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# Medical waste management and environmental assessment in the Rio University Hospital, Western Greece

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ABSTRACT

At this study a multi-criteria model was developed to examine the available procedures, techniques and methods of handling infectious waste in the large healthcare unit of University Regional General Hospital of Patras, Western Greece. Particularly, this study examined the: a) current legislation and Directives issued for medical waste management at Greece and among the other EU-members, b) contribution of healthcare wastes (HCW) generation rate on social and economic parameters in selected European countries, c) available procedures, techniques, and methods upon the disposal of infectious wastes at the healthcare studied, and, d) propositions for integrated management of such hazardous wastes. Specifically, the Analytic Hierarchy Process (AHP) methodology was applied under pair wise comparison matrices in two stages: 1) the scale factors and the indicators, and 2) the criteria and their sub–criteria. The assessment of these pair wise matrices included the indicators and the sub–criteria. Subsequently, two pair wise comparison matrices, upon a) the "Fulfillment of environmental objectives" indicator and b) the "Energy consumption" sub criterion, were denoted. The AHP methodology yielded good results; however there is still space of improving the environmental performance. The normalized relative weights obtained for the criteria and sub criteria motivated specific actions that have to be handled. Particularly, the results indicated a very good value in environmental management criteria due the values obtained for the commitment towards the environmental policy standards and the waste management procedures. However, further improvements on staff awareness (such as development programs to enhance sensitivity) and more green purchasing suppliers, should be further addressed.

## 1. Introduction

### 1.1. Theoretical background

Healthcare is considered among the largest industries worldwide. At the EU, healthcare sector accounts for 10% of gross domestic product (GDP), 15% of public expenditure and 8% of the EU's workforce. In the US healthcare sector accounts for 17.9% of GDP (in 2009), consuming billions of kW and employing millions people, but it is producing 5.9 million tons of wastes annually and 8% of total US carbon dioxide emissions (Voudrias, 2018). While utmost importance factor of hospital management is prioritized to the delivery programs of advanced healthcare services, feasible minimization of wastes and partially recycling them, in favour of saving both environmental resources and financial assets. A framework among any healthcare organization can be modeled under the following steps (Voudrias, 2018):

Establish a "green team": Including the labour force which is working at a healthcare center, including administrative staff, housekeeping, nursing, and engineering labour, as well as the health, safety, and accounting personnel. This green team is devoted to conduct and run courses on HCW management, being oriented on implement the setting strategies and overall environmental behaviour of the healthcare center.

Measure waste production: Since almost 15–20% of HCW produced

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**Abbreviations**

| | |
|---|---|
| AHP | Analytic Hierarchy ProcessEMAS: Eco-Management and Audit Scheme |
| EMS | Environmental Management Systems |
| ESY | Healthcare in Greece is provided by the National Healthcare Service, or ESY |
| F-AHP | Fuzzy Analytic Hierarchy Process |
| F-CNP | Fuzzy Cognitive Network Process |
| GDP | Gross Domestic Product |
| GHGs | Greenhouse Gases |
| HCW | Healthcare Waste |
| HDI | Human Development Index |
| HDPE | High-density Polyethylene |
| HWPC | Healthcare Waste Purely Contagious |
| IF-AHP | Intuitionistic Fuzzy Analytic Hierarchy Process |
| JMD | Joint Ministerial Decision |
| MADM | Multiple Attribute Decision Making |
| MHW | Municipal Hospital Waste |
| OECD | Organization for the Economic Cooperation and Development |
| PCJM | Pairwise comparative judgment matrix |
| PCM | Pairwise Comparison Matrix |
| P-CNP | Primitive Cognitive Network Process |
| PETE | Polyethylene Terephthalate |
| PVC | Polyvinyl Chloride |
| SUD | single-use medical device |
| TOPSIS | Technique for Order Preference by Similarity to Ideal Situation |
| USEPA | United State of Environmental Protection Agency |
| USD | US Dollars |
| WHO | World Health Organization |

is considered harmful to environment, it is important to measure the generation of hospital wastes, under the precondition that these quantities are recorded from the relevant department of hospital wastes management. Particularly, this step aims at gathering data on wastes compounding and identifying those wasteful practices and measures undertaken to handle these waste materials. As hazardous fractions are increasing there is need of improvement wastes segregation, otherwise higher wastes quantities can be treated, causing significant high wastes expenditures.

*Minimization of HCW*: This goal can be achieved when purchasing stocks and supplies of low hazardous trace, eliminating mercury products, amalgam, batteries, and replace them with supplies without need of targeted disposal required. Besides, feasible management and practices can be oriented to purchase of chemicals, pharmaceuticals and hospital supplies. Moreover, under the HCW minimization cost and waste reduction can be accomplished through regular monitoring disposable, obsolete, and unnecessary items at healthcare centers. Additionally, waste segregation into different categories can be achieved, being oriented to eliminate hazardous and costly waste streams.

*Safe reuse:* Under this process single-use materials can be disposed under reasonable handling behaviour, leading to moderate cost of use and their waste production. Therefore, the design of reusable custom packs can replace the disposable ones. Such an example is the sterilization and reuse of medical equipment to be used in a healthcare centers.

*Recycling:* A portion of hazardous HCWs' is complex to be recycled due to special constraints and regulations of handling. However, other hospital material are conveniently and safely recyclable, offering environmental benefits and monetary savings. Such recyclable materials are glass, paper, polyethylene terephthalate (PETE) and high-density polyethylene (HDPE) plastic, as well as electrical appliances and electronic equipment. Moreover, recycling can be oriented in “upcycling”, thus, adding environmental and commercial value to, otherwise, disposed wastes while upgrading their utility under the principles of circular economy.

*Reprocessing:* It is perceived as the potential to exploit health single-use medical devices (SUDs) after repair, cleaning and sterilization upon already used ones. Even though such SUDs should sustain Reprocessing is interlinked to dispose healthcare single-use medical devices (SUDs) after repair, clean, and sterilize those already used device. Such SUDs sustain a wide range of pricing benefits and reducing costs of managing HCW by the hospital units, there is an ongoing consideration about reprocessing of SUDs. Indeed, at many countries reprocessing is forbidden or strictly regulated, while there are also aroused moral issues (upon patients consent); legal issues (after accidental harm caused by reprocessed SUD); as well as safety risk issues to patient (mainly due to nursing malfunction, or infection caused by cross-patient implications).

Infect-, sharp-, pathology-, pharmacy-, chemical-, radioactive-, or household generated wastes are typical sources of HCWs. In the relevant literature production Voudrias (2018) stressed out that the integrated approaches of HCWs can be handled as specific waste components, no as a whole stream of wastes manipulation. Such targeted HCWs manipulation at healthcare centers is considered profitable and environmentally friendly. Besides, this managerial approach of HCWs manipulation has to be applied by medical manufactures under the existing legal and economic framework. Moreover, HCWs manipulation should abide to the principles of circular economy, production of highly reused goods, upcycling of materials having no or eliminated hazardous compounds, thus supporting the minimum possible manufacturing of specific wastes. Besides, Voudrias (2018) signified that the mainstream of the infectious fraction upon healthcare wastes contains body tissues or material which is contaminated with blood and other body fluids, having no circular-specified techniques to create value from such materials, while excessive energy consumption is further required. Therefore, traditional linear solutions alike to: extract-produce-consume-dispose, cannot be abandoned (Voudrias, 2018).

Contrarily to the aforementioned generic HCW-born streams, wastes generation at hospital units are considered among the most productive streams of HCW. Subsequently, the various types of wastes generated from hospitals are now recognized as a main hygiene and environmental problem, having noxious effects either on the environment and to humanity through direct contact or, indirectly, through final disposition to sites of high environmental sensitivity.

In recent years demand for highly quality medical services and the accompanied healthcare wastes management is a challenging issue, mainly attributed to the rapid pace of the growing global population (Windfeld and Brooks, 2015). Furthermore, the volume and composition of healthcare waste has dramatically increased over the last 30 years as a result of population growth combined with development in the field of bio-medical technology. HCW, because of its complexity and hazardous nature, needs special attention, to avoid environmental and public health problems, especially to transmission of infectious diseases, such as HIV infection and hepatitis, but also of gastro-enterological, respiratory and skin infections (Graikos et al., 2010; Marinkovic et al., 2008). The rise in incidence of such maladies makes the possibility of infection of personal handling these waste and risk to public health resulting from the transport of infectious waste. Moreover, environmental nuisance may also arise due to foul odor, flies, cockroaches, rodents, and vermin as well as contamination of underground aquifers by untreated medical waste in landfills. Thus, there is global and active interest to apply strict control on disposing HCWs (DEFRA, 2005).

Based on the international literature, 75–90% of HCW is liking to household wastes and is considered non-hazardous, whereas the remaining 10–25% of HCW is considered dangerous and contaminated to anyone who is exposed to them (EEDSA, 2006). Healthcare Waste (HCW) and by-products cover a diverse range of materials, as the following list illustrates (EEDSA, 2006):

*infectious waste*, including those blood-contaminated, bodily fluids, laboratory-generated cultures and stocks of infectious agents, or being generated through wards and medical equipment.

*pathological waste*, including tissues, organs, fluids, or parts of human origins.

*sharps,* including syringes, needles, blades, disposable scalpels.

*Chemical waste,* including laboratory-used, solvents, reagents, disinfectants, sterilants as well as heavy metals that are compounding medical devices: mercury in thermometers, and batteries.

