in terms of these impacts. The recast Directive of 2009 followed establishing the basis for the future eco-design requirements for energy related products in general and then the preparatory study for the abovementioned product group, codenamed as ENTR Lot 4, started in 2010 and was completed in 2012 [8].

Finally, on 18 April 2014, the Working Document for the Eco-design Consultation Forum of the 16th of May on industrial and laboratory furnaces and ovens, was published, highlighting the most significant conclusions of the preparatory study and setting the appropriate issues to the Consultation Forum and the interesting parties for conversation. [9] This Working Document demonstrates the main policy
options to be implemented and presents the first “draft modelled” energy savings, simultaneously with some initial indicative numerical values of possible measures. It also refers to the already existing Industrial Emissions Directive (so called IED - Directive 2010/75/EU) [10] and its Best Available Technologies (BAT) Reference documents (BREFs) and conclusions [11] along with the Emissions Trading System (so called ETS - Directive 2003/87/EC) and the Energy Efficiency Directive 2012/27/EU (EED) and its associated legislation. [12, 13] A graphic presentation for the product group legislation route, is demonstrated below (Figure 2):

The Main Policy Options. The ENTR Lot 4 preparatory study classifies furnaces depending to their size to laboratory (<120 litres), small and medium (laboratory capacity <10 tonnes for batch and laboratory <20 tonnes / day for continuous) and finally, large and very large (>10 tonnes capacity for batch and >20 tonnes / day for continuous). It also categorizes the product group in 7 major base cases (BCs) as follows [14]:

1) BC1: Laboratory ovens and furnaces
2) BC2: Medium size batch oven (electric /gas)
3) BC3: Batch chamber furnace (electric/gas)
4) BC4: Continuous oven (electric/gas)
5) BC5: Continuous belt furnace (electric/gas)
6) BC6: Large furnace (fossil fuel [gas])
7) BC7: Very large oven (fossil fuel [gas])

In this review, there is focus on the medium and large sized furnaces and oven products which consume approximately 1,646 TWh of energy per year together, consequently the 2-7 base cases.

The 2014 Working Document concludes in two main policy options for further investigation within the ENTR Lot 4 preparatory study [8, 14]:

1. Draft proposals for Eco-design Implementing Measures relevant for Lot 4 furnaces and ovens, subdivided according to Base Case and
2. Regulating Lot 4 furnaces and ovens through the Industrial Emissions Directive (IED) sectoral BAT conclusions (higher chance of being more effective, through sectoral customisation) or the Horizontal Energy Efficiency BAT conclusions, via the same “Eco-design-style” provisions. This option would enhance IED by providing clearer energy consumption targets, but should not conflict with ETS and its “benchmarking” system.

The 1st Policy Option investigates the mandatory energy-saving targets and strategies/measures that could be set through a daughter regulation from the Eco-design directive and stand alone, without any connection with the existing legislation which partly deals with the product group (IED & ETS). The 2nd Policy Option concerns the same issues as the former, but to be applied in the scope of the IED sectoral Best Available Technologies conclusions (the already existing, relevant legislation) [8, 9, 14].

First Draft Measures and Requirements. The Ecodesign measures’ proposals based on the ENTR Lot 4 preparatory study and finally depicted on the EC’s Working Document, concerning the 2-7 base cases (medium and large sized products) as mentioned before, consist of the next eco-design strategies [8, 9, 14].

(1) Communication of the energy consumption estimates and data to the end users. This eco-design strategy concerning the energy consumption information communication to the end users, is already applied extensively for large industrial furnaces, as part of the preliminary processes or/and the tendering contract and the design phase of the product [8,9,14].

(2) Heat recovery and reuse (direct gas-fired base cases). This eco-design strategy refers to the direct-(fossil fuel) fired processes. During these processes the excess unused heat is partly released along with the flue gases. This heat could be reused within the furnace or generally the industrial facilities. The proposed mandatory heat recovery and reuse measures with draft values are presented in Table 1 [9].

The heat recovery process can be achieved via several methods, i.e. the use of regenerative/recuperative burners. Such burners can reduce energy consumption from 20% to over 50%, depending on several factors such as the burner design, etc. The percentage of heat recovered by regenerators can reach 85%, while for recuperators ranges between 20%–50%, with these percentages linked to the combustion gas temperature, the size of the regenerators/recuperators and the process. It is noteworthy that oxy-fuel burners are exempted from these mandatory requirements because they are already very efficient [9, 14].

FIGURE 2

Temporal presentation of European environmental legislation regarding Ecodesign in Industrial Furnaces
TABLE 1
Potential mandatory heat recovery measures according to the European Commission’s Working Document [9]

<table>
<thead>
<tr>
<th>Size of the process</th>
<th>Temperature of the process</th>
<th>Minimum amount of heat recovery per specific time period for flue gas containing 3% oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2016 and afterwards % recovered &amp; reused</td>
</tr>
<tr>
<td>Medium</td>
<td>&lt;1 000°C</td>
<td>-</td>
</tr>
<tr>
<td>Large</td>
<td>≥1 000°C</td>
<td>≥35% (flue gas≤500°C)</td>
</tr>
<tr>
<td>Medium</td>
<td>≥1 000°C</td>
<td>A minimum of 40% heat recovery</td>
</tr>
<tr>
<td>Large</td>
<td>≥1 000°C</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 2
Draft mandatory eco-design requirements for insulation based on an ambient temperature of 20°C/calm air, according to the European Commission’s Working Document [9]

