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ORIGINAL PAPER

Sustainability of Medical Waste Management in Different Sized Health Care Facilities

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Abstract In recent years the waste produced within healthcare facilities has raised great attention. The proper management of such waste is fundamental to avoid both public health issues and environmental pollution, so that several countries have been enforcing specific legislative acts to regulate medical waste classification, collection, treatment and disposal. In this context, both the classification of medical waste and its segregation in healthcare facilities play a key role in the techno-economic optimization of the whole management systems. This study collected annual data dealing with the waste generation in five hospitals characterized by different size in terms of bed capacity. In each facility the amount as well as the composition of medical waste generated over 4 years were analysed; results were also discussed in relation to the hospital operating conditions, including the different forms of admission as well as the occupancy rates. The costs associated to the management of medical waste were presented as well. The analysis of these data pointed out that the waste source separation yields performed in the investigated hospitals suffer from inadequate implementation of the operating procedure, whose simplification could promote the system effectiveness as well as cost reduction.

Keywords Classification · Hazardous waste · Hospital · Operating costs · Sanitary environmental risk · Source separation

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Introduction

The term "medical waste" refers to the residues that originate from healthcare activities and medical procedures performed in hospitals, clinics, laboratories, veterinary clinics, research centre. A recent definition of medical waste by the World Health Organization [1] further includes household waste produced out of healthcare procedures realized at home.

The definition of medical waste can vary significantly among countries. In European Union, medical waste items are those belonging to the chapter 18 of the European Waste Catalogue, identified as the wastes from human or animal healthcare and/or related research, whereas in the US the Medical Waste Tracking Act of 1988 defines medical waste as "any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals". In Japan, waste generated at hospitals and clinics are divided into infectious and non-infectious [2]; in Turkey, it is categorized as infectious, pathological and sharp objects [3].

Despite its specific definition, the classification of medical waste is usually referred to major categories of the waste as pathological wastes, human blood and blood products, discarded medical plastics, culture and stocks, waste sharps and other mixed waste [4]. Liquid waste, such as radioactive solutions [5], has also to be mentioned.

The amount of medical waste generated depends on factors such as waste management techniques, the type of healthcare institution, healthcare specializations, the quantities of reusable equipment available in the hospital/clinic and the number of patients admitted in the healthcare facility and it is quantified as a relatively small amount of the total waste generated in a community [6].

However medical waste management is regarded as a critical issue throughout the world. A significant portion of medical waste is indeed potentially dangerous since it may contain a great variety of pathogenic agents and hazardous substances. As it can differently affect both environment and public health through several routes [7], special handling, treatment and disposal of medical waste is required [8, 9].

Inadequate management involves a high risk of environmental contamination by improper treatment and disposal as well as the risk of infection and injury to personnel in contact with this waste because of the possible transmission of blood-borne infections [10]. It has been recently estimated that the most frequently occurring exposures involves contact with sharps, infectious agents and hazardous substances and personal injuries during waste handling. Although approximately 65 % of the reported exposure occur within wards, the possible contamination of general waste with infectious agents during unsafe handling poses wider risks for environment and public health [11].

In this context several European countries have enforced legislation and proposed good practice guidelines to identify medical waste classes, in accordance with specific properties, in order to implement source segregation of selected medical waste categories and provide the most adequate packaging, storage, treatment and disposal [12]. Nevertheless, as pointed out by Kermenidou et al. [13], the design and costing of a proper system for the management of medical waste is tightly related to its characteristics, both in terms of production and composition.

Aim of this study was in assessing the sustainability of medical waste management system in different sized health care facilities, which belonged to the same sanitary district. To this end hospital operational parameters were evaluated; waste production data were discussed and the expenditure for the management of this waste was analysed as well.

Materials and Methods

In order to address the aim of this study, a sanitary district was considered.

It was located in the Province of Salerno, in the south of Italy, and it included 5 hospitals with different bed capacities, as given in Table 1.

