論文の内容の要旨

APPLICATION OF ANALYTICAL HIERARCHICAL PROCESS TO ANALYZE STAKEHOLDERS' PREFERENCES FOR MUNICIPAL SOLID WASTE AND SEWAGE MANAGEMENT SYSTEMS

(一般廃棄物および下水管理システムにおけるステイクホルダーの選好分析への階層分析法の適用)

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Abstract

Despite of the improvement through the installation of various schemes, development of new treatment technologies and implementation of economic instruments, solid waste and wastewater problems still impose an increasing pressure on cities and remain one of the major challenges on urban environmental management. There is no single solution to the problem since each city has different set of characteristics and treatment plans. Since Brundtland report, sustainable development has become a prominent and broadly accepted guiding principle in post industrial societies. Current assessment usually aspires to measure economic, ecological and social aspects of waste management system as these areas contemplated to be the basis for sustainable development. There are different realities or circumstances towards this matter. Into a retrospective, treatment systems have improved technologically and managerial but little we know about how different sectors among the society (stakeholders) think about the subject. Integrating waste management and stakeholders' participation within decision making process

is a complex situation.

Usually, waste management systems are configured based upon local conditions. For instance, Boston (USA) solid waste treatment system has increasingly suffered from space capacity constrains for the final disposal site and therefore the priority has been towards the development of solutions to reduce the volume of waste to be disposed. On the other hand, Zurich (Switzerland) wastewater treatment system and nutrients recycling issues face a completely different situation where the paradigm of which recycling plans is the most appropriated.

Solid waste and wastewater management systems for these two case study needs to be build in a sustainable manner, reflecting the characteristics of each case and including the complex societal part as preferences of the different stakeholders groups. Consequently, there is a need to develop a systematic approach that integrates these preferences and environmental analysis towards a series of waste treatment plans as a decision support tool for decision making process.

Based on this goal, the dissertation aim was to investigate three constituent components of the decision making, i.e. stakeholder groups, criteria (impact categories) and preferences with regard to solid waste and wastewater treatment plans. In addition, the dissertation analyzes the differences in these decision theoretical components between stakeholders groups (e.g. residents, non governmental organizations and local governmental organization) and its contribution on the final decision scheme. As the stakeholder group's preferences vary according to the problematic, Analytical Hierarchical Process (AHP) was chosen as means of

analysis and integration. Specifically, the objectives of this thesis include;

- Study the theoretical aspects of Analytical Hierarchical Process and Life Cycle Assessment (LCA).
- Develop a methodology based on LCA and AHP to evaluate possible treatment plans.
- Application of the developed methodology to evaluate a series of treatment plans for Boston solid waste system and Zurich wastewater system.
- Investigate which assessment criteria (impact categories) were the most relevant on the selection of the best treatment plans from the different stakeholders' perspective.

As the first part of the assessment, it is defined the primary goal of the treatment system where as for Boston case study, it was to propose alternative treatments for the actual household solid waste management system considering the improvement and development of the municipal solid waste system in a sustainable manner. As for Zurich case study, the context is on the wastewater treatment system and the subject of phosphorus and nitrogen recycle. The differences among the treatment plans within each particular study case aims to provide the basis for a challenging decision scheme where the preferences of each stakeholders' groups may differ according to the treatment plan. Under this frame, data gathered and estimated following LCA framework is used to compute the different impact categories defined for each case, reflecting the environmental loadings, energy and resource consumption. The impact categories are parameters that essentially were conceived according to the solid waste or wastewater management situation, independents from each other and with values crucially influenced by each of these treatment plans. Based on the system boundaries and data collected, the chosen impact categories can be estimated through the application of Life Cycle

Assessment (LCA) and cost analysis methods. Under this framework, the treatment scenarios were developed aiming to create the basis for the decision problem and the application of AHP to analyze the stakeholders' preferences.

In this study, a framework was proposed for this approach and it is divided into 1) Goal definition and scenario development, 2) Definition of system boundaries, 3) Impact categories selection, 4) Data source analysis, 5) Impact categories estimation (based on LCA and cost analysis), 6) Stakeholders groups' analysis and definition, 7) Survey/questionnaire design, 8) AHP implementation and 9) Stakeholders' preferences analysis. As for the case studies, this procedure was followed to implement the decision problem and analyze the stakeholders' preferences. As for the definition of the impact categories, the concept of sustainability was integrated by analyzing the case study characteristics such as feasibility of the treatment plans and the perception that these stakeholders groups had (refer to chapter 3, section 3.2 and 3.3).

From the analysis conducted in Boston case study solid waste management system, interviews with the stakeholders groups and questionnaire survey, three management plans were proposed. Plan I is defined as the present household solid waste treatment and disposal system. Plan II involves the introduction of biogasification as a treatment option for organic kitchen waste and yard trimming waste in order to divert a fraction of residential solid waste that its landfilled and to produce energy. Plan III combines the concept of Refuse Derived Fuel (RDF) and solid waste export, where approximately fifty percent of MSW that is normally landfilled is transformed into dry RDF pellets (dRDF) that are exported to other states as material for waste to energy plants. These scenarios were compared according to a series of impact categories which are broken-down into Operation Cost, Green House Gases (GHG), Disposal Capacity of

local landfills and Health Damage (counted as lost of life expectancy). Each plan represents a solution for the MSW system with a certain degree of trade-off between benefit and its consequences that provides the basis for the decision problem among residents, non governmental organization (NGO) and a local governmental agency.