<table>
<thead>
<tr>
<th>Base Case</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6 (&gt;1000°C o.t.*)</th>
<th>6 (450°C to 1000°C o.t.)</th>
<th>7 (&lt;450°C o.t.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandatory Requirements</td>
<td>(W/m² away from “hot-spots”)</td>
<td>&lt; 300</td>
<td>&lt; 300</td>
<td>&lt; 500</td>
<td>&lt; 400</td>
<td>&lt; 500</td>
<td>&lt; 400</td>
</tr>
</tbody>
</table>
*o.t.: operating temperature

TABLE 3
Draft mandatory eco-design requirements regarding “λ,” maximum values, according to the European Commission’s Working Document [9]

<table>
<thead>
<tr>
<th>Time Frame</th>
<th>λmax value per Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NG</td>
</tr>
<tr>
<td>2016 and afterwards</td>
<td>1.25</td>
</tr>
<tr>
<td>2019 and afterwards</td>
<td>1.15</td>
</tr>
</tbody>
</table>

(3) Improved insulation (electricity and direct gas-fired base cases). Improved insulation can contribute to furnace’s efficiency, through reducing heat losses by keeping the temperature stable. This eco-design strategy has also another advantage: while heat recovery and optimized fuel/air ratio apply only on direct fossil fuel combustion, improved insulation can be implemented for electrical heating also. The first draft eco-design mandatory requirements concerning improved insulation, are shown in Table 2 (ovens set for maximum temperatures of ≤450°C & furnaces set for maximum temperatures of >450°C). The external wall surface temperatures away from the hot-spots and the corresponding wall heat losses are considered as: for temperatures 40 - 50°C → 200 - 300 W/m² of heat losses respectively (for ovens) and for temperatures 60 - 70°C → 400 - 500 W/m² of heat losses respectively (for furnaces). [8, 9, 14]

(4) Optimised control of fuel/air ratio (indirect gas-fired base cases). Optimal management of the fuel/air ratio can result to lesser amount of fuel used to achieve the desired temperatures inside the furnace. The draft mandatory eco-design measures demonstrated in the European Commission’s Working Document, apply to indirect-fired fossil fuels furnaces only, at higher temperatures and are presented in Table 3. “λ” (lambda value) is defined as: (actual mass ratio of air/fuel) / (stoichiometric mass ratio of air/fuel). The lower the “λ” value, the lower the fuel consumption. [8, 9, 14]

These measures regarding fuel/air ratio, do not apply on electric furnaces and where special atmospheric conditions are required (i.e. reducing atmosphere).

All of the above eco-design measures cover a large range of furnaces. But due to the heterogeneity and complexity of the processes, applications, user requirements and the product group contents in general, there is a number of limitations and exceptions in furnaces and the associated equipment (such as burners) even on a base case to base case level, in terms of the proposed mandatory requirements and measures. Any specific exceptions and limitations are omitted and not presented as well as they are beyond the aims of this review.

Some representative examples of typical furnaces and ovens and the corresponding characteristics, performance parameters and improvement estimates through current BAT are presented in the Tables 4 & 5. These values are based on data provided by stakeholders according to the ENTR Lot 4 European study. The Eco-design options proposals were...
built on processing of data similar to these, after extensive analyzes and calculations, combining several indicators and parameters. [8, 9, 14]

At this point it should be mentioned, that the previously, briefly presented performance parameters, are indicative and by no case cover the range of processes and furnaces types. The full performance parameters (per industrial sector, process etc.), along with the corresponding stakeholders data, calculation methods, estimations, assumptions and restrictions, are demonstrated in detail in the ENTR Lot 4 European study (Task 5) [8, 9, 14].

**TABLE 4**

Types of EU Furnaces and their Operational Characteristics according to the ENTR Lot 4 European study [8]

<table>
<thead>
<tr>
<th>Type of Furnace/Oven</th>
<th>Average Power Rate (MW)</th>
<th>Energy Consumption</th>
<th>Working Hours, Capacity Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement Rotary Kiln</td>
<td>130</td>
<td>1000 GWh/year</td>
<td>8000 h/year, 60%</td>
</tr>
<tr>
<td>Flat glass melting gas</td>
<td>60</td>
<td>156 – 477 GWh/year</td>
<td>Continuous for 15 years</td>
</tr>
<tr>
<td>Rotary ferrous melting furnace gas</td>
<td>1 – 4</td>
<td>200 to 27,000 MWh/year</td>
<td>10 h/day</td>
</tr>
<tr>
<td>Rotary non-ferrous melting gas</td>
<td>1 – 4</td>
<td>300 – 43,000 MWh/year (copper)</td>
<td>10 h/day</td>
</tr>
<tr>
<td>Steel wire heat treatment (various,</td>
<td>1.1 – 1.5</td>
<td>11 GWh/year</td>
<td>8000 h/year, 90%</td>
</tr>
<tr>
<td>gas)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel wire galvanizing (various,</td>
<td>0.3 – 1</td>
<td>7.2 GWh/year</td>
<td>8000 h/year, 90%</td>
</tr>
<tr>
<td>gas)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat treatment aluminium gas</td>
<td>1 – 20</td>
<td>6.4 – 128 GWh/year</td>
<td>8000 h/year, 80%</td>
</tr>
<tr>
<td>Wall tile kiln</td>
<td>&lt; 1</td>
<td>4 GWh/year</td>
<td>6500 h/year, 60%</td>
</tr>
<tr>
<td>Sanitary ware kiln</td>
<td>6</td>
<td>14,000 MWh/year (estimate)</td>
<td>335 days/year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12,000 MWh/year (estimate)</td>
<td>335 days/year</td>
</tr>
</tbody>
</table>