Each facility housed both general surgery and general medicine wards. In H1 approximately 65 % of the beds was devoted to these wards, whereas the remaining bed capacity was divided between the dermatology and the intensive therapy units. The latter ward was present in all the hospitals under investigation, along with other medical branch units: both the number and the speciality of wards were observed to enhance for increasing bed capacity. In this view cardiology, genecology, obstetrics and paediatrics could be recognized as the most relevant wards in the hospitals belonging to the class "B". H3 and H4 were also found to house further specialized units like nephrology and orthopaedics. The biggest hospital, namely H5, was the one providing the highest level of differentiation of its medical performances, as a relevant number of beds was also devoted to highly specialized healthcare sectors including gastroenterology, otorhinolaryngology, psychiatry and oncology. Some of the specialized wards obviously provided both clinical and surgical treatments, but any detail about this differentiation was provided.

Table 1 Bed capacities of the selected hospital facilities (H)

Hospital	No. of beds	Bed capacity class[a]
H1	43	A
H2	103	B
H3	120	B
H4	125	B
H5	381	D

[a] As given in the relative Italian classification

For each facility the collection of data on annual basis dealt with:

- the number of patients admitted under different reception forms (day hospital/day surgery; hospitalization);
- waste production per category, as identified according to the European Waste Catalogue (EWC) codes;
- waste costs, including collection, transport and disposal.

The analysis was performed over 4 years, in the period between 2008 and 2011. All data were provided by the hospitals, so that they resembled the registration procedures adopted for either patient admission or waste generation monitoring.

In this respect, the number of admitted patients refers to the number of performed medical procedures, which were distinguished in daily or overnight extended treatments. The registered daily performances include both clinical and surgical therapies, so that it was not possible to distinguish between day hospital and day surgery.

The collected data were used to assess the operating performances of each hospital, evaluated with reference to both the bed occupancy index (OI) and the turnover index (TI). The former was calculated as the ratio, expressed as percentage, between the actual hospitalization days (Hd) and the theoretically available ones, whose number was assessed, in turn, as the product of the number of available beds (b) and that of days in a year, as given in Eq. 1. The turnover index was calculated as the ratio between the

actual hospitalization days (Hd) out of the theoretically available ones and the overall number of admissions (a) in a year (Eq. 2).

The bed occupancy index represents the percentage of available resources used in a year, whereas the turnover index identifies the average number of admissions performed in the same period of time.

$$OI = \frac{Hd}{b \times 365} \quad (1)$$

$$TI = \frac{(b \times 365) - Hd}{a} \quad (2)$$

As for waste generation, each healthcare facility registers the amount of produced residues and delivers them to authorized companies, which usually collect waste and transport it to the destination site. Available data included the annual mass of produced waste and the overall expenditure for its management service; any indication of the share of collection, transport and disposal operation costs out of the total one was provided.

Results and Discussion

Hospital Performances

The admission of patients at the hospitals considered in this study can be provided by:

- ordinary hospitalization, which is intended to require the patient admission and his staying overnight;
- day-care performances, including both day-hospital and day-surgery activities. In this case the patient come to the hospital for either a clinical treatment (day-hospital) or a surgery (day-surgery) and leave the facility on the same day.

In each hospital approximately 20 % of the total number of beds was estimated to be devoted to day-care treatments (Fig. 1), which represented the minor healthcare activity.

Ordinary hospitalization and daily healthcare treatments require different admission and registration procedures. The relative operating conditions are thus referred to different indices, which are the average number of hospitalization days and that of provided treatments for hospitalization and day-care admissions, respectively.

Figure 2 plots the average number of performed activities over the investigated period. Slight variations can be observed over time in each facility, with the exception of H1 and H3: the relevant standard deviation is related to the drop in the number of health services that these facilities provided in 2011.