*Pharmaceutical waste,* including contaminated drugs and unused vaccines.

*Cyctotoxic waste,* including substances with genotoxic properties (i.e. mutagenic, teratogenic or carcinogenic), and cytotoxic drugs for cancer treatment.

*Radioactive waste,* including radionuclides, radioactive, and radiotherapeutic materials.

*Non-hazardous or general waste,* including having no biological, chemical, radioactive, or physical hazard.

In the light of a new doctrine that pursues the development of sustainability, fundamental ecological principles of solidarity between generations and resource renewal are compiled. Moreover, the environmental dimension is considered as a parameter of paramount importance which should be taken into consideration during the procedures of regional or national planning. Thus, based on this evidence, the understanding of the waste management and especially of medical waste management is by all means significant in an effort to achieve the desirable sustainable development (Zamparas and Kalavrouziotis, 2018).

At the study it was conducted: a) overview upon the current legislation and Directives issued for medical waste management at Greece and among the other EU-members, b) investigation upon the dependence of HCW generation rate on social and economic parameters in selected European countries, c) examination upon the available procedures, techniques and methods of handling and disposal of infectious in a large healthcare unit in Greece, such as University Regional General Hospital of Patras, and, d) propositions derived from the management of hazardous medical waste, under an integrated generation-disposal approach.

### *1.2. Medical waste generation in Greece and Europe*

In response to the ongoing urbanization at Europe and the imperative need for healthcare and medical service to densely populated European cities, during the last two decades, there is produced an extensive legislative work of European Directives regarding the classification, characterization, and treatment of medical wastes. It is noteworthy the Directive 2008/98/EC on waste and repealing certain Directives, the Directive 2000/532/EC in which the wastes are listed, the Directive 75/442/EEC on coding waste (e.g. 18 01 03, refers to infectious waste). Moreover, all available European legislative framework upon wastes management has to further comply with Greece legal regulations. In this respect, it is noteworthy the significant documentation of the Greek case under which hospital and infectious wastes are documented within the European Court Reports 2005 II-01721, Case T-85/05 R. Moreover, for the scopes of this study, it is important to frame the general structure under which the medical wastes are legislatively approached by the European Directives. Therefore, the following legislative deployment is succinctly presented at the following subsections.

#### *1.2.1. Definition of wastes*

The main legislative work upon wastes is devoted at the definition, assessment, and classification of wastes. Particularly, under the framework of 2000/532/EC Directive, the definition of wastes is outlined as follows (Directive 2000/532/EC):

- "hazardous substance"
- "heavy metal"
- "polychlorinated biphenyls and polychlorinated terphenyls" ("PCBs")
- "transition metals"
- "stabilisation"
- "solidification"
- "partly stabilised wastes"

While assessing the hazardous properties of wastes, the criteria laid down in Annex III to Directive 2008/98/EC shall apply. Besides, where a substance is present in the waste below its cut-off value, it shall not be included in any calculation of a threshold. Moreover, a hazardous property of a waste has been assessed by a test and by using the concentrations of hazardous substances as indicated in Annex III to Directive 2008/98/EC, the results of the test shall prevail (Directive 2000/532/EC).

#### *1.2.2. Classification of wastes*

While classifying wastes, there are attributed codes per each one entry, where all wastes listed and marked with an asterisk (*) are considered as hazardous waste pursuant to Directive 2008/98/EC, unless Article 20 of that Directive applies. Specifically, the following notes included in Annex VI to Regulation (EC) No 1272/2008 may be taken into account when establishing the hazardous properties of wastes (Directive 2000/532/EC):

- Notes relating to the identification, classification and labelling of substances: Notes B, D, F, J, L, M, P, Q, R, and U.
- Notes relating to the classification and labelling of mixtures: Notes 1, 2, 3 and 5.
- After assessing the hazardous properties for a waste according to this method, an appropriate hazardous or non-hazardous entry from the list of wastes shall be assigned.
- All other entries in the harmonised list of wastes are considered non-hazardous.

#### *1.2.3. List of wastes*

Each one different type of waste is fully defined and listed by a six-digit code for the waste and the respective two-digit and four-digit chapter headings. Therefore, the following steps should be taken to identify and list each one waste (Directive 2000/532/EC):

"*Identify the source generating the waste in Chapters 01 to 12 or 17 to 20 and identify the appropriate six-digit code of the waste (excluding codes ending with 99 of these chapters). Note that a specific production unit may need to classify its activities in several chapters. For instance, a car manufacturer may find its wastes listed in Chapters 12 (wastes from shaping and surface treatment of metals), 11 (inorganic wastes containing metals from metal treatment and the coating of metals) and 08 (wastes from the use of coatings), depending on the different process steps.*

If no appropriate waste code can be found in Chapters 01 to 12 or 17 to 20, the Chapters 13, 14 and 15 must be examined to identify the waste.

If none of these waste codes apply, the waste must be identified according to Chapter 16.

*If the waste is not in Chapter 16 either, the 99 code (wastes not otherwise specified) must be used in the section of the list corresponding to the activity identified in step one*".

Under the aforementioned approach of [Definition, Classification, List] of wastes, the medical wastes examined at this study are classified under the Chapter 18. For the scopes of this study a precise coding and listing information upon the "wastes from human or animal health care and/or related research" it is noteworthy to be presented, Table 1 below.

While focusing the aforementioned framework of coding and listing HCW it is noteworthy that this classification can include all the waste generated by: a) hospitals and other small health facilities, b) laboratories and research centers, c) mortuary and autopsy centers, d) animal research and testing laboratories, e) blood banks and collection services, as well as, f) nursing homes for the elderly citizens. In adapting the aforementioned European-directed classification of HCW to the Greek hospital unit examined, an indicative grid of the main streams under which the HCW are classified, it can be depicted in Fig. 1, where a detailed overview of the average healthcare waste production is deployed that unveils the current medical waste management practices as a whole grid of affections at an international context of applicability. These links are developed in association with the legislation adopted by each country. It is noteworthy that healthcare among developing economies shows that there are only few of them having well established legislative framework on infectious wastes, upon separating, treating and disposing them in a sustainable manner.

Contrarily to the aforementioned generic HCW-born streams, wastes generation at hospital units are considered among the most productive streams of HCW. Subsequently, the various types of wastes generated from hospitals are now recognized as a main hygiene and environmental problem, having noxious effects either on the environment and to humanity through direct contact or, indirectly, through final disposition to sites of high environmental sensitivity.

The dependence of HCW generation rate on social and economic indices at selected European countries is presented at Table 2. In this Table 2 the HCW generated in 11 European countries are presented alongside data showing each country's healthcare expenditure per capita (in PPP U.S. dollars) and Human Development Index (HDI) respectively. Healthcare expenditure per capita is calculated by considering the percentage of gross domestic product (GDP)-spent on healthcare, and multiplying this percentage by each country's per capita GDP (OECD, 2016). Besides, HDI is directed to the utmost important criterion of peoples capabilities to assess the development of a country, not merely its economic status alone. The HDI is a summarized appreciation tool on monitoring key-dimensions of human development, including long and healthy life while ensuring decent standard of living.

Fig. 2 illustrates the association between the healthcare wastes generated in kg $bed^{-1}$ $day^{-1}$ against each country's healthcare spending per capita. Linear regression was conducted to investigate the correlation of the HCW generation rates with the health expenditure per capita GDP. Linear trend-line were fitted to the data, which reveal the positive correlation ($R^2 = 0.83$) between healthcare waste generation (kg $bed^{-1}$ $day^{-1}$) and expenditure per capita in healthcare. It is obvious that countries having high GDP are also supporting high generation rates of HCWs. Comparison of world data sustains large differences between developed and developing countries (Pruss et al., 1999). The difference in quantities caused by the fact that European (mainly developed) countries invest much more money in health systems, leading to larger amounts of healthcare waste generation. Besides, Fig. 3 depicts the behaviour between the aggregated quantity of the healthcare wastes generated in kg $bed^{-1}$ $day^{-1}$versus HDI index. Based on this behaviour it was shown that while upgrading of healthcare services offered, it results in the purchase of additional medical equipments and consumables (including medical supplies, reagents, and medicines), more patient's services increases, thus, more HCW are generated.

At the following subsections 1.3 and 1.4 the literature overview was further oriented to apply the particular methodology of the AHP on manipulating of HCW-derived data, subsection 1.3, while the main managerial applications upon the healthcare sector were developed at the subsection 1.4.