**TABLE 5**

Indicative Performance Parameters for EU Furnaces according to ENTR Lot 4 European study [8]

<table>
<thead>
<tr>
<th>Type of Furnace</th>
<th>Maximum Process Temperature (°C)</th>
<th>Worst</th>
<th>Average</th>
<th>Best</th>
<th>BAT</th>
<th>Energy Saving Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Recovery from combustion gases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat glass melting gas</td>
<td></td>
<td>30%</td>
<td>45%</td>
<td>56%</td>
<td>60%</td>
<td>5%</td>
</tr>
<tr>
<td>Rotary ferrous melting (gas)</td>
<td></td>
<td>10%</td>
<td>12%</td>
<td>20%</td>
<td>20%</td>
<td>5%</td>
</tr>
<tr>
<td>Rotary non-ferrous melting (gas)</td>
<td></td>
<td>0%</td>
<td>10%</td>
<td>25%</td>
<td>25%</td>
<td>10%</td>
</tr>
<tr>
<td>Fossil Fuel / Air Ratio supplied to Burners as λ values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement Rotary Kiln</td>
<td>1.25</td>
<td>1.15</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1%</td>
</tr>
<tr>
<td>Wall tile kiln</td>
<td>1.25</td>
<td>1.2</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1 (NG), 1.25 (LPG)</td>
<td>1%</td>
</tr>
<tr>
<td>Sanitary ware kiln</td>
<td>1.25</td>
<td>1.2</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1 (NG), 1.25 (LPG)</td>
<td>1%</td>
</tr>
<tr>
<td>Heat Loss (W/m²) from external surface of insulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel wire heat treatment (various,</td>
<td>1100</td>
<td>600</td>
<td>410</td>
<td>290</td>
<td>230</td>
<td>3% (20% of insulation losses)</td>
</tr>
<tr>
<td>gas)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel wire galvanizing (various,</td>
<td>450</td>
<td>540</td>
<td>410</td>
<td>290</td>
<td>290</td>
<td>6% (30% of insulation losses)</td>
</tr>
<tr>
<td>gas)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat treatment aluminium</td>
<td>500</td>
<td>450</td>
<td>365</td>
<td>300</td>
<td>200</td>
<td>6%</td>
</tr>
<tr>
<td>Flue Gas Temperatures at 3% oxygen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel wire heat treatment (various,</td>
<td>1100</td>
<td>900 at 0.5% (790 at 3%)</td>
<td>750 at 0.5% (659 at 3%)</td>
<td>600 at 0.5% (527 at 3%)</td>
<td>200 at 0.5% (176 at 3%)</td>
<td>25%</td>
</tr>
<tr>
<td>(austenitizing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotary ferrous melting gas</td>
<td>1600</td>
<td>700</td>
<td>600</td>
<td>450</td>
<td>450</td>
<td>25% using heat exchangers 45% using oxy-fuel burners</td>
</tr>
<tr>
<td>Cement Rotary Kiln</td>
<td>1450</td>
<td>350</td>
<td>265 (280 at 2%)</td>
<td>237 (250 at 2%)</td>
<td>237</td>
<td>10% (recovered heat must be used elsewhere)</td>
</tr>
</tbody>
</table>
TABLE 6
Energy Consumption per annum and per base case according to European Commission’s Working Document [9]

<table>
<thead>
<tr>
<th>Base Case</th>
<th>Energy Consumption (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-5 (small-medium size)</td>
<td>211 TWh/year</td>
</tr>
<tr>
<td>6-7 (large size)</td>
<td>1 435 TWh/year</td>
</tr>
<tr>
<td>Total</td>
<td>1 646 TWh/year</td>
</tr>
</tbody>
</table>

1 650 TWh/year with the 4TWh/year of the laboratory devices added. However including energy consumption both in the manufacture/dispose phase and the use phase.

Potential Energy savings. According to the European Commission’s Working Document (2014), the Industrial Furnaces and Ovens product group energy consumption per year depending on each base case, is formed as in Table 6. Large industrial furnaces consume almost 87% of the total EU27 industrial furnaces’ energy consumption and approximately 50% of the European Union’s Industrial Sector energy consumption [8, 9, 14].

The next charts, based on Annex E of the European Commission’s Working Document [14] represent the energy savings that will occur if the proposed policies’ requirements are implemented (Figures 3, 4). There are two main policy options as described in the previous paragraphs (Eco-design measures & BAT according to IED) that are proposed to be adopted. In Figure 3 (Policy 1), three main scenarios are demonstrated (considering measures only for new products - new sales) [14]:

1) The No action scenario, considering that there will be no energy saving technologies/measures for the forecast time period (until 2035),
2) The (proposed) Eco-design measures policy scenario, and
3) The Least Life Cycle Cost (LLCC) scenario – a reference/hypothetical scenario for what would occur if the LLCC option were to be hypothetically implemented from 2016.