Each hospital carried out a number of treatments congruent with its size, so that the greatest number of

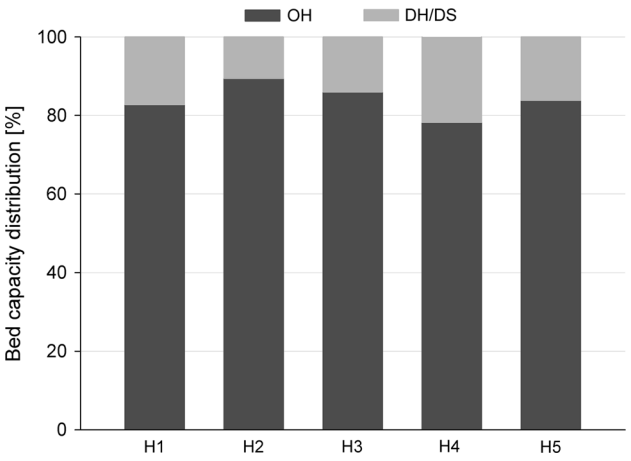

Fig. 1 Percentage of bed capacity devoted to either ordinary hospitalization (OH) or day-hospital (DH)/day-surgery (DS)

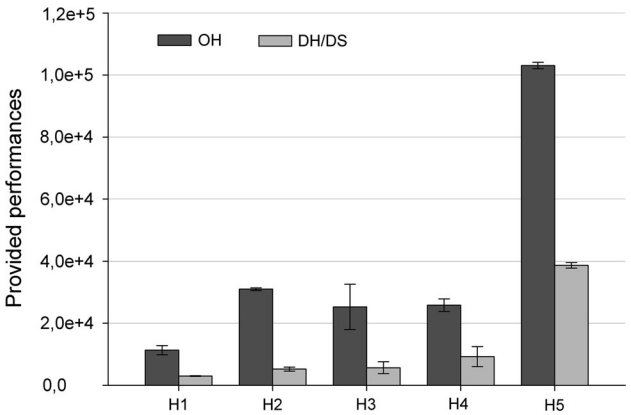

Fig. 2 Average number of provided performances as ordinary hospitalization (OH) and day-hospital (DH)/day-surgery (DS)

performances was observed in the biggest hospital (H5). Nevertheless each hospital was observed to work close to the saturation level, as indicated by both the occupancy and turnover indices reported in Fig. 3. Italian national standards set the acceptability of occupancy bed at 75 % and that of the turnover index at 3.66 days, so that the outcomes from this study point out the critical operating conditions of the investigated facilities.

In each hospital the annual occupancy index ranges around 80 %, as plotted in Fig. 3a. Due to the high number of occupied beds, the time between a patient discharge and the admission of another one is also quite short, as indicated in Fig. 3b.

In 2011 the percentage of occupied beds was found to be as low as 60 % for both H1 and H3. This evidence can be attributed to the drops in healthcare treatments, which in turn resulted in the enhancement of the time between discharge and admission of a patient: the turnover index values was observed to increase up to 3.46 and 2.93 for H1 and H3, respectively.