**Table 1**
Coding and listing of healthcare-produced wastes under the Directive 2000/532/EC. Source: Directive 2000/532/EC.

| | |
|---|---|
| 18 | WASTES FROM HUMAN OR ANIMAL HEALTH CARE AND/OR RELATED RESEARCH (except kitchen and restaurant wastes not arising from immediate health care) |
| 18 01 | wastes from natal care, diagnosis, treatment or prevention of disease in humans |
| 18 01 01 | sharps (except 18 01 03) |
| 18 01 02 | body parts and organs including blood bags and blood preserves (except 18 01 03) |
| 18 01 03* | wastes whose collection and disposal is subject to special requirements in order to prevent infection |
| 18 0104 | wastes whose collection and disposal is not subject to special requirements in order to prevent infection (for example dressings, plaster casts, linen, disposable clothing, diapers) |
| 18 01 06* | chemicals consisting of or containing hazardous substances |
| 18 01 07 | chemicals other than those mentioned in 18 01 06 |
| 18 01 08* | cytotoxic and cytostatic medicines |
| 18 01 09 | medicines other than those mentioned in 18 01 08 |
| 18 01 10* | amalgam waste from dental care |
| 18 02 | wastes from research, diagnosis, treatment or prevention of disease involving animals |
| 18 02 01 | sharps (except 18 02 02) |
| 18 02 02* | wastes whose collection and disposal is subject to special requirements in order to prevent infection |
| 18 02 03 | wastes whose collection and disposal is not subject to special requirements in order to prevent infection |
| 18 02 05* | chemicals consisting of or containing hazardous substances |
| 18 02 06 | chemicals other than those mentioned in 18 02 05 |
| 18 02 07* | cytotoxic and cytostatic medicines |
| 18 02 08 | medicines other than those mentioned in 18 02 07 |

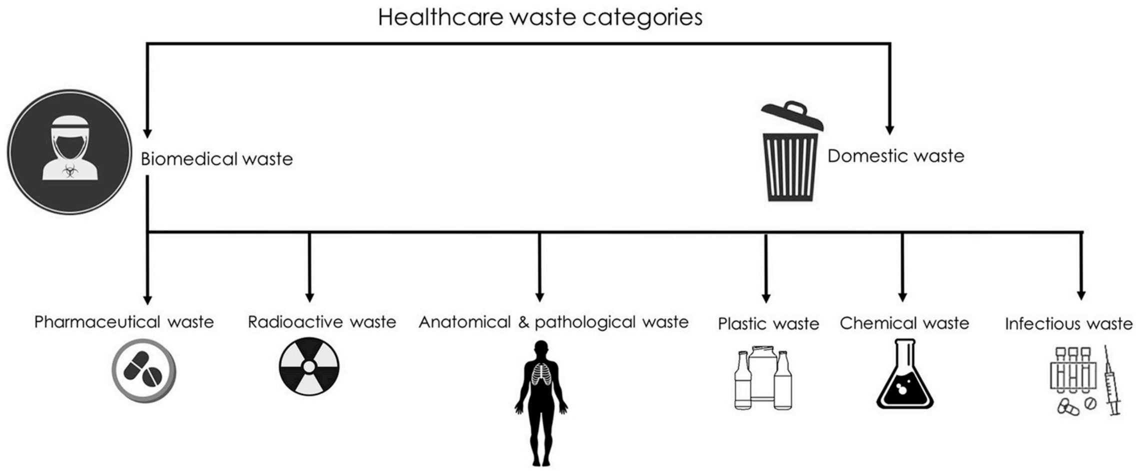


**Fig. 1.** Grid of classifications on Health Care Waste (HCW) (Authors own study).

### *1.3. Analytic hierarchy process (AHP): theoretical background*

The Analytic Hierarchy Process (AHP) was developed by Saaty in the late 1970s as one quantitative method for multi-criteria decision making. Particularly, the AHP disaggregates a perplexed decision problem into varied hierarchical levels, while attributing different weights per criterion, while alternatives are valued in pairwise comparisons, and priorities are drawn under the Eigenvector method applied. In the relevant literature it has been argued that the increasing pace of AHP applicability is motivating this AHP exploration and adaptation at the healthcare centers (Schmidt et al., 2015). These authors reported the inconsistent applicability of AHP in healthcare literature production. Indeed, this literature production revealed that only studies have investigated all healthcare aspects. Thus, the research statements are unavoidably limited only on these studies concluding remarks. Hence, the determinant parameters of further research upon the AHP applicability at the healthcare sector aim to determine the participants interviewed, the ways of manipulating inconsistent answers, and the trustfulness of the outcomes yielded and presented. Moreover, the selection of the appropriate target groups is determining the optimum ways of challenging issues derived from the AHP applicability (Schmidt et al., 2015).

In agreement with Schmidt et al. (2015), the variability of service quality of healthcare sector was also denoted by the study of De Felice and Petrillo (2015). Specifically these authors examined the improving features of Italian healthcare service quality using the AHP methodology. It was argued that measuring and enhancing the service quality becomes vital in recent times, especially due to the fact that there are lots of ways to measure the service quality but, it is absolutely affirmed that an integrated model based on AHP consists a systematic service quality measurement process. In the context of this research framework, a critical issue is the personalization of healthcare services, enabling them to be tailored to the needs of each patient. The personalization of these healthcare services is considered the creation of the group of those entities that are delivering the healthcare service to each patient in a dynamic manner, through applying the AHP methodology (Fengou et al., 2013).

In the relevant literature it is noteworthy the evolutionary behaviour of the AHP methodology, in adaptation to different decision-making needs aroused on the healthcare sector. This evolutionary behaviour of (the primitively introduced) AHP is succinctly represented below, in reverse chronological order of literature introduction: Fuzzy Cognitive Network Process (F-CNP) (Yuen, 2014a), Primitive Cognitive Network Process (P-CNP) (Yuen, 2014b), and Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) (Sadiq and Tesfamariam, 2009).

Even though AHP methodology can be effectively applied to the healthcare centers, medical research based on pairwise reciprocal matrix remains dubious. In this respect, in the relevant literature the related drawbacks have been examined, while it was further recommended the alternative suitability of the pairwise opposite matrix (Yuen, 2014b). Pairwise opposite matrix is the key-component of the Primitive Cognitive Network Process (P-CNP), which contains the

**Table 2**
Profile of medical waste generation vs healthcare expenditure per capita GDP and HDI in selected European countries.

| Countries | Healthcare expenditure per capita GDP (in PPP USD) [OECD (Organization for Economic Co-operation and Development, 2016] | Human Development Index (HDI) | Healthcare waste generation (kg $bed^{-1}$ $day^{-1}$) Marinkovic et al. (2008) Windfeld and Brooks (2015) Vaccari et al. (2017) |
|---|---|---|---|
| Norway | 6.64 | 0.949 | 2.6 |
| UK | 4.19 | 0.909 | 3.3 |
| France | 4.6 | 0.897 | 3.3 |
| Italy | 3.39 | 0.887 | 2.7 |
| Portugal | 2.54 | 0.843 | 1.5 |
| Greece | 2.22 | 0.866 | 1.4 |
| Bulgaria | 0.57 | 0.794 | 0.4 |
| Turkey | 1.09 | 0.767 | 1.39 |
| Latvia | 0.78 | 0.83 | 1.18 |
| Croatia | 0.85 | 0.827 | 1.2 |
| Poland | 1.79 | 0.85 | 2.6 |

*PPP: Purchasing power parity (PPP).

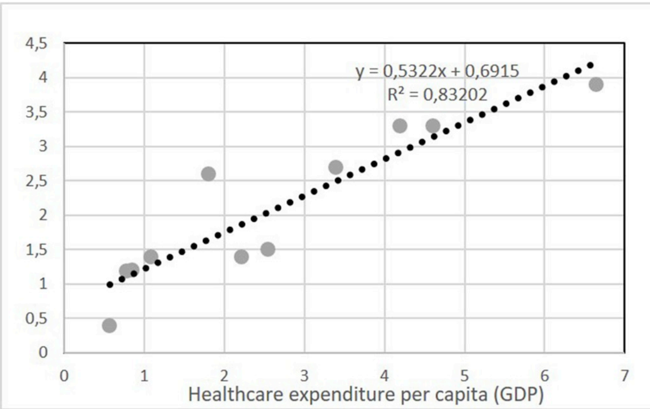


**Fig. 2.** Healtcare waste (kg bed$^{-1}$ day$^{-1}$) vs Healthcare expenditure per capita (in PPP U.S. dollars) in european countries.

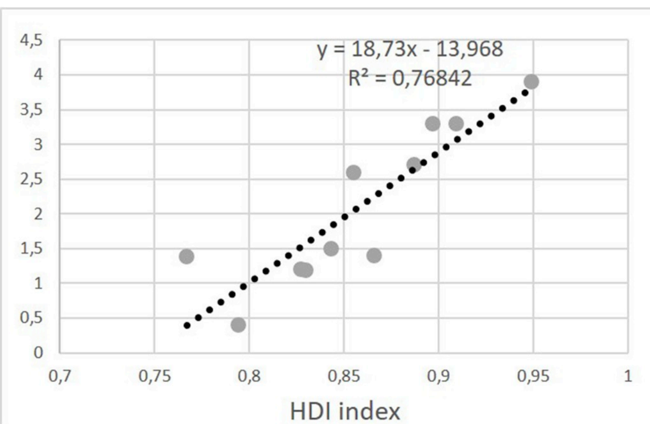


**Fig. 3.** Healtcare waste (kg bed$^{-1}$ day$^{-1}$) vs Human Development Index (HDI).

practical features of the AHP approach. Specifically, the medical evaluation using AHP can be revised by P-CNP under the frame of a step-by-step tutorial (Yuen, 2014b). This evolutionary healthcare-based method supports promising alternative tool to AHP, in sharing information among patients and medical staff, as well as to propose the proper therapy, medical treatment, healthcare technology and policies to be followed (Yuen, 2014b). At a similar study it was stressed out that fuzzy analytic hierarchy process (F-AHP) has interestingly been applied in many scientific fields, including the healthcare sector (Yuen, 2014a). Among them, the misconception and cognition complexity upon the semantic representation of the linguistic rating scale used in F-AHP, all are producing misapplications (Yuen, 2014a). This author proposed the fuzzy cognitive network process (F-CNP) as an ideal alternative to F-AHP. Therefore, an evolutionary application in using F-AHP is that of the F-CNP. It was denoted that the F-CNP sustains an improved mathematical definition and results, in terms of the fuzzy paired interval scale upon human perception of paired difference (Yuen, 2014a).