In the EC’s Working Document and the ENTR Lot 4 study, the results of the calculations for the LLCC usually coincide with the BAT (Best Available Technology) scenario. [8, 9, 14]

In Figure 4 (Policy 2), the IED BAT policy option’s predictions are represented. IED BAT refers to the Best Available Technologies implementation under the Industrial Emissions Directive (IED) BREF mechanism, or under the Horizontal Energy Efficiency BAT conclusions, or the comparative assessment (hypothetically) via the Emissions Trading System (ETS) (or both IED and ETS) for the existing industrial furnaces stock (parts renewal, etc) and new sales. There are three time-related scenarios (except the No action as mentioned before) for this policy: a) the Optimistic scenario ~ BAT implementation on 2016, b) the Pessimistic scenario ~ BAT implementation on 2022 and c) the Pragmatic scenario ~ BAT implementation on 2018. The energy savings arithmetic results are the same between these 3 scenarios – the only difference occurs to the year of implementation [14, 15-18].

The estimations show that the proposed mandatory Eco-design requirements/measures would have almost immediate energy-saving results compared with the No Action scenario. More specifically, the mandatory Eco-design measures are expected to provide 10% energy savings on 2035 compared to the No Action Scenario for all base cases.
and the respective LLCC/BAT hypothetical scenario 12.9% energy savings for all base cases as a whole (including base case 1). On the other hand, the BAT under the IED are expected to provide 19.2% energy savings compared to the No Action scenario. [14]

The estimation for the potential energy savings technically available, calculated over a 25 year period, from 2011 to 2035, for all ovens and furnaces if the best available technology (BAT) and also least life cycle costs (LLCC) is implemented, is almost 90 TWh/year, with 82 TWh/year occurring from the large furnaces and ovens (approximately 91% of the total savings). [9]

CONCLUSIONS

European environmental legislation process concerning the eco-design of industrial furnaces/ burners is not yet completed and in any case has not reached final conclusions. Until now, a basic framework of draft, indicative measures and corresponding proposals are indicated. These proposals will be reviewed and re-evaluated, but nevertheless, reflect an initial effort to conclude gradually, to the final, mandatory and official regulations. The forecasted energy savings are encouraging, however the Con- 

mandatory and official regulations. The forecasted an initial effort to conclude gradually, to the final, 
reviewed and re-evaluated, but nevertheless, reflect 
ing proposals are indicated. These proposals will be 
work of draft, indicative measures and correspond-

reached final conclusions. Until now, a basic frame-
burners is not yet completed and in any case has not 
concerning the eco-design of industrial furnaces/
total savings). [9]

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A SIMPLIFIED DECISION MAKING APPROACH FOR THE ENERGY RENOVATION OF BUILDINGS: THE CASE OF THE DADIA FOREST HOTEL SETTLEMENT

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ABSTRACT

Settlements in forest areas are subject to restrictions and rules that differ quite significantly from those of “regular” buildings. The case study considered in this paper is of a settlement consisting of the administration building, a traditional timber restaurant and an ecotourism hotel situated in Dadia protected wildlife forest, in Greece. The bioclimatic renovation of the settlement in order to reduce energy consumption relies on the collection of climatic data and of data on the building’s performance, which depend on in-situ measurements. Low cost instruments were used to measure climatic parameters (air temperature, relevant humidity, solar radiation, wind speed and direction) in the area.

Small scale business are lacking adequate funds and specialized scientists. Furthermore, due to economic crisis they cannot attract managers to undertake a formal decision making process. The methodology used provides a simplified approach of decision making that can be applied in building renovation linked to the improvement of energy performance of ecotourism hotel. These actions are based on bioclimatic design techniques and green building concept methods that have been successfully applied in practice in Greece providing a combination of cost effectiveness and optimum energy consumption outcome in compliance to European and national directives actions against climate change.

The results revealed a low annual average wind velocity, of 1.90 m/s, an annual monthly average solar insolation of 150 W/m², an annual temperature range of -3.1 to 36.3 °C and of relevant humidity from 20.6 to 100%. The proposed bioclimatic renovation actions focused on the alteration of the HVAC systems proposing the use of biomass for heating, installation of sun thermal systems for hot water and ceiling cooling fans, combined with passive design measures, such as, the enhancement of insulation, the replacement of old windows and exploitation of natural ventilation.

KEYWORDS:
climatic parameters, thermal comfort, bioclimatic design, energy performance, forest environment

INTRODUCTION

Buildings account for almost 40% of the energy consumption in Europe [1]. The efforts of the international scientific community against climatic change resulted in the adoption of directives and standards and guidelines concerning the energy performance of buildings, such as the European Commission’s Energy Performance Buildings Directive (2010/31/EU) [2], the ASHRAE standard 90.1:2013 [3] and the International Energy Conservation Code for buildings (IECC) [4].

Thermal comfort, together with indoor air quality, has also been in the focus of scientific and regulatory effort, and developments moved on at a pace similar to that of the energy performance [6]. The main international standards concerning thermal comfort conditions tools for improving energy performance without compromising indoor thermal comfort of buildings are the U.S. American Standards Institute ANSI/ASHRAE-55/2010 (2013) [7], and ISO 7730/2005 [8] (International Organization for Standardization) and European Standard EN 15251/2007 [9]. In Greece the corresponding framework is the national regulation on energy performance, KENAK [10], accompanied by the four technical guidelines TOTEE 20701, parts 1 to 4 [10].