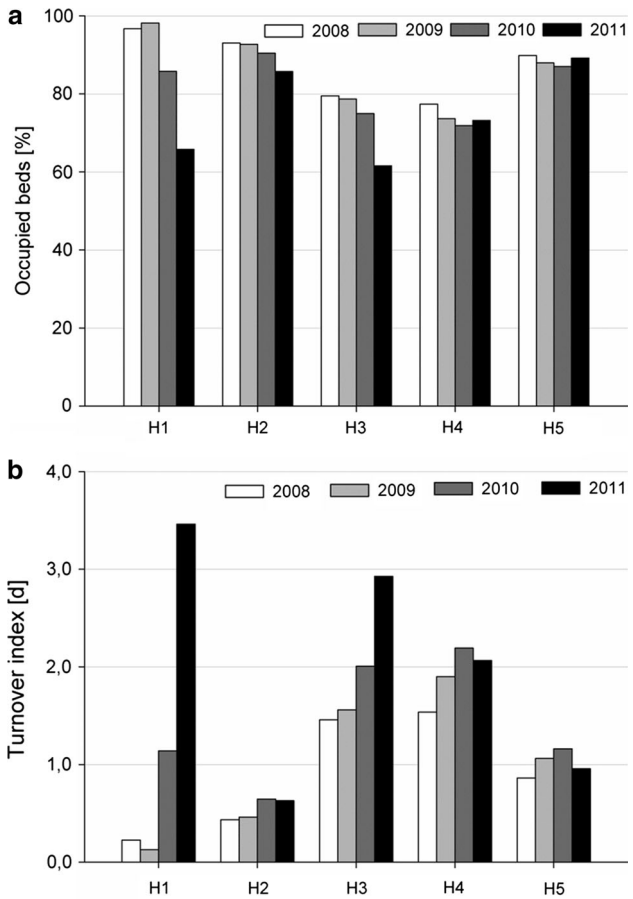

Fig. 3 Hospital performances as percentage of occupied beds (**a**) and turnover index (**b**)

The analysis of the operating conditions of investigated hospitals suggested that relevant waste amounts could be expected to be produced over time.

Medical Waste Generation

The average annual amount of medical waste produced in the investigated hospitals ranges between 1.1 and 2.6 kg/bed/d, as plotted in Fig. 4. Comparable data were reported in other studies [14, 15], but Komilis et al. [16] indicated half values for Greek hospitals; severe differences can also be recognized for Israeli facilities, as reported by Elimelech et al. [17] who estimated a daily generation rate one order of magnitude lower than the one reported in the present study. The great variability of annual generation rates of medical waste produced in different countries had already been discussed in the study of Jang et al. [4], who attributed this aspect to several factors, including healthcare services, the amount of disposable or reusable medical devices, the existence of enforced regulations and the consequent medical waste management policies.

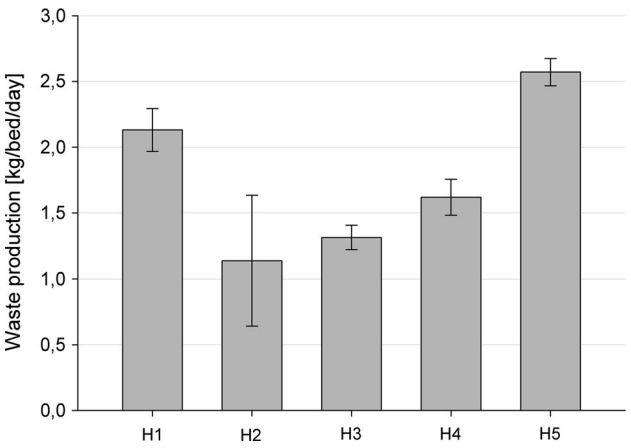

Fig. 4 Specific medical waste generation

Over the investigated period, the specific waste production of medical waste was found to enhance for increasing bed capacity, with the exception of H1. This facility is characterized by the lowest number of beds, but its specific waste production was observed to be comparable with that of the biggest healthcare facility among those considered, identified as H5. However it should be considered that a high number of beds in H1 is devoted to both surgery and general medicine wards, which have been recognized as the ones providing the greatest waste production [18]. It can be further pointed out that the annual specific production of medical waste in H2 is highly variable over the observation period if compared with that of other facilities: this evidence can be attributed to the greater waste production registered in 2011 due to the activation of new wards.

The overall production of medical waste was found in direct correlation with bed capacity ($R^2 = 0.92$), but not with the hospital performance indices; moreover, when considering only those facilities characterized by comparable size, the correlation between waste production and bed capacity was observed to be not significant. These outcomes confirm the influence of the kind of health treatments provided on the quantity and quality of generated medical waste.

A recent study, conducted by Xin [19], highlighted that medical waste generation is directly dependent on both the diagnosis-related groups (DRGs) and the case-mix index (CMI): the former indicates a strategy set to bring together patients into groups that are clinically meaningful as well as homogeneous in resource consumption; the latter reflects the complexity of cases faced in the healthcare facility. The higher DRGs and CMI are, the greater is waste production. In this view, highly specialized healthcare facilities are expected to produce much medical waste than hospitals offering basic healthcare services.