An important feature of the AHP utility theory that has been based on a decision-making technique on a premise that the decision-making of complex problems, it can be handled by structuring them into simple and comprehensible hierarchical structures. However, the main constraints of the AHP methodology are the involvement of human subjective evaluation, therefore, decision-making has to consider the disadvantages of vagueness and uncertainty in developing the membership function (or degree of belief) to fuzzy pairwise comparisons (causing the so named: ambiguity) (Sadiq and Tesfamariam, 2009). Subsequently the environmental decision-making problems are becoming more pronounced. Therefore, the uncertainty vagueness and ambiguity stated at the environmental decision-making process under a multi-criteria methodology, can be handled under the IF-AHP (Sadiq and Tesfamariam, 2009).

In a strategic viewpoint, the AHP applicability as a tool for healthcare policy is considered under the Delphi facet. Particularly, AHP methodology can be used to classify the decision levels of healthcare policies using the Delphi professional survey at developed countries (Kim and Park, 2017) and developing countries (Ahsan and Bartlema, 2004). Kim and Park (2017) argued that foremost importance healthcare policy is the national health insurance, being followed by the healthcare delivery systems and its available resources. Specifically, the reimbursement system is mainly concerning the national healthcare insurance and its providers. Effective development of healthcare policies is determined by central government (mainly developed economies) and the opinions all healthcare providers (Kim and Park, 2017).

In a similar research framework it was stated that multi-criteria healthcare decision problems play a decisive role to improve the health and socio-economic conditions at developing countries (Ahsan and Bartlema, 2004). These authors showed how the multi-criteria decision-making method could facilitate implementation of healthcare performance analysis, especially for the public healthcare system of Bangladesh. The applied methodology included the joint deployment of the Delphi and the AHP methods. The outcome of the Delphi method was utilized as input for the AHP functionality and determined the performance of the healthcare activities. In this context AHP was valued as a managerial policy-making process for implementation in decision-making, towards improvement of overall healthcare performance (Ahsan and Bartlema, 2004).

### *1.4. Analytic hierarchy process (AHP): managerial applications upon the healthcare sector*

The main applications of the AHP methodology upon the (narrow) context of healthcare sector and the (wider) contexts of energy and environment are collectively stated as: a) Functionality of a fuzzy analytic hierarchy process (F-AHP) towards the development of energy storage technologies, b) AHP deployment upon waste management, including the main drivers to be considered, and c) AHP evaluation upon cloud computing service systems for use at the healthcare sector. Particularly, these three applicability issues of the AHP methodology are presented as follows:

The majority of process systems of engineering encounters design problems, thus, requiring the selection one among the predefined set of alternatives. Therefore, the selection process involves multiple conflicting quantitative or qualitative criteria (Promentilla et al., 2015). The use of multiple attribute decision making (MADM) is an effective technique of promising transparent and rational characteristics in problem solving. In this context the AHP is valued as a variant version of the MADM technique, which can be effected by the selection of low-carbon technologies. Under this technique, optimal alternatives are selected by the incorporation of the judgment of domain experts along with the level of confidence through the use of fuzzy numbers for the pairwise comparison ratios in the AHP decision framework. The fuzzy AHP approach can derive crisp weights from an incomplete fuzzy pairwise comparative judgment matrix (PCJM), while maximizing the degree of consistency of all judgments included. The aforementioned selection problem is proven significant mainly upon the intermittent nature of renewable energy sources, whom full development necessitates cost-effective auxiliary energy storage subsystems (Promentilla et al., 2015).

Another applicability of the AHP is attributed to the accruing problems that waste management has become increasingly complex. The main drivers in accomplishing sustainable waste management systems are the increasing amount of generated waste, adopted legislation in the field of waste management, administrative issues, economic impacts and social awareness. In practical level of analysis there are also many other drivers that are mutually conflicting to each other. In defining accurate drivers and sub-drivers to develop a waste management system Tot et al. (2016) examined two levels of decision making: the first contains a pair-wise comparison of the drivers in accordance with the goal and the second contains a pair-wise comparison of the sub-drivers in accordance with the driver and the goal to be achieved. All waste management drivers were integrated under the AHP-supported decision-making process. Authors showed that the most important driver which developed a sustainable waste management system was that of Institutional-Administrative driver (Tot et al., 2016).

A noteworthy applicability of AHP is its utility to assess healthcare-oriented cloud computing service systems (Liao and Qiu, 2016). These authors denoted that healthcare industry sustains striking operational features comparing to other industries. Indeed, accruing difficulties in the business operation of the healthcare industry are attributed at volatility, importance of healthcare, requirements of health insurance policies, and the statuses of healthcare providers. Healthcare centers are continually orienting and adapt their business operational goals, taking into consideration the multifaceted financial risks, the updating information technologies, and the constant changes in healthcare methods of pricing and payment services. Under this framework cloud computing is a challenging and contentious issue, since through clouding computing healthcare centers can control the quality and the costs of healthcare services, in response to aging population and the dominant role of Internet facilities at contemporary societies. Therefore, the evaluation healthcare services –through cloud computing systems– enable decision makers to proceed in a comprehensive assessment method, under prioritizing decision-making factors. Under this framework, the AHP methodology can be applied to compare cloud-computing and healthcare items thus, unveiling that the primary factor that affects the design and implementation of optimal cloud computing-based healthcare systems is the cost effectiveness, while secondary (practical) factors are that of software design and system architecture.

## 2. Methodology and analysis

### *2.1. Methodological principles and consistency based on the analytic hierarchy process (AHP)*

The sustainability in healthcare centers is accomplished through green practices, human resources attitudes, and behaviours oriented to environmental aspects. In the relevant literature various systems to measure environmental performance in healthcare organizations have been proposed, whereas the lack of strategic focus and complexities of improving the environmental performance in hospitals has been also denoted (Romero and Carnero, 2019). In this research context of hospital units the mainstream literature approach on their environmental assessment systems has been based on mathematical models, making difficult the objectivity and the open judgment upon them. Nevertheless, it is noteworthy that study of Romero and Carnero (2019) who developed a system of assessing environmental sustainability through a F-AHP, based on the annual counts of treatments and objective comparisons undertaken among different organizations. Specifically, under modelling in the fuzzy environment, Romero and Carnero (2019) modeled the Technique for Order Preference by Similarity to Ideal Situation (TOPSIS), towards assessing the environmental responsibility of a healthcare center. Nevertheless, the main limitation of such studies is that they do not perform an environmental audit in the healthcare context, due to lack of inclusion economic or legal criteria (Romero and Carnero, 2019).

Last decades, AHP methodology has been used as a powerful method in many problems, due to its flexibility to formulate complex and unstructured problems into multi criteria decision making approaches in several applications. Some of the most popular include: Choice of an alternative between others, prioritization of advantages in a group, assignment problems under constraints, comparison of materials, systems and markets, quality control guaranteeing consistent application. There are four discrete steps in the development of such a method and analyzed in the lines below.

Step 1: Model structuring. It includes the decomposition of the problem in to multi level hierarchy elements, each one with common features or characteristics. At the top, the single goal of the problem is standing, while the criteria and sub – criteria are following to the intermediate levels. At the bottom of hierarchy, the alternatives to be judged are included. The flexibility derives from the fact that there is no a single hierarchy structure but it is a need driven design methodology depending of the problem we face.

Step 2: Judgments and Pair wise Comparison Matrix (PCM). Here, the methodology constitutes of data collection and measurements, while the weighting of the elements is the core of the AHP process. In fact, the structured hierarchy is broken down into a series of comparison matrices, taking into account the reciprocal property ($a_{ij} = 1/a_{ij}$) for each single pair. Consequently, the A matrix

$$A = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ 1/a_{1n} & \cdots & 1 \end{bmatrix},$$

is structured with the data $a_{ij}$ derived from the preference between row $i$ and column $j$.

This is done by using the 1–9 intensive scale (Saaty, 1987). The translation of judgments into ratios is based into preference scale functions, and according to the literature many methodologies may be used (mean arithmetic, mean geometric, power, logarithmic, quadratic, etc) and the criteria are assessed in pairs to obtain the impact on the whole objective, while the alternatives are measured by the same way to find their importance under each criterion.

Step3: Priorities and consistency. In this stage the priorities of the elements of the hierarchy and the consistency of the judgments is determined. Moreover, the composite weight for each alternative is obtained by the synthesis of priorities based on the preference scale functions derived from the comparison matrix. The relative weights ($w$) were found using the mean arithmetic method. Following this procedure the pair wise comparison matrix (A) and the relative weights of the main criteria were obtained. That property requires all columns and rows of the comparison matrix to be linearly dependent. The consistency ratio of the aggregate matrix is defined as follows as $CR = \frac{(\lambda_{max} - n)}{(n-1)RI}$, where $RI$ stands for a random index of consistency, $n$ derives from the order of the matrix and $\lambda_{max}$ equals to the sum of the column – vector of the average sum of each row, such that $\lambda_{max} > n$. According to Saaty (1980) the $CR$ is accepted when it is less than 0.1, in order for the matrix to be consistent. In case that it is $CR > 0.1$, the decision maker has to revise the elements of $a_{ij}$ to realize better consistency in the PCM.