In order to define thermal comfort several mathematical models and indices have been developed over time. The main disadvantage of these models and indices are their complexity in terms of calculations, the required special instruments and the need for controlled experiment environment. The whole process is far beyond the capabilities of a standard team of users. Usually the implementation is carried out by academics and specialized scientists (Epstein and Moran, 2006) [11]. Furthermore, due to the economic crisis [5], it not affordable for small and medium size businesses to
respond to the required investment for the implementation of a complete decision making procedure consisting of multiple tools and high cost instruments [12]. This paper presents a simplified cost effective approach in order to measure and record the basic climatic parameters as well as for the decision making process for the selection of renovation techniques for optimizing the energy performance of the ecotourism hotel.

The research area is limited to the building establishments and its surrounding area of the Dadia-Lefkimis-Souflis Management Body at an altitude of 93m above sea situated at the east side of the forest road (Figure 2) operating as an entrance to the visitors.

The research area is a famous wild bird conservation and protection area where visitors have the opportunity to observe wild birds from watch towers that are spread within the Dadia forest. The ecotourism hotel located at this area is the main accommodation building for visitors. The need for improvement of energy performance of the ecotourism hotel is justified for the following reasons:

1. Increasing trend in ecotourism, attracting users that are environmentally aware. In order to take advantage of this trend it is of vital importance to comply to environmental building regulations as well. The forest environment alone is not enough for visitors that are highly concerned with environmental issues so their accommodation should also meet environmental standards.

2. The need for reduction of energy consumption for economic and environmental reasons.

3. The economic crisis led to reduced funds for building’s operation expenses as well as for energy saving actions imposing a need for low cost measures and decisions making procedures.

4. The potential for job creation as a social impact for the local community with respect to wood fuel production in a sustainable manner.

The decision making on proposed renovation-retrofit actions for the improvement of energy performance at existing buildings requires the implementation of multiple procedures. These procedures consist of installation of instruments recording local climatic data and technical tools such as energy simulation programs. Furthermore, analytical tools such as Life Cycle Assessment, Life Cycle Cost and cost/benefit analysis implementation are of vital importance, not to mention procedural tools like Environmental Management systems or rating Systems [14]. The Greek ministry of Environment, Energy and Climate change in cooperation with Technical Chamber of Greece published technical guidance documents [30, 31] as implementation tools for the national Regulation on the Energy Performance of Buildings KENAK [10] concerning building’s energy performance calculation methods and as a guide for the implementation of bioclimatic techniques towards the aim of nearly zero energy building scheme. Those pieces of legislation are the harmonization of the Directives 31/2010/EU [2], on the energy performance of buildings and on energy efficiency 27/2012/EU [15]. Specifically the latter states that all member states must establish a long term strategy for mobilizing cost effective investments approaches in the renovation of the national

**FIGURE 1**
Location of Dadia forested National Park at the North-East borders of Greece

**FIGURE 2**
The research area and the positions of recording instruments source: Google Earth 2015

**MATERIALS AND METHODS**

**Research Area.** The area under consideration is the protected forested National Park of Dadia-Lefkimi-Souflis situated on North East borders of Greece as shown in Figure 1. The area is managed by the Dadia-Lefkimi-Souflis Management Body [13], an Institution enacted by law by the Ministry of Environment, Energy and Climatic Change as part of the network of Institutions of Protected Regions founded in 2003. Apart from protection activities the Dadia-Lefkimi-Souflis Management Body is implementing events and programs of environmental education and have the ability to accommodate visitors mainly interested in ecotourism and recreation within the forest environment. The Dadia forest covers an area of 428 km², 72.9km² out of which are strictly protected.
Instrument recordings of climate data. The most commonly accepted index is the Predicted Mean Vote - Predicted Percentage of Dissatisfied persons (PMV-PPD) developed by P.O. Fanger [17] and has been adopted by the ASHRAE-55 [7], ISO 7730 [8] and EN 15251 [9] standards which set the requirements for indoor thermal conditions. The complexity of the above methods has been a drawback resulting in need for simplification and this is a usual for most scientific operations that require the use of special instruments and equipment [16]. Earlier research showed that thermal comfort is strongly related to the thermal balance of the body, therefore temperature being the most important parameter on human perception, concerning thermal comfort [12]. Following these findings Toftum et.al [18, 19] experimented in the percentage of dissatisfied persons from fluctuations of air temperature and air humidity, setting upper limits of air humidity for thermal comfort. These findings led to the determination of a diagram depicted in Figures 7 and 8, consisting of air temperature against air humidity defining thermal comfort and satisfaction zones. This diagram has been adopted in this case for its practicality on checking the indoor thermal comfort conditions.

The instruments and software selection has been made based on the following criteria, in line with valid standards and guidelines [19].

- Ability to record continuously specific climatic parameters for prolonged period.
- Accuracy of measurements.
- Cost.
- Convenience, user friendly processing of data

**TABLE 1**

<table>
<thead>
<tr>
<th>Instrument Label</th>
<th>Type of Measurements</th>
<th>Recording characteristics</th>
<th>Accuracy</th>
<th>Cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Predictor 2.0 [20]</td>
<td></td>
<td></td>
<td>+/- 3%</td>
<td>405</td>
</tr>
<tr>
<td>Hobo U-12-011 × 2 Indoor Loggers [21]</td>
<td></td>
<td></td>
<td>+/- 0.3°C (0 to 50°C)</td>
<td>120 × 2 = 240</td>
</tr>
<tr>
<td>Hobo U-23-002 Outdoor Logger [22]</td>
<td></td>
<td></td>
<td>+/- 0.2°C (-40 to 70°C)</td>
<td>157</td>
</tr>
</tbody>
</table>

The recording period was from April 2013 to September 2014.