In case of Zurich case study, three management plans involving nutrient recycling were proposed. Plan I is defined as the present wastewater and sludge treatment system. Plan II involves the introduction of a separation scheme at the user level with the aim to separate the urine which is source of a series of nutrients from the wastewater stream. Plan III combines the actual wastewater system and sludge treatment through incineration with the phosphorus recovery from chemical precipitation. The nutrient recycling scenarios were compared according to a series of impact categories as green house gases (GHG), euthrophication, acidification, operation cost and nutrient recycling. Each plan besides the actual treatment system presents a different approach for nutrient recycling as the basis for the decision problem focused to residents in the area of Zurich, NGOs and; federal office for environment and agriculture.

The rank or weight of the management plans for Boston case study shows that for the resident group, Plan II and III were ranked first and second respectively. Despite Plan II involved kitchen and yard trimming waste sorting, residents choice of this plan could be motivated by the actual yard waste separation program in the city of Boston and the home composting carried out by some of the residences. In case of Plan III, the possibility to obtain a benefit by creating RDF pellets from solid waste and to increase the landfill capacity may also played a relevant role, as well as the reduction of local air emissions. In case of the NGO group, plan III

and II are ranked first and second respectively which stress the importance the NGO gives the management constrains, especially to the landfill space capacity. Plan III represented the export of solid waste to other states in the form of RDF pellets as source of energy. Even though solid waste separation is not applied at the household level as in plan II, the amount of solid waste disposed in the local landfill site is expected to decrease by the export of RDF. Local governmental agency rank distribution for plan II and III is first and second respectively. The selection of Plan II where Biogasication is introduced could respond to its contribution to separate *Kitchen and Yard solid waste* from the main stream and consequently extending the landfill capacity, which also answer to the choice of management capacity as the most preferred impact category by this group; following the state policy for implementing solid waste diversion programs.

Despite the low return rate for the questionnaire survey carried out for Zurich case study, residents' preferences towards plan II (based on urine separation scheme) are higher than the rest of the treatment plans, although this plan requires the cooperation of every member in the household by the use of a special toilet. As for treatment plan I which represents the actual wastewater and sewage sludge treatment, most of the respondents rated this plan the second or even the most preferable options rather than plan III which it may leads us to assume the possible bias the term of sewage sludge may have on the respondent. As nutrient recycling through different schemes is currently being analyzed in Switzerland by the governmental institution, there are no clear policy issues towards these plans at this moment. However, it is possible to highlight that no further development is expected until the health risk associated to micropollutants and heavy metals on nutrients recycled from wastewater and sludge treatment cycle is improved, and market is open to the use of vegetables grown with this kind of

fertilizers.

In summary, solid waste and wastewater management involves complex decision making situations that require the understanding of different sectors within the society. This research presents AHP based methodology as a decision making support tool that allows the consideration of several stakeholders' groups preferences during the multicriteria evaluation of different treatment plans. From the case studies, it was proven that in combination with other methods to characterize the different treatment plans (such as LCA), AHP is a useful technique to distinguish the preferences of several sectors and support the decision scheme. However, both the availability and credibility of data plays an important role on characterizing the different plans. Although the impact categories defined on this study represent somehow relevant issues towards solid waste and wastewater treatment systems, there is still a need for a better selection and representation of these categories. From the perspective of the decision problem and stakeholders participation, the results of this analysis may not only provide an starting point for the development of suitable treatment plans according to stakeholders preferences but as well a better understanding to improve it acceptance.

Regarding the dissertation structure; chapter 1 refers to the introduction the solid waste and wastewater management decision problem, the questions and objectives of this work are presented. Chapter 2 is a literature review highlighting the role of multicriteria based methods and AHP. Chapter 3 describes the methodological framework applied on this study where it combines evaluation approaches as LCA and AHP. Chapter 4 analyze how the solid waste management in Boston has changed over the past 15 years and what kind of issues will become relevant on the next 15 years, a comparison with the city of Yokohama is also carried out.

Based on the results of this analysis, the decision problem for Boston case study is presented considering how solid waste management would develop in the coming years. According to the decision problem, the impact categories for the different treatment scenarios are calculated through the LCA framework and the related stakeholder groups are described. Chapter 5 introduces the decision scheme for wastewater treatment for Zurich case study where the calculation of the impact categories for the treatment scenarios follows the same approach as chapter 4, as well as the analysis of stakeholder groups.

On chapter 6, a questionnaire survey for each case study was designed based on the characteristics of the treatment scenarios (such as the calculated value for the impact categories). Through the implementation of AHP of the survey results, the preferences of the different stakeholders groups are estimated for the treatment plans and impact categories; considering the analysis of the stakeholder's role on the decision scheme. Conclusions and further recommendations are presented on chapter 7.