Step4: Aggregation. Following the calculation of the priorities in each level, they are aggregated to calculate the overall priorities of the alternatives. For this, the second step values used to determine the best alternative and after the construction of the pair wise matrix the normalized values of each elements is obtained by dividing it with the sum of the column.

The easiness of usage and the simplicity of the AHP technique are making it to be widely accepted by policy makers and researchers. Among the most pronounced applications are that of: choice of selection among a range of available alternatives; prioritization, which is deployed after a set of alternative to be determined; resource assignment upon finding the most suitable set of alternatives, under a frame of restrictions given; comparison among markets, which is actually based on comparison among processes or systems while accumulating prior knowledge of these processes or systems available; as well as quality control, which guarantees the consistency upon the application selected (Romero and Carnero, 2019).

### 2.2. Environmental indicators and criteria of waste management in healthcare units

Environmental indicators are proven an inseparable part of environmental impact assessment, thus, their influential role on environmental management and the design of environmental policies is predominant. These indicators offer a quantified appreciation upon the state of the environment, the human influence, and their effectiveness to protect environmental sources (Romero and Carnero, 2019).

In the relevant literature, among the available managerial tools, "Public Society for Environmental Management" consist an environmental indicator to quantify environmental evolution, protection, and controlling measures to be taken by environmental policy makers over time. The main characteristics of those environmental indicators are that of: "relevance" at national, even regional or local, level of analysis, and, "pertinence" regarding the principles of sustainable development (Romero and Carnero, 2019). Based on these authors, and in association with the context of the Commission of the European Communities for applying regulation (EC) no. 761/2001 (EC/761/2001), feasible criteria that are applicable can be classified into three main groups: "environmental behaviour", "environmental management", and "environmental condition". Each criterion contains first- and second-levels of sub-criteria, having identified (and associated-to-scale levels) indicators.

Specifically, criteria for environmental behaviour determine the processes planning upon environmental impacting to an organization, followed by the sub-criteria of: Atmospheric emissions, Water, Energy consumption, Consumption of materials, and Waste. In linking the aforementioned research framework to this study it is noteworthy that the wastes generated is a contentious environmental problem for healthcare centers. Therefore, such wastes effective control and management it is an imperative need. In the Spanish legislative system healthcare-generated wastes can be categorized as: general, bio-sanitary, special bio-sanitary, bodies- and human-remains, chemical, cytotoxic, and radioactive. The recognition of the waste types –that are compounded healthcare centers indicators– it is defined, enabling the control of those types whom inadequate control is mostly problematic (Romero and Carnero, 2019).

In a wider environmental framework, waste can be considered as a type of raw materials and, such as, it is related to the issues of: supply, limited substitutes, and applicability of prioritizing among alternatives: production of clean energy, defense, healthcare, and electronics. Disruptions in supply of critical raw materials can cause severe negative consequences for firms, consumers, and local economies. Potential mitigation strategy for firms is related to the aspects of: implementation of circular economy in supply chain, operations, and end-of-life management (Gaustad et al., 2018). Focusing on wastes utility, their composting (mainly at developing countries) consists a choice of marketing value to the urban provinces participated. Therefore, the surplus of compost production at rural areas can be sold by producers to meet the high demands for fertilizers. Besides, the organic portion of wastes left uncollected can be openly dumped (Bekchanov and Mirzabaev, 2018).

In a better understanding the paths of waste generation, it is important to perceive and outline the paths of nutrients' flows. Particularly, nutrients enter the living bodies through the consumed food and fodder, while many quantities of nutrients are also contained through harvesting losses and food wastes during consumption (Zamparas et al., 2015). Under limited recycling facilities to sanitary removal of biogradable organic wastes– these types of wastes are openly dumped into environment, while accelerating eutrophication and provoking health risks (Zamparas and Zacharias, 2014; Gianni et al., 2013; Zamparas et al., 2019). However, composting systems play a determining role to close nutrients" loop and enhance soil health, mainly to nutrients' circulation and returning back to soil through leachate and runoff of composting matter (Bekchanov and Mirzabaev, 2018).

Soil nutrients from biodegradable waste can further moderate the reliance on chemical fertilizer and the degradation of croplands. Therefore recovered nutrients can support the inter-provincial marketing and the development of composting programs. As a result effective waste management is accompanied by costs minimization on collecting wastes, open dumping them (being considered as environmental pollution externalities), landfill, segregate wastes through composting of its biodegradable fraction, and transport it. Based on the conceptual framework of this cost minimization problem, Fig. 4 is focused primarily on nutrients' recovery from organic waste, thus,

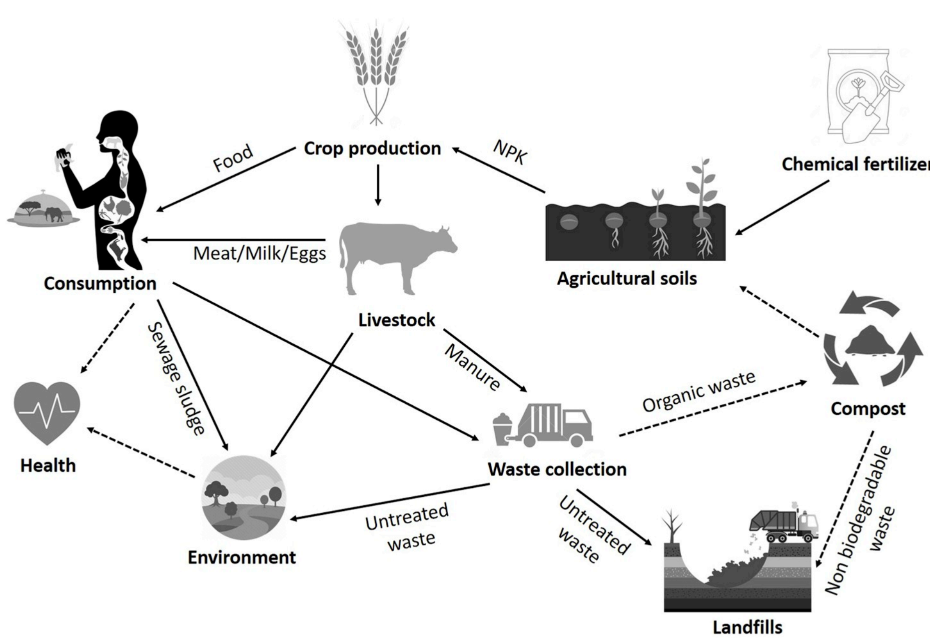


**Fig. 4.** Grid of nutrient flows among waste management chains: The "Health" node is positioning (adapted by Bekchanov and Mirzabaev, 2018, p. 1109).

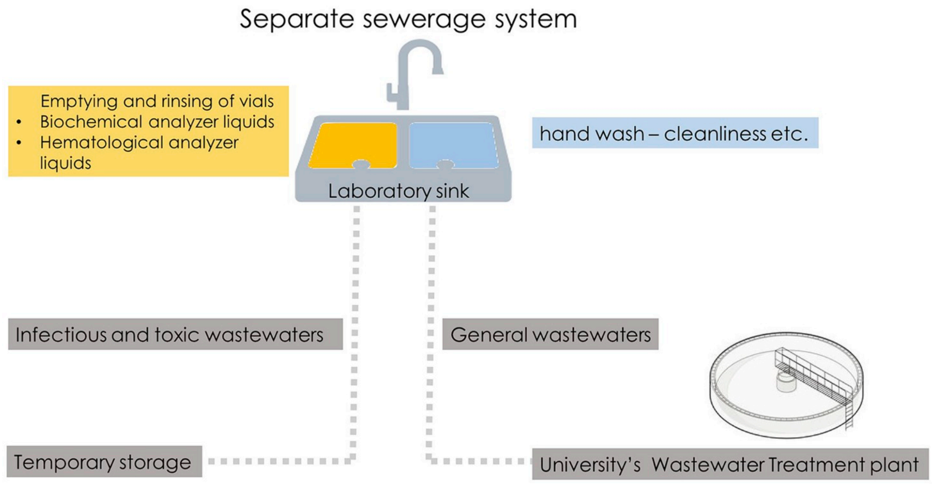


**Fig. 5.** Infectious and toxic wastewaters from laboratories in sewerage system of Rio University Hospital (authors own study).

partially substituting non-renewable chemical fertilizers. Food availability, nutrient content or the related-health outcomes from improved food security, and reduced environmental pollution, are not considered at this model, whereas lower healthcare costs –due to decreased environmental pollution– are appreciated (Bekchanov and Mirzabaev, 2018).

### 2.3. Case study

#### 2.3.1. Methodology background

Many hospitals in Greece do not have a separate sewerage system (Tsakona et al., 2007). Moreover, in a recent study Zamparas and Kalavrouziotis (2018) showed that chemical waste generated in laboratories in liquid form is not segregated in most of the surveyed Greek hospitals, and it is disposed off through the public sewerage system. However, at Rio University Hospital, wastewater from Microbiology, Biochemistry, Haematology and Cytology laboratories is drained away in a separate sewerage system where it undergoes chemical neutralization. The toxic wastes from the sergegated sewerage network of the hospital are collected in two external reservoirs that are connected to this network, Fig. 5. According to the schematic representation given at Fig. 5, the Hazardous Waste and Purely Infectious Liquids from Hospital Laboratories can be either discharged directly into the hospitals' sewerage system, according to manufacturers' instructions (at minimum a dilution treatment is obligated), or collected in small containers of suitable material (excluding PVC) of 10–30 lt capacity with biohazard label (Fig. 5). After proper pre-treatment with sodium hypochlorite substitutes, this type of waste can be discharged into the drainage. Then, mixing them with the appropriate amount of hypochlorite (chlorine) in a ratio of 1/10 (10 lt of liquid waste to 1 lt of insoluble chlorine), being disposed in the drainage after taking all protective measures' scheduled, Table 3, below (see Table 4).