Building stock both public and private [16]. The aim is to provide technical details for designing buildings with less energy consumption, incorporation of renewable energy sources and reduction of emissions against climate change phenomenon.
Instr.3 in order to measure thermal comfort conditions in the building on a daily basis.

4. The Hobo data logger U-23-002 [22] outside the coffee-restaurant timber lodge facing north, labeled as Instr.4 in order to measure the external conditions protected from sun influence.

**Building characteristics.** The building under consideration is a small ecotourism hotel named “Hotel Inn” Ecotourism Hotel of Dadia”. It is situated at the east side of the research area (Figure 2). It consists of two longitudinal rows of one storey and two storey semi-detached rooms and a breakfast hall with a longitudinal patio in between. The building’s characteristics are:

1. Twenty double bed rooms with an average size of 15 m² each, a breakfast hall of 128 m² and a reception area of 25 m², summing to a total area of 453 m².
2. Mainly intermittent (weekends) and seasonal use.
3. A central 232 kW oil boiler for heating and 25 individual air condition systems for cooling needs.
4. Three solar thermal collectors for water heating of 200 liters volume each.
5. Recently renovated, focused on decoration, alterations of space usage, replacement of electrical, mechanical equipment and plumbing networks (drainage and water supply), without including any works for the improvement of its energy performance.
6. Wood frame windows and doors that are partly compliant with energy saving standards.

The area is characterized by a heating load of 1,798 Heating Degree Days (base temperature 18°C) and only 136 Cooling Degree Days (base temperature 24°C). Therefore, the energy requirements are mainly for heating. Still, in order to ensure comfort for the guests even in summer, each room has an air-conditioning unit, i.e. a split-unit heat pump. This need for cooling appliances is justified by the fact that although the cooling degree days are limited to 136°C, the numbers of hours exceeding 28°C in the hottest months (July-August) are 496. In that sense, in a short period of two months, it can become quite uncomfortable.

Forested areas have their own microclimate, imposing a need for on-site measurements, rather than from national data bases, in order to obtain reliable climatic data of the research area.

Based on a significant number of surveys concerning application of renovation-retrofit applications conducted in practice during the last 25 years throughout the country by specialized contractors in the renovation market, it was found that a number of energy-saving measures have been recorded as the most important with successful energy reduction results [16]. These refer to the existing building stock relating to the building shell, heating and cooling systems, hot water systems, etc. (Table 2).

According to research conducted by Hotel Energy Solutions (2011) [23] in more than 1,200 hotels across Europe it was found that at most hotels, energy use falls in the range 200-400 kWh/m²/yr and the hotel sector’s contribution to global warming and climate change, is estimated to include annual releases between 160 and 200 kg of CO₂ per m² of room floor area. Space conditioning (heating/cooling, ventilation and air-conditioning) is the largest single end-user of energy in hotels, accounting for approximately half of the total consumption. Domestic hot water is commonly the second largest user, accounting for up to 15% of the total energy demand. Based on studies carried out in Greece, it was determined that the main measures for energy conservation can be summarized in Table 2 [24, 16].

Point 6 is of importance, as the national regulation on energy performance [10] requires that new buildings, but also those undergoing major renovation, must cover at least 60% of the energy required for hot water by the use of solar thermal systems or other renewables.

**RESULTS AND DISCUSSION**

**Climatic analysis results.** The data analysis has been focused on the main climatic parameters of air temperature, relevant humidity, wind speed, wind direction and solar insolation. The results cover the recorded period of 12 to 18 months depending on the parameter analyzed, considering mean values. The data have been exported from the software interfaces of the instruments into Microsoft Excel from which the Figures 3 to 8 produced.

**TABLE 2**

<table>
<thead>
<tr>
<th>No</th>
<th>Energy Saving Measure</th>
<th>Percentage Saving [%]</th>
<th>Indicative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermal Energy</td>
<td>Electricity</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Wall thermal insulation</td>
<td>33-60</td>
<td>Up to 50€/m²</td>
</tr>
<tr>
<td>2</td>
<td>Restoration of glazed units (windows, doors, frames)</td>
<td>14-20</td>
<td>200-250 €/unit</td>
</tr>
<tr>
<td>3</td>
<td>Installation of new high efficient heating systems</td>
<td>Up to 17</td>
<td>8000-10000 €/unit</td>
</tr>
<tr>
<td>4</td>
<td>Installation of ceiling fans</td>
<td>Up to 60</td>
<td>180 €/unit</td>
</tr>
<tr>
<td>5</td>
<td>Night ventilation</td>
<td>Up to 10</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Installation of solar hot water systems</td>
<td>50-80</td>
<td>1000 €/unit</td>
</tr>
<tr>
<td>7</td>
<td>Increased air tightness</td>
<td>16-21</td>
<td></td>
</tr>
</tbody>
</table>

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The calculated average monthly values over a 14 months period for wind velocity is 1.90 m/s and the average monthly value of solar insolation for a 12 months period (April 2013- March 2014) has been equal to 150 W/m². The minimum and maximum air temperature values over the 18 months period was -3.1°C and 36.3 °C and the corresponding minimum and maximum of relevant humidity was 20.6% and 100%. Finally, focusing on relative humidity during summer (Figure 9.), the recorded maximum daily average relative humidity was 69.50% and the minimum daily average was 39.6%.