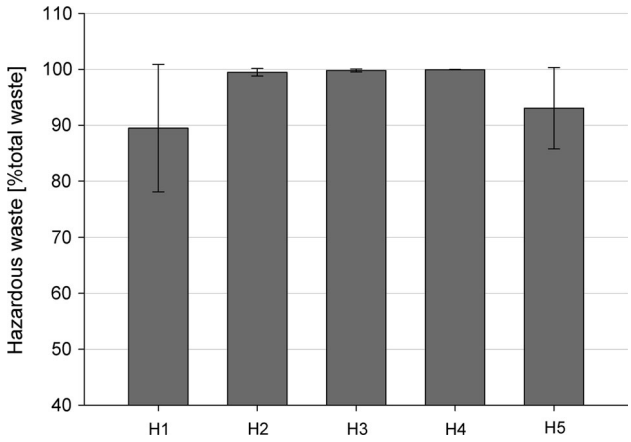

Fig. 5 Hazardous medical waste out of the total waste production

The composition of medical waste was given by EWC codes. Hospital waste was thus classified by their originating process, namely the medical performances, as well we by their possible hazardous properties: any indication about the presence of specific items could be obtained.

Over 90 % of produced medical waste was classified as hazardous (Fig. 5) and it was mainly composed of infectious waste, in percentages ranging between 76 and 90 % of the total production. Figure 6 shows the share of infectious waste out of the hazardous one in the investigated healthcare facilities, pointing out its variability in both H1 and H5. This evidence reflects the increase of the infectious waste amount registered over time in these hospitals. Another relevant waste category, accounting between 9 and 23 % of the total waste produced in each facility, was constituted by liquid medical waste containing hazardous substances. The data analysis further showed that cytotoxic and cytostatic pharmaceuticals [13] were produced only in H5, housing the oncology wards and they accounted between 0.05 and 1.12 % of the total waste

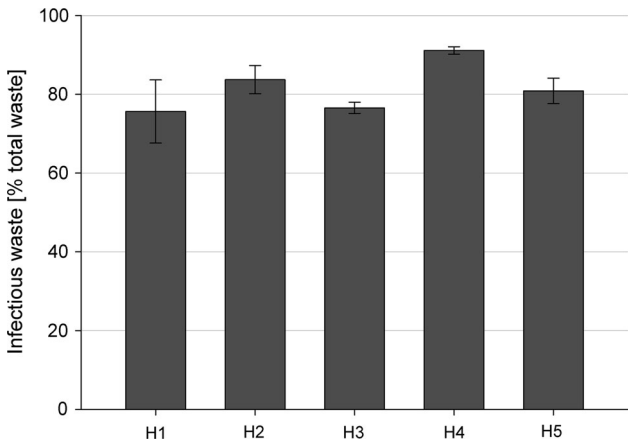

Fig. 6 Infectious medical waste out of the total waste production

production. Non-hazardous waste was observed to represent only a small portion of the overall medical waste produced in the hospitals under investigation, which was found to be recorded only in 2009.

The composition of medical waste observed in this study was rather different than the one found by other authors. Mohee [20] stated that 90 % of hospital waste was similar to domestic residues and only the remaining 10 % was classified as infectious: these data were consistent with previous studies performed in healthcare facilities located in France and USA, where infectious waste accounted for 15–20 % of the total production. However the share of infectious waste can be highly variable among different countries. Mühlich et al. [21] compared the composition of the waste produced in five university hospitals, located in Freiburg (Germany), Nottingham (UK), Grenoble (France), Forlì (Italy) and Sabadell (Spain). They found that in the Italian hospital 51 % of the total amount of produced waste was classified as infectious, differently from the facilities of Freiburg and Sabadell, where this class of residues accounted between 3 and 4 %. This outcome was attributed to the generic definition given to the infectious waste, which included all waste generated by patients. Although the share of infectious waste registered in the Italian hospital is higher than that found in the other investigated facilities, it is still far from the percentage found in the present study.