According to the Joint Ministerial Decision (Governmental Gazette B1537/8-5-2012) all packaging waste has to be labelled under noting basic content information and production details. Specifically, the embedded waterproof label is typed via permanent ink, bearing international-applied symbol and infectious or hazardous waste labelling (under the UN classification of wastes). Moreover, "hazardous waste" characterization has to be clearly displayed and the UN-risk number to be also noted. Additional labelling information of wastes contains: date of production and packaging, location of production (chamber/section/lab), quantity, and destination scheduled. A study investigating the Greek healthcare units (Zamparas and Kalavrouziotis, 2018) revealed that insufficient labelling information (for the receptors) of the contained wastes material at all hospital units studied. Although labelling was implemented at all wastes, labelling was fully and consistently formulated under the aforementioned JMD only at the case of the University Hospital of Patras. The above finding is also verified at this study.

#### 2.3.2. Analysis

The conducted case study was based on the University Regional General Hospital of Patras, which is a public healthcare facility located next to the University of Patras in Rio, Central Greece, few kilometers away from the city of Patras. The construction of the hospital was completed in 1988 and a few months later it began operation with almost every clinical department and laboratory service. It is part of the ESY, the National Healthcare System of Greece.

The hospital is affiliated with the University of Patras. It is teaching facility of University of Patras' School of Medicine and has earned a reputation as a respected medical center. Supporting a capacity of 800 beds and an area of 75.000 sq.m, it is the largest Hospital in the region of Peloponnese and one of the largest hospitals in Greece with over 10.000 operations performed, and over 300.000 cases handled each year.

The comparison of healthcare facilities and medical waste production levels is a challenging issue upon proper metric selection. The reasonable metric in quantifying wastes generated at hospital units is given by: total kilograms of waste generated per day, while dividing that total by the number of occupied beds at the hospital. The unit of wastes generation measured is: kg $day^{-1}$ $bed^{-1}$, and it can be

**Table 3**
Typical packaging and storage measures for selected types of wastes.

| Type of Waste | Type of container | Colour of container and markings |
|---|---|---|
| USW - Urban Solid Waste | Polyethylene bag | black |
| HWPC - Hazardous Waste Purely Contagious [sterilization] | Leak-proof plastic bag or container (hospital box) | Yellow with biohazard symbol |
| HWPC - Hazardous Waste Purely Contagious (Sharps) [sterilization] | Puncture-proof container | Yellow, marked - SHARPS with biohazard symbol |
| MHW - Mixed Hazardous Waste [incineration] | Leak-proof plastic bag or container (hospital box) | Red, labelled with appropriate hazard symbol |

**Table 4**
Pair wise comparison matrix for “Fulfillment of environmental objectives” indicator.

| | | B2.6.1 | B2.6.2 | B2.6.3 |
|---|---|---|---|---|
| The environmental objectives are similar to those listed by management of the health care organization (Best) | B2.6.1 | 1 | 1 | 0,20 |
| The environmental objectives are not similar to those listed by management of the health care organization. | B2.6.2 | 1 | 1 | 0,2 |
| Doesn't know/doesn't answer (Worst) | B2.6.3 | 5 | 5 | 1 |
| | | | CR = | 0, 01 |

adjustable at hospitals units where both the plethora of illnesses treated and the severity of patient diseases, are implying that patients with of serious illness may be hospitalized for many days, whereas patients with less serious injuries may be visited hospital at short bed-occupied treatment, for only few hours. It is commonly argued that the unit of kg $day^{-1}$ $bed^{-1}$is optimistically suitable for hospital waste generation at studies where the number of beds in service are strongly associated with the amount of HCW produced among its departments (Windfeld and Brooks, 2015).

The research data were collected in different stages. Following the extended literature analysis conducted, in order to extract the appropriate indicators for this study –being based on the aforementioned subsection– a factor analysis was utilized to recognize a reduced number of factors that explain the variance within these variables. Then, according to the aforementioned, a questionnaire consisted of indicators, sub criteria and scale factors for the survey was administrated to experts and specialists on the health care management area using a non-probabilistic sampling technique. The five-point intensive scale was used in the following bands: Excellent; Very Good; Good; Deficient; Very Deficient. The data were collected and analyzed from the pertinent chemical engineering of the hospital. Moreover, three experts in corresponding areas, that of health care organizations, environmental issues and decision making methods, were judged on specific scale factors or at fields where inadequate elements found.

The following Fig. 6 depicts the goal, and the four levels of analysis. Therefore, the pair wise comparison matrices were considered in two

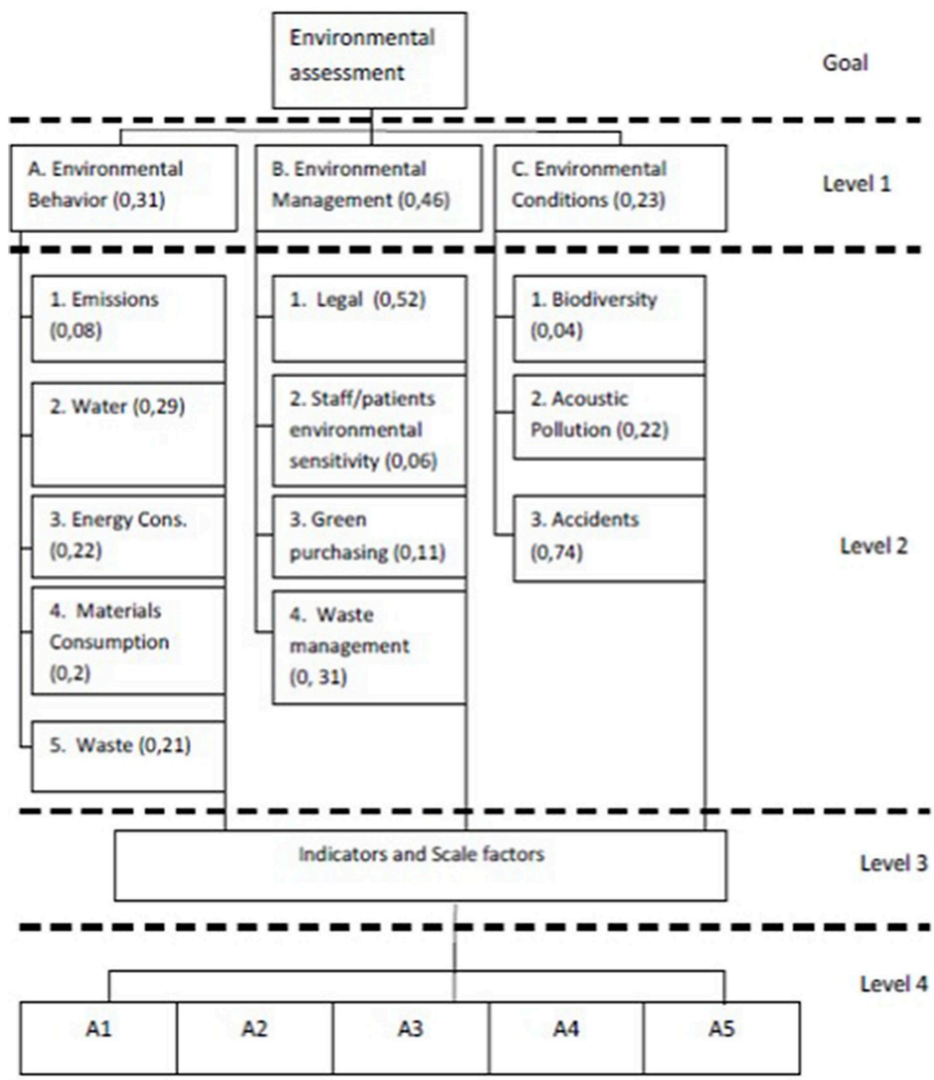


**Fig. 6.** Criteria and sub criteria levelling upon levels towards the goal of environmental assessment. (Source: Adapted from: authors Romero and Carnero, 2019, and modified by authors). Preliminary assessment and weights evaluation under the AHP methodology.

**Table 5**
Pair wise comparison matrix for "Energy consumption" sub criterion.

| Type of consumption | | A31 | A32 | A33 | A34 |
|---|---|---|---|---|---|
| Gasoil consumption | A31 | 1 | 0,33 | 1 | 3 |
| Electricity consumption | A32 | 3 | 1 | 5 | 5 |
| Diesel/Natural gas consumption | A33 | 1 | 0,2 | 1 | 3 |
| Renewable sources consumption | A34 | 0,33 | 0,2 | 0,33 | 1 |
| | | | | CR = | 0,056 |

stages between: 1) the scale factors and the indicators, and 2) the criteria and their sub–criteria. The assessment of 63 pair wise matrices has taken place to include the indicators and the sub–criteria. According the 2.1 section and the process development, the assignment of judgments was derived from the thorough analysis of the questionnaires regarding qualitative and quantitative comparisons on a value scale, thus showing the relevance among elements under a certain property, as noted at Table 5. Specifically, Table 5 depicts the sub-criterion energy consumption pair wise comparison matrix. The relative weights are: [A31, A32, A33, A34] = [0.191, 0.560, 0.172, and 0.076] and the consistency ratio is below the value of 0.1.