Proposed measures for optimization of building’s energy performance. The improvement of energy performance of existing buildings is a strive accomplishment compared to the application of bioclimatic design at the design stage and likewise the cost is much higher for existing buildings renovation or retrofit. The following proposed renovation-retrofit measures are based on facts of
successful renovations in practice. Their success is measured according to their output concerning energy consumption reduction, enhancement of efficiency and increasing the share of renewable energy sources for energy production at the building sector and specifically at hotels. The actions are categorized into (A) passive building design techniques and (B) HVAC systems alteration for energy production.

A) Passive building design improvements.
1. One of the most successful measures towards the reduction of energy consumption is the increase of insulation. Placement on the outside is more suitable for permanent use like residential buildings while placement on the interior is favorable for hotels or vacation use because the interior insulation increases the responsiveness of the heating system in order to reach thermal comfort conditions [25]. The challenge by the application of internal

![Figure 6](image6.png)

**FIGURE 6**
Monthly mean relevant humidity over the recording period

![Figure 7](image7.png)

**FIGURE 7**
November 2013 thermal comfort diagram.

![Figure 8](image8.png)

**FIGURE 8**
May 2014 thermal comfort diagram

![Figure 9](image9.png)

**FIGURE 9**
Average daily Relative Humidity values of July 2013
insulation to the existing walls is the possible liquefaction of the interior humidity on the internal side of walls due to the fact that the building becomes more airtight. The provision of a humidity barrier on the internal side of the insulation may be necessary to avoid mould problems in colder climates.

2. Replacement of windows with certified energy conservation ones. Windows and doors are the weakest areas of a building's fabric. The heat transfer coefficient of windows are always higher compared to the opaque parts of the building, the differences being higher for old types of windows with un-insulated frames and single glazing. Fortunately, modern windows use insulated frames and double glazing, sometimes with special heat transfer resisting gases between the glazing. Wood frames provide more resistance to heat transfer than aluminum ones due to the microscopic structure of wood containing pores and voids, characterized as a natural insulating material with an average value of thermal conductivity value \( \lambda \) equal to 0.14 W/(m·K) [31] that complies to EN ISO 13789 and 6946 (2009). Moreover, Wood frames will adapt better to the forest environment for aesthetic reasons.

3. The low annual average wind speed is not capable in producing energy as the threshold for wind power exploitation by installing a small scale wind turbine is 3.5 m/s [30]. The locally prevailing winds do not exceed 2.0 m/2. Consequently any investment in wind turbines for energy production is clearly not feasible.

B) Improving HVAC systems for energy conservation. The building was built prior to the regulations for reduction of energy consumption [10] and as such it does not comply with the new standards so there is a need for improvement on energy performance via the following measures:

1. Replacement of the old oil-fired heating system. This measure is characterized as one of the most cost effective energy retrofit measures for buildings other than residential [33]. The average oil consumption during the winter is 9 m\(^3\) corresponding to an average of 50% reservation and a corresponding cost of 7500 €. The oil consumption for heating has been equal to 9m\(^3\) and the corresponding energy consumed is equal to:

   Heating energy consumption: 9m\(^3\) \( \times \) 10000 kWh/m\(^3\) = 90000 kWh

   Heating energy consumption per square meter: 90000 kWh / 453m\(^2\) = 198,6 kWh/m\(^2\) (2)

   The acceptable consumption corresponding to the heating degree days of the area should be much lower in order to comply with the low energy building regulations, below 100 kWh/m\(^2\) to an average of 65 kWh/m\(^2\) while for passive houses these numbers fall even more to an average of 15 kWh/m\(^2\) [34]. According to the Greek Energy Regulation [10] buildings located in the area of Dadia belong to climate zone C and the corresponding energy consumption for this building should be less than 150 kWh/m\(^2\) in order to be acceptable [16]. The area of Dadia is a pure forested one, with an operating wood production industry mainly of fuel wood.

   The forests are managed in a sustainable way based on rotation harvesting system in order to maintain the forested area. The cost of fuel wood is quite low in the local market (50 €/stacked m\(^3\)). The use of wood as a fuel that has been produced from sustainable managed forests is considered to be carbon neutral and is categorized as a renewable resource of energy [2], Oil prices are fluctuating considerably from year to year from 1.3€ (2013) to 0.85€ (2015) making a fuel budget estimation almost impossible. The modern wood fuel boilers provide high values of efficiency and low emissions compared to stoves or older boilers [35].

   Furthermore the area has plenty of space for storage of wood fuel. The fully automated boilers are those using wood chips, but some wood logs one provide automated feeding of wood. The prices of wood boilers are almost the same with oil ones and those using wood chips are slightly more expensive but more efficient and provide a standard automated feeding system. The advantage is clearly viewed from an environmental perspective, as wood is a renewable energy resource and also is locally produced. To optimize the use of heating system with respect to energy consumption is to use two separate boilers, one small, for periods with low occupancy and a larger for the high season. This would of course lead to a higher initial cost but it is probably the most cost effective one as boilers can operate at the highest efficiency. Special care should be given to the good seasoning of fuel wood in order to avoid possible soot emissions.