Non-hazardous medical waste usually comprises residues of healthcare procedures, like bandages or plaster casts, as well as the waste that can be assimilated to the municipal one. The latter category is usually destined to the municipal collection systems, thus making its quantification hard to define. Differently, non-hazardous waste related to medical procedures is destined to the same collection strategy set up for the hazardous component, ensuring its traceability.

The discordance of observations with scientific literature, along with the irregularly recorded data of non-hazardous waste, suggests an improper segregation of waste. This issue was reported to be common among healthcare facilities [22] and it was related to the limited awareness of medical staff on the specific hazardous properties of the produced waste fractions. This, in turn, negatively affects medical waste separate collection as well as registration procedures, which result to be improper for the monitoring of the management system.

Inadequate source segregation can determine the contamination of non-hazardous medical waste by the hazardous residues, thus enhancing the occurrence of injury at work, which has been recognized as the main risk in the waste management system, along with the lack of protective equipment and the inappropriate waste packaging and handling [23].

Further problems from the incorrect medical waste separate collection can be identified in the enhancement of the treatment and disposal expenses. Hazardous waste, like the infectious one, is usually managed at higher costs than non-hazardous residues.

In this context hospital staff formation plays a key role [24–26]. Mosquera et al. [27] recently pointed out that after a proper educational intervention in a Spanish hospital, the production of infectious waste was halved and, despite an overall reduction in waste production, a higher amount of non-hazardous waste was recorded. However the staff training can prove to be not sufficient if not coupled with an effective separate collection program. The study of Oroei et al. [22] indicated that inadequate organization in internal medical waste management as well as the absence of proper monitoring measures can adversely influence the proper source sorting of infectious waste. Similar outcomes were drawn by Moreira and Günther [28], who monitored the variation deriving from the implementation of a medical waste management plan in a Brazilian primary health care centre. The method relied on the application of a check list of the legally established requirements for the management of medical waste. The use of checklists could be encouraged also in European countries as either a guideline for the medical staff or a simple monitoring instrument to assess the quality of the adopted medical waste management strategies.

Costs Associated to Medical Waste Management

The issue of the medical waste source segregation plays is fundamental for the post-collection activities: the higher costs associated with the disposal of hazardous waste makes the segregation of non-hazardous fractions from the hazardous ones an important economic factor in healthcare facilities [29].

According to the observed data on medical waste production, the correspondent expenditure related to its collection, transport and disposal was expected to be driven by that of hazardous waste. The prevailing presence of medical waste classified as "infectious" was indeed reasonably supposed to affect the overall costs of medical waste management. Data analysis confirmed this hypothesis, showing that infectious waste handling accounted for 99 % of the total expenses: the average specific cost for waste handling in the medical district under investigation was thus comparable with those reported for the only disposal of infectious waste in both USA and United Kingdom [30].

In medium size hospitals the average daily expenses were found to reflect the total medical waste generation rates, whereas in both H1 and H5 daily cost trends were found to be consistent with the infectious waste production. In medium size hospitals (Fig. 7b–d) the amount of waste classified as infectious was indeed almost constant over time and accounted between 77 and 90 % of the total production. Conversely in H1 (Fig. 7a) and H5 (Fig. 7e), infectious waste was observed to enhance over time: the increasing trend of medical waste expenses could be reasonably attributed to the greater amount of infectious waste produced, which accounted for the highest portion on the overall waste management costs.

This outcome further supports the consideration for which infectious waste handling determined the most relevant expenditure, thus influencing the overall costs of waste management system. In this view the annual variation of the expenses related to medical waste management in the healthcare facilities under investigation reflects the trend of infectious waste production that, in turn, is related to healthcare performances. The reduction of hazardous waste, particularly the infectious one, is thus fundamental to decrease the relative management costs and it can be pursued by different strategies.