Finally, the aggregation weights resulted in an environmental assessment of the overall goal. The high values indicated good response while the low values necessitated scores need a better insight in improving the overall assessment.

Based on the correlation among HCWs quantities generated versus the HDI index, it was shown that as the quality of healthcare services is upgraded, more medical equipment and consumables –including medical supplies, reagents, and medicines– are purchased, patients' services increase, and, thus, more HCW are generated. The estimated quantities of medical waste (Purely Contagious) produced by the various nursing departments in hospitals are presented at Table 6.

The structure of the questionnaire delivered it has been presented in Tabled format at the Appendix of this study. Specifically, the rate of responses was classified upon the study of Romero and Carnero (2019), having the following valuation profile:

- Alternative 1 (A1): EXCELLENT: showing optimum environmental assessment and all contributing levels being always satisfied.
- Alternative 2 (A2): VERY GOOD: showing highly acceptable environmental assessment, while most of the setting indicators are reaching optimum performance and poorer outcome could be improved.
- Alternative 3 (A3): GOOD: showing generally acceptable EAS and a partial satisfaction of levels included, whereas moderate or low achievement of other indicators could be further improved.
- Alternative 4 (A4): DEFICIENT: showing low or undesired satisfaction among levels included, whereas EAS should be changed.
- Alternative 5 (A5): VERY DEFICIENT: showing the worst assessment system comparing the other alternatives, whereas corrective management has to be conducted, for better improvement to be achieved.

Material-based Indicators: This type of indicators is including the consumption of paper/ink/batteries/toner/fluorescent tubes; Radiograph. At this research group the majority of indicators were valued as "very deficient", except for the "paper consumption" and "radiography indicators" which were valued as "excellent". This valuation can be attributed to the fact that in public-owned organizations the materials flow is in compliance with the linear model of materials: extraction-consumption-disposal, rather than a circular appreciation and valuation of those degraded materials. However, the paper and radio-hazardous materials sustain a long-lasting past experience of recycling due to its reuse-easiness (in case of paper), or hazards-involved (in case of radiography-based matter).

**Table 6**
The estimated quantities (g $bed^{-1}day^{-1}$) of medical Hazardous Waste Purely Contagious, produced by the various nursing Departments in the Rio University Hospital, Greece.

| Department | HWPC<br>Hazardous Waste Purely Contagious |
|---|---|
| *Pathological Unit* | |
| Pathological Dept. | 0.41 |
| Cardiology Dept. | 0.15 |
| Neurology Dept. | 0.07 |
| Surgery Depart. | 0.66 |
| Dermatology Dept. | 0.16 |
| Pediatrics Dept. | 0.23 |
| Midwifery Dept. | 0.82 |
| Short hospitalization (emergency) | 1.14 |
| Oncology Dept. | 0.14 |
| *Surgical Unit* | |
| Surgery &Resuscitation | 2.88 |
| Ophthalmology Dept. | 0.08 |
| Otolaryngology Dept. | 0.43 |
| Urology Dept. | 0.38 |
| Orthopaedics Dept. | 0.25 |
| Neurosurgery Dept. | 0.33 |
| Obstetric surgery | 0.82 |
| *Special Units* | |
| Intensive Care Unit of kids | 0.51 |
| Intensive Care Unit | 4.53 |
| Coronary Care Unit | 0.71 |
| Artificial Kidney Unit | 2.53 |
| *Laboratory Units* | |
| Microbiology Dept. | 25 |
| Biochemistry Dept. | – |
| Haematology Dept. | 25 |
| Histopathology/Cytology | – |
| Nuclear (*in vivo&invitro*) | 4 |
| Blood donation Dept. | 25 |
| Haemodynamic Dept. | 70 |
| Metabolic Diseases Dept. | – |

Waste-based Indicators: This type of indicators is including the ratios of "potentially infectious waste per patient", "cytotoxic waste per treatment", "chemical products with hazardous substances"; Water waste with hazardous substances. At this research group the groups of "infectious waste" and "cytotoxix waste" per treatment account for considerably low levels of "kg per patient" –having also "very good" environmental appreciation comparing to the "chemical products with hazardous substances"– mainly due to extended diversification in quality and quantity of chemical-sensitive matter in serving almost all hospital departments, rather than the moderate wastes' production by infectious and cytotoxic ones.

Legal-based Indicators: This type of indicators is including the ISO 14001 and EMAS. The responses received in these questionnaire aspects verified that healthcare organizations obtained a certification in accordance with standard ISO 14001 and the EMAS regulation, towards positive environmental audits, and supporting a continuous process of ongoing improvement.

Indicators upon staff/patient/environmental valuation: This type of indicators is including the environmental training plan; Awareness campaigns; Professionals' engagement to managerial improvements; Environmental progress and costs; Fulfilment of environmental goals; Complains and suggestions. The environmental goals are consistent with the healthcare management conducted, while there are running environmental training plan and awareness campaigns, in order to support the environmental friendliness of the hospital processes.

Waste management Indicators: This type of indicators received the most "very deficient" responses. This result cannot be attributed to the

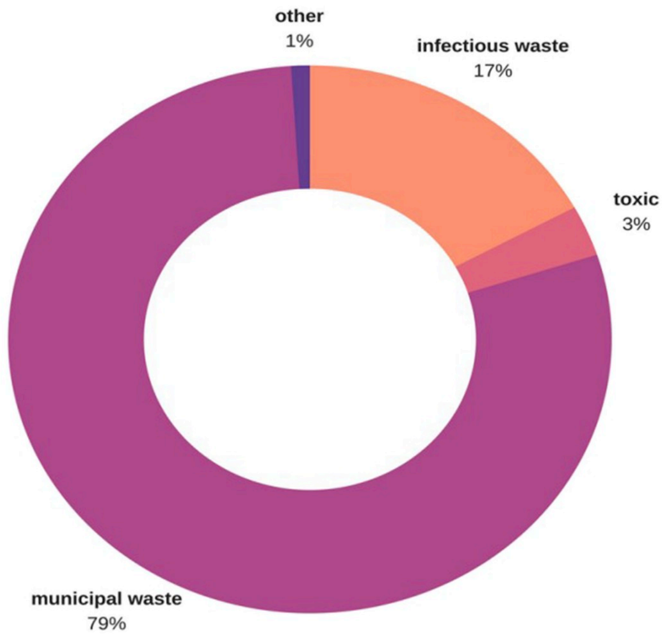


**Fig. 7.** Average percent distribution (% weight) of the general, infectious (hazardous) and other non-infectious wastes produced by University Regional General Hospital of Patras.

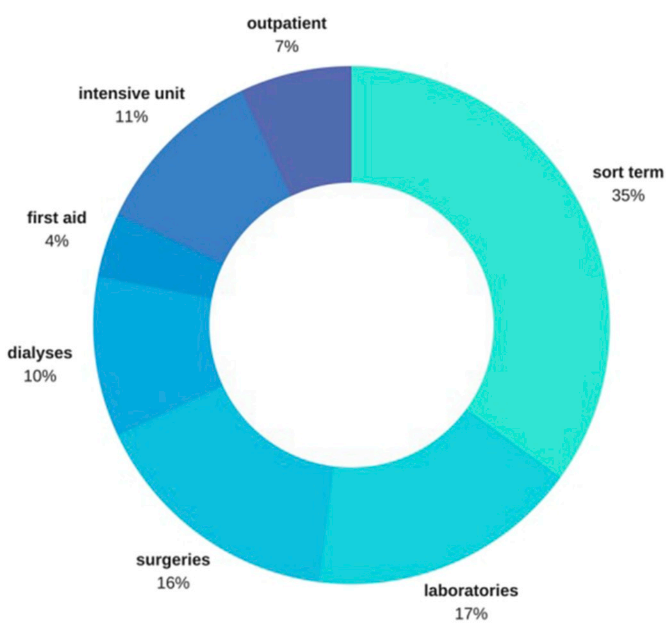


**Fig. 8.** Medical waste generation (% weight) at different health care facilities University Regional General Hospital of Patras.

managerial vulnerability. It is rather a wider socio-economic and cultural phenomenon. Specifically, while medical waste management is directed to risk reduction upon hazardous wastes, there are different treating chemical processes and environmentally friendly techniques which are directed to mitigate the negative environmental consequences. The main research objective of an effective energy and waste management in such large healthcare organizations should be directed to associate regulatory requirement with voluntary initiatives toward environmental mitigation, though implementing environmentally-alarming and sustainability-driven education programs (Romero and Carnero, 2019).