2. The 20 individual air-conditioning units installed should be replaced by a central unit and while a separate air conditioning unit, probably a VRV one, should cover the needs of the breakfast lounge and the reception. Furthermore, ceiling fans should be installed at each room. The building’s throughout openings at each room should be exploited in order to provide natural cross-ventilation. Natural ventilation is very effective, especially when applied at nights during the summer period, by reducing cooling loads as much as 70% depending on duration of natural ventilation hours [26]. The above measures should be implemented in conjunction for better results. In temperate climates, or during moderately hot weather, ceiling fans may allow occupants to avoid using air conditioner altogether [28]. This is justified by the affordable daily average relative humidity values during summer (Figure 9.) that were not high enough to require operation of air conditioners.
Another aspect concerning energy consumption is primary energy resources consumed. Both cooling fans and air conditioner use electricity from the national electricity network. In Greece, electricity is produced mainly by lignite, oil and natural gas while only by 16% of the total national production comes from renewable energy sources (Ministry of Environment, Energy and Climate change, 2012) [29]. Not surprisingly, according to the Greek Technical Chamber’s corresponding directive 20701-1 (2012) [30] that complies to EN ISO 13789 and 6946 (2009), electricity has a primary energy resources consuming factor of 2.9, the highest among fossil fuels, compared to 1.05 for natural gas as 1.0 for renewable energy sources.

3. Increase the number of solar water heaters because the existing ones do not have the adequate capacity. The consumption of hot water per person is higher at hotels compared residential buildings in the range of 60 to 100 lit/person depending on the hotel category [30, 31]. Thus during high season the demand reaches 2400 lit daily, 10 times the currently existing capacity. According to the Hellenic Network of Solar Energy [36] the yearly sum of global irradiation received by orientated PV mounted at optimum angle for the area of North east Greece ranges between 1700 to 1800 kWh/m² (recording from 2002-2013) and the corresponding experimental solar data collection resulted to a value of 1794 kWh/m². The solar radiation values are adequate to justify installation of more solar water heaters to meet hot water demand when fully occupied.

Finally one zero cost measure, but nonetheless a very effective one, is related to the proper use of the building premises by the occupants. Occupant’s behavior plays a key role to energy consumption of a building. They may cancel any of the benefits a successful energy saving renovation may offer or, on the other hand, may enhance even more the improvement of the energy performance of a renovated building. A classic misuse example is the use of an air condition with open windows, when there is no interlock automation. A notification at every room will have the desired impact as hotel occupants notice printed information more carefully during their stay. The information should consist of the following tips:

A. Use of windows when air-conditioning is not running
B. Setting the thermostat to the appropriate temperature
C. Do not use water and hot water excessively

As the dominant energy need of the hotel is for heating and hot water production, the hotel management body lost a good chance to improve the hotel’s energy performance during the recent renovation. This revealed a matter of poor decision making, at least with respect to energy management. The proposed actions include the most successful practices, aiming at a combination of passive design and HVAC improvement measures, in a sense that the optimization would be provided by their successful combination.

The local climatic data, as shown from the in-situ measurements, proved the existence of a potential for the exploitation of renewable energy sources, specifically solar and biomass (wood fuel) by installing more solar water thermal systems in order to cover hot water consumption and by replacing the existing heating system that uses oil with a wood chips one. Furthermore, considerable reduction of energy consumption is going to be implemented if two boilers are installed, based on the concept of using only the smaller during low occupancy period.

Any investment on the exploitation of wind should be excluded due to the low annual average wind speed. Figure (5) show the area’s requirement for both heating and cooling. Concerning the indoor parameters of thermal comfort, namely the air temperature and relevant humidity, it appears that in most cases thermal comfort is satisfactory with some temperature values above limits as shown on figure (8), although the number of cooling degree days of the area is low. The period that requires operation of heating system ranges from October to May.

Finally, it should be noted, that the total cost for both instruments and analysis software was limited to 91€.

CONCLUSIONS

The increased energy consumption of the ecotourism hotel studied calls for measures to improve the energy performance in compliance to the European and national regulations. The first part of the presented simplified low cost approach on decision making addresses a low cost method of recording and analyzing climatic data, compare them to the prevailing thermal comfort conditions and evaluate the building’s overall performance. The second part refers to the decision making processes with respect to energy saving measures applied to the building, which is quite particular as it is located in a the highly sensitive forest area of Dadia.

The recent renovation did not take under consideration the need for reducing the energy consumption of the hotel, in line with the requirements of national legislation. This omission revealed a lack of integrated decision making procedures on basic aspects of building improvement issues by the administration and a lack of specialized consultation.

The proposed actions provide a combination of passive design measures, such as the increased insulation, replacement of old windows and exploi-
ation of natural ventilation. In addition the installation of additional DHW solar systems will diminish the use of fossil fuels in favor of renewable energy sources. Concerning the improvement of HVAC systems, the replacement of the old oil-fired boiler for heating, with two biomass-fired ones, with separate operation for low and high occupancy. All those measures are based on successful building renovation practices, with respect to improving the energy performance of the hotel, establishing good thermal comfort conditions, for the particular characteristics of the area’s specific climate. Furthermore the method considers the cost-effectiveness of the proposed actions in order to be suitable for small to medium scale businesses that cannot afford the cost of the official decision making processes but also lack the scientific background or managerial skills.

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