The identification of medical waste categories produced in different wards could be used to set an easy-to apply strategy to control waste generation rates with reference to the provided healthcare services as well as to sort hazardous from non-hazardous residues. This would allow a ward-specific cost analysis, which could prove more adequate to address the optimization of medical waste management system via focused strategies, aiming at waste minimization and correct source segregation. Such approach would prove to be even more effective if the differentiation between medical and surgery procedures was addressed during the patient registration procedure, even for the daily healthcare treatments. As surgery procedures generate significant amounts of medical waste, several studies have been focused on the analysis of the related waste costs, pointing out the factors that can influence their variability, like the operation technique [31], the relevance of disposable materials (DM) [32] as well as the relation between DM and surgical time [33]. In most cases results could not be generalized in order to compare waste management in different healthcare facilities, but the precise calculation of costs could be performed per diagnosis-related groups. The latter aspect could be particularly interesting to evaluate the efficiency as well as to address the optimization of those hospital waste management systems working on DRG-based payments.

The registration of medical waste at ward level also represents a simple strategy to monitor the relative management systems. However it needs to be properly introduced by training activities to support the correct classification and segregation of different waste categories as well as to reduce the expenses. Source segregation has indeed a strategic role in the reduction of the hazardous fraction of medical waste, representing the first step for its