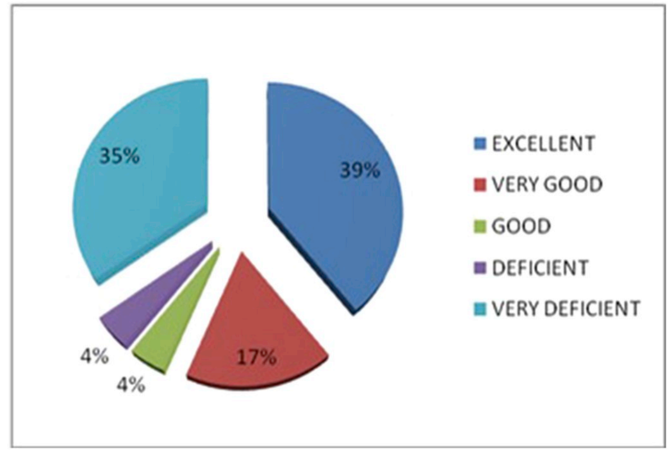


**Fig. 9.** Results Profile of the sustainability assessment in Rio Hospital.

## 3. Results and discussion

The results of the case study are represented at Figs. 7 and 8, below. Particularly, Fig. 7 represents the average composition of medical waste in the studied hospital. It is obvious that almost ~80% refers to the urban waste. In total, the characteristics of medical waste produced in the health care activities have been classified as follows: municipal waste 79%, infectious waste 17%, toxic (chemical, pharmaceuticals) 3%, and others 1%.

Fig. 8 illustrates the medical waste generation (%) at different health care facilities University Regional General Hospital of Patras. In the present study a portion of 35% of total infectious-HCWs is related to short-term patients, following in descending order by laboratories (17%), surgeries (16%), intensive unit (11%), dialyses (10%), outpatient (7%) and emergency care unit (4%).

Moreover, Fig. 9 depicts a profile of the sustainability assessment in Rio Hospital under demonstrates the results of the questionnaires responses on the sustainable indicators which used in this survey. The values of 39%, 17%, 4%, 4% and 35% were given, correspondingly, correlated to the corresponding classifications of EXCELLENT, VERY GOOD, GOOD, DEFICIENT and VERY DEFICIENT classification of the scale factors, all indicating the awareness of these groups needed towards the alternatives.

On the other hand, the approach of the AHP methodology indicated that there is still room to improve the overall performance. The normalized relative weights obtained for the criteria and sub criteria provided a signal to specific actions that have to be handled.

Particularly, the results indicated a very good value in environmental management criteria due the values obtained for the commitment towards the environmental policy standards and the waste management procedures. However, there is space for further improvements on in terms of staff awareness (such as developing programs to enhance sensitivity) and more green purchasing suppliers, should be further addressed.

At the same time, the environmental behaviour criterion lacks of an environmental inventory of the atmospheric emissions (since only the carbon footprint is known) or there were no information provided. The high rate of the other sub–criteria indicated a good level of performance. Finally, the biodiversity indicator is valued as low due to the lack of information on the corresponding scale factors.

Based on the aforementioned results it can be stressed out that the infectious- and hospital-generated HCWs quantity reported at this study is in accordance with the relevant literature, indicating good practices in hazardous medical waste management. United States Environmental Protection Agency (1989), assumed that only 10–15% of hospital wastes are infectious, while WHO (1999) denoted that almost 85% of hospital wastes are non-hazardous, 10% are infectious, and 5% are non-

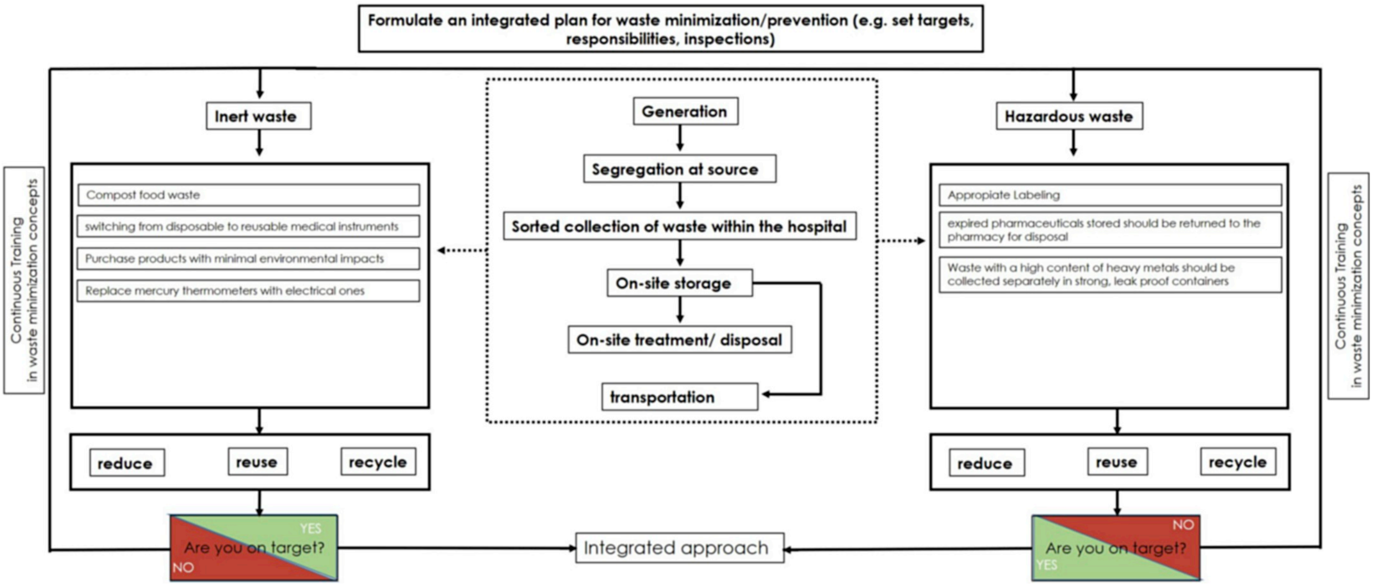


**Fig. 10.** Scheme of an integrated approach of healthcare waste management.

infectious, but toxic. In a schematic depiction of an integrated approach of HCW management, Fig. 10, the proposed steps to be followed are the following:

- Formulation of environmental policy by the management of Hospital.
- Definition of environmental management officer.
- Definition of responsibilities and responsibilities between staff.
- Identification of pollution sources, categories and waste streams, quantitative and their qualitative elements and the need for or not to use appropriate antifouling systems.
- Adoption of good practices in order to use more environmentally friendly techniques in reducing polluting discharges from Hospital to the environment.
- Training programs for staff to create environmental awareness and skills.

### *3.1. Adequate number of staff and expertise*

The main challenging issues that can be addressed at future research orientations are outlined as follows:

- A feasible choice to sustainable treatment of waste, especially among developing economies, is the development of waste biorefineries. This infrastructure would improve the public health and support a sustainable environment to local inhabitants. This choice could be materialized through upgraded biorefinery technologies and the strategic switch to renewable and green resources. Environmental policies of pronounced significance are the: reduction in greenhouse gas (GHG) emissions, mitigation of climate change impacts, protection of public health, advancement and intensification of agriculture production, the launch of numerous greener products, as well as the enhancement of renewable energy production. Other challenging aspects are the energy savings from the waste biorefineries, raw materials savings at production, transportation, and manufacturing. In developing waste biorefineries offer new opportunities to the sectors of: firstly, agriculture, food, chemicals, healthcare, pharmaceutical and logistics and, secondly, fuels' production, power, heat, and of added-value commercial products (Nizami et al., 2017).
- Wastes disposal in a sustainable manner is still in early development among developing countries, mainly attributed to constraints in budgeting, infrastructure, and facilities. Therefore, wastes in these developing countries are representing an important feedstock of biomass-, recycled-, chemical-, and energy-embodied sources, after proper collection and management followed. Contrarily, the high generation content of organic waste and its traditionally environmental-irresponsible choices of disposal (mainly dumping or non-sanitary landfilling) are causing socio-economic marginalization and environmental degradation (Nizami et al., 2017).
- The main challenging objective of a modelling program is the precise assessment of all hospital units in a systematic and thorough manner, enabling the improvement its overall environmental management. Under this context it is proposed that modelling has to be focused on those criteria with the weakest scores, in order to assess them and take the proper measures to improve the modelling results. Once these steps are closely followed, it is anticipated betterment in the sustainability assessment when applying the same methodology again either for the same hospital unit, or for other hospital units which support similar managerial and waste characteristics (Romero and Carnero, 2019).

## 4. Conclusions

This study provided a holistic theoretical background, methodological development, and environmental assessment of HCWs at healthcare centers. Under this context, the AHP methodology can support each hospital unit to check its environmental situation, as well as to specify those areas and processes that should be improved toward a sustainable environment. Furthermore, the novelty of this model resides to the fact of contributing to foster the socio-economic advancement of similar healthcare organizations, having similar capacities of HCW. Unlike traditional audits, the applicability of multi-criteria decision techniques supports policymakers to easily problem setting and explicitly draw the desired objectives. The followed modelling at the case study can enable policymakers to set measurable criteria through a common scale. Besides, it can be signified that varied hospital units can be assessed by planners and healthcare managers while having access and informed the relevant sustainability reports.

Focusing on results outcomes it can be denoted that the infectious- and hospital-generated HCWs quantity reported at this study is in accordance with the relevant literature, indicating good practices in hazardous medical waste management. Nevertheless, it is argued that a conceptual model is absolutely needed to be conducted while highlighting potential solutions for the management of hazardous medical waste, as an integrated approach from the point of generation up to the final disposition.

Conclusively, the optimum research orientation is researchers to proceed in assessment of other hospitals, while comparing and contrasting these results in order to structure an improved hierarchy. Simultaneously future research should eliminate those criteria that are actually no necessarily assessed, where disposable, while redefining and adding those new criteria further suited. Also, future modeled analysis should be verified in the light of other multi-criteria techniques.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scp.2019.100163.

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