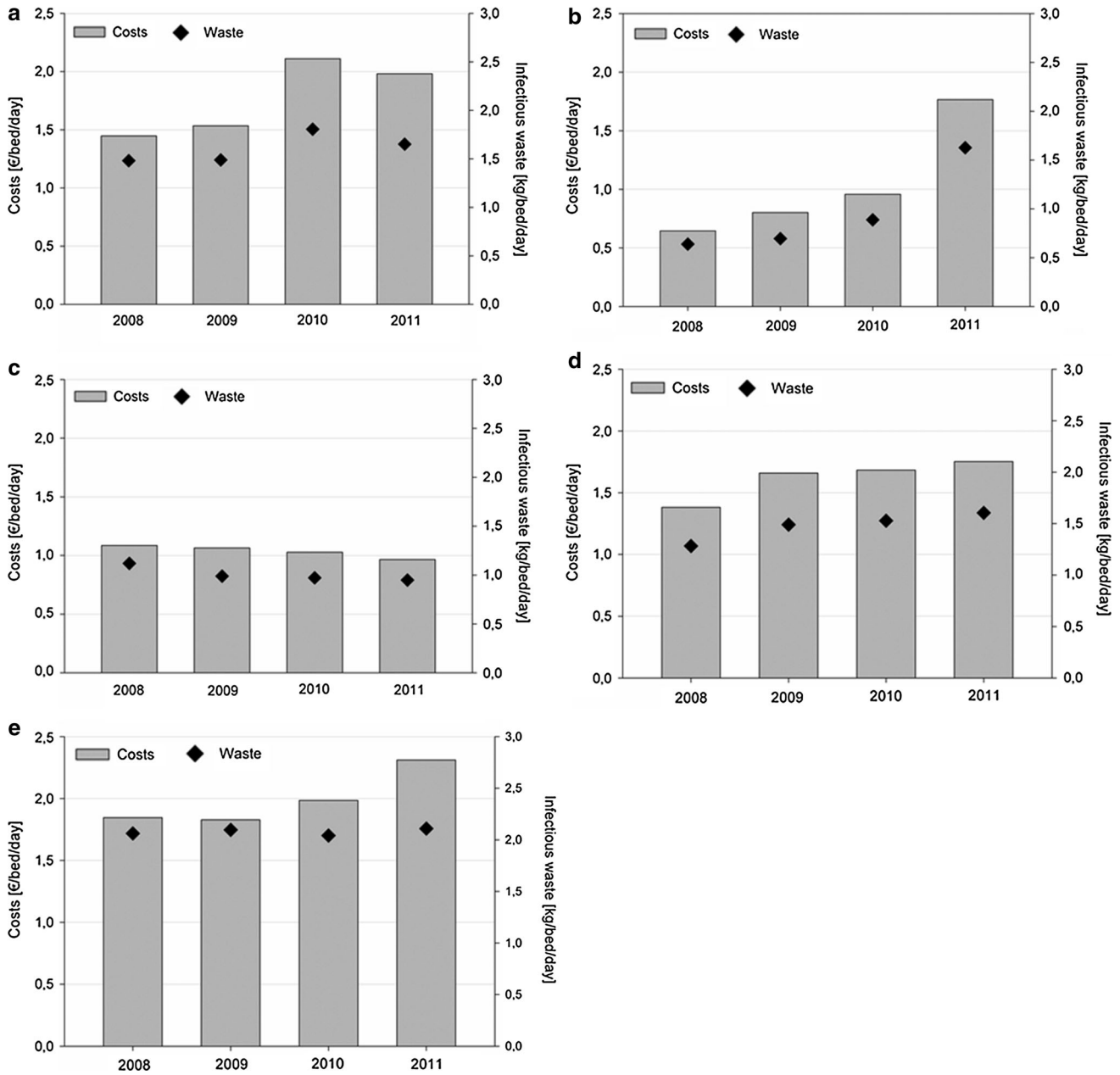

Fig. 7 Specific management costs and production of infectious waste in **a** H1, **b** H2, **c** H3, **d** H4 and **e** H5

most suitable treatment. Further reduction in the costs associated with hazardous waste handling can be pursued by adopting proper sterilization techniques [34]. The main advantage lays in the possibility of further handling sterilized residues as non-infectious waste, thus reducing both the environmental burdens and the costs associated to its management [7].

The economic effectiveness of waste handling plays indeed a key role either in the reduction of healthcare operating costs or in the re-allocation of resources, which could determine an overall improvement of the medical performance quality. It has been estimated that the implementation of a healthcare waste reduction programme can result in disposal savings in the range 40–70 % [35, 36].

Conclusive Remarks

The management of medical waste represents a critical issue worldwide. Although the waste production from healthcare facilities and medical procedures is not comparable with that of municipal solid waste, the potential hazardousness of this kind of residues requires its proper

identification and handling. The reduction of the sanitary and environmental risk associated to medical waste management is usually pursued by specific legislation or guidelines, which are implemented at national level with different results.

The analysis of the waste management system implemented in five hospitals belonging to the same sanitary district but characterized by various bed capacities showed that the operating conditions of each facility, working close to the saturation level, is as important as the kind of medical performances provided in defining the amount of generated medical waste. In both the smallest and the biggest investigated hospitals, similar medical waste generation rates, of approximately 2.3 kg/bed/d, were observed due to the presence of surgery wards.

As for the composition, severe differences were found between the outcomes of this study and existing literature: the most generated medical waste fraction was found to be the infectious one, which ranged between 76 and 90 % of the overall waste production in the investigated hospital facilities. Conversely the non-hazardous portion of medical waste was observed to be discontinuously recorded over time.

The proper identification of medical waste categories was thus recognized as a critical aspect within the implemented waste management system, negatively affecting its overall sustainability.

Inadequate categorization causes incorrect source segregation that, in turn, can determine the contamination of non-hazardous medical waste by the hazardous one, increasing injury occurrence at work. Moreover as the costs for hazardous waste disposal are much higher than those for non-hazardous waste, the improper segregation of the two streams results in improved expenditures for waste management.

In the studied hospitals, where infectious residues represented the prevailing portion of medical waste, their handling accounted for 99 % of the total expenses, which were found to be comparable with those reported for the only disposal of infectious waste in other countries.

The analysis performed in this study suggested that the optimization of medical waste management systems in the investigated hospitals requires the identification of easy-to-apply procedures for waste categorization: this would promote the correct source sorting of medical waste as well as the application of the most suitable treatment according to its actual hazardous properties.

To this end medical personnel training seems fundamental to raise the awareness towards the environmental and economic implications of a correct segregation of waste. Further efforts should promote effective controls on waste production and composition at ward level.

This would give the possibility of monitoring healthcare waste management system with reference to diagnosis related groups, which are often the payment base-criteria in several facilities throughout Europe. The savings from optimized waste management systems, that have been reported to reach up 70 %, could thus be used to improve the overall quality of medical performances and healthcare facilities